UNIVERSIDAD DE EXTREMADURA

TESIS DOCTORAL

USO DEL PERFIL FUERZA-VELOCIDAD PARA LA INDIVIDUALIZACIÓN DEL ENTRENAMIENTO EN ACCIONES BALÍSTICAS

JUAN ANTONIO ESCOBAR ÁLVAREZ

PROGRAMA DE DOCTORADO EN CIENCIAS DEL DEPORTE

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CONFORMIDAD DE LOS DIRECTORES

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2020

El Doctor Juan Pedro Fuentes García de la Universidad de Extremadura y Pedro Jiménez Reyes, Doctor en Ciencias de la Actividad Física y del Deporte, por la Universidad Pablo de Olavide.

CERTIFICAN:

Que D. Juan Antonio Escobar Álvarez, Graduado en Ciencias de la Actividad Física y del Deporte por la Universidad de Extremadura, ha realizado la Tesis Doctoral "USO DEL PERFIL FUERZA-VELOCIDAD PARA LA INDIVIDUALIZACIÓN DEL ENTRENAMIENTO EN ACCIONES BALÍSTICAS" bajo nuestra dirección y que, a nuestro juicio, reúne las condiciones exigidas para optar al grado de Doctor.

Y para que así conste, expedimos y firmamos el presente certificado en Cáceres, a 23 de Septiembre de 2020.

Dr. D. Juan Pedro Fuentes García | Dr. D. Pedro Jiménez Reyes

AGRADECIMIENTOS

Esta ha sido la sección más difícil de escribir, muchas son las personas que han tenido una influencia significativa durante la realización de esta Tesis Doctoral y condensar todo en un puñado de líneas ha sido extremadamente complejo, además de que aún no tengo claro si este apartado verdaderamente está más destinado a pedir disculpas por no prestar toda la atención y tiempo que estas personas se merecen…

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"Lo que no te mata, te hace más fuerte"
(Frederick Nietzsche)

"A la gente no le gusta que, uno tenga su propia fe"
(Georges Brassens)

"La verdadera ignorancia no es la ausencia de conocimientos, sino el hecho de negarse a adquirirlos".
(Karl Popper)

"Nuestro conocimiento es necesariamente finito, mientras que nuestra ignorancia es necesariamente infinita"
(Karl Popper)

"No todos los que deambulan están perdidos"

(JRR Tolkien)

"Si piensas que la aventura es peligrosa, prueba la rutina. Es mortal"
(Paulo Cohelo)

"Experiencia es lo que consigues cuando no consigues lo que quieres"
(Randy Pausch)

"Todo soñador sabe que es perfectamente posible sentir nostalgia por un lugar en el que nunca se ha estado, quizás más nostalgia que por algo conocido"

(Judith Thurman)

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LEYENDA

1RM: 1 repetición máxima.

1s líneas: Posición de primeras líneas en rugby.

2s líneas: Posición de segundas líneas en rugby.

BM: Masa corporal.

CMJ: Salto en Contra movimiento.

D_{rf}**:** Ratio de disminución de fuerza.

ES: Tamaño del efecto de Cohen.

$F\text{-}V_{IMB}$: Déficit del perfil F-V.

F: Fuerza.

F_0: Fuerza teórica máxima.

HFD: Alto déficit de fuerza de ≥ 60% $F\text{-}V_{IMB}$ (≥40% $F\text{-}V_{IMB}$, según My jump 2).

h_{PO}**:** Distancia a la que se realiza el empuje balístico.

LFD: Bajo déficit de fuerza de 60-90% $F\text{-}V_{IMB}$ (10-40% $F\text{-}V_{IMB}$, según My jump 2).

Perfil *F-V-P*: Perfil Fuerza-Velocidad-Potencia horizontal (Perfil Horizontal medido en sprint).

Perfil *F-V*: Perfil Fuerza-Velocidad vertical (Perfil Vertical medido durante la acción de salto).

P_{max}: Potencia máxima.

***RF*:** Ratio de fuerza.

RF_{max}: Valor máximo de ratio de fuerza.

RST: Entrenamiento horizontal resistido con trineos.

S_{fv}**:** Perfil Actual de F-V.

SJ: Salto en sentadilla.

***V*:** Velocidad.

V_0: Velocidad teórica máxima.

$\Delta\text{-}P_{max}$: Magnitud de mejora de la P_{max}.

RESUMEN/ABSTRACT

Facultad de Ciencias del Deporte
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RESUMEN

El objetivo fundamental de la presente Tesis Doctoral ha sido profundizar en la monitorización y utilización del perfil fuerza-velocidad vertical (perfil *F-V*) [1,3] y perfil fuerza-velocidad-potencia horizontal (perfil *F-V-P*) [4] para la mejora en acciones balísticas como el salto vertical y el sprint en diferentes poblaciones deportivas. Esta Tesis se ha realizado por compendio de cuatro publicaciones [5–8], entre las cuales se pueden identificar un estudio descriptivo-comparativo, dos estudios cuasi-experimentales y un estudio descriptivo-correlacional.

El **estudio I** fue una investigación descriptiva-comparativa. El objetivo fue comparar y analizar las variables mecánicas del perfil *F-V* y la altura del salto en contra movimiento (CMJ) de bailarinas de ballet clásico en función de su posición [5]. Una muestra de 87 bailarinas profesionales de ballet (edad: 18.94±1.32 años, altura: 164.41±8.2cm y peso: 56.3±5.86Kg) participaron en este estudio, divididas en función de su posición (41 “cuerpo de ballet”, 30 segundas solistas y 16 solistas). La altura del CMJ y las variables mecánicas del perfil *F-V* (*F-V*$_{IMB}$, F_0, V_0, P_{max}) se midieron utilizando una aplicación móvil válida y fiable basada en video análisis (*My jump 2*) [9], la cual utiliza el método de Samozino [1,3].Todas las participantes mostraron déficit de fuerza alto (HFD) y bajo (LFD) de acuerdo a los umbrales propuestos en previas investigaciones [2,10]. Fueron encontradas diferencias significativas en CMJ, V_0 y P_{max}, entre los diferentes subgrupos, siendo las solistas y segundas solistas las que mostraron valores más altos respectivamente.

Una vez se observó la tendencia del perfil *F-V* en las bailarinas de ballet, se realizo el **estudio II**. En este sentido, se diseñó un estudio cuasi-experimental para observar la efectividad de un entrenamiento individualizado basado en la reducción del *F-V*$_{IMB}$ de 9 semanas para la mejora del CMJ en esta población [6]. La altura del salto vertical y las variables mecánicas del perfil *F-V* fueron medidas en un pre-test previo a las 9 semanas de intervención y un post-test posterior con My Jump 2 [9] a 47 bailarinas (edad: 18.9±1.1 años, peso: 54.8±6.1Kg y altura: 163.7±8.4cm), divididas en un grupo control (n=10) y un grupo experimental (n=36). A las 3 y 6 semanas de intervención se midió el perfil *F-V* de las participantes para observar la

evolución del F-V_{IMB} y ajustar el entrenamiento en función de los umbrales propuestos en la literatura científica [2,10]. Todas las participantes en el estudio mostraron déficit de fuerza [2,5,10]. La comparación intra-grupo no reveló diferencias significativas en el grupo control entre pre-test y post-test tras 9 semanas siguiendo su rutina de entrenamiento normal, excepto en la P_{max}, aunque con un tamaño del efecto trivial. Por el contrario, el grupo experimental mostró cambios significativos con un tamaño del efecto grande en la mejora del CMJ, con reducción del F-V_{IMB} y V_0. Mientras que se encontraron diferencias significativas muy grandes en el aumento de la F_0. En la comparación entre el grupo control y el grupo experimental, no se encontraron diferencias significativas en el pre-test para ninguna de las variables de estudio. Por el contrario, en el post-test se encontraron diferencias significativas con un tamaño del efecto grande en CMJ, F-V_{IMB} y V_0, y muy grande para F_0.

El **estudio III** [7] se llevó a cabo un estudio cuasi experimental con dos objetivos principales: (I) Observar el efecto de un entrenamiento resistido horizontal de 8 semanas con trineos con la carga óptima para la producción de P_{max} en jugadoras de rugby amateur y (II) observar si los valores de fuerza horizontal inicial influyen en la mejora del rendimiento en sprint. A 31 jugadoras de rugby amateur (edad: 23.7±3.3 años, peso: 69±9Kg y altura: 167.5±5.2cm) se les midió la altura del CMJ, los tiempos en 30m sprint (y los tiempos parciales en 5m, 10m, 15, 20m, 25 y 30m), y las variables mecánicas correspondientes al perfil *F-V* y *F-V-P*, con My jump 2 [9] y My sprint [11] respectivamente. Las participantes fueron divididas en un grupo control (n=10) y dos grupos experimentales en función de la posición de las jugadoras: 1s líneas (n=13) y 2s líneas (n=8). Durante 8 semanas todos los grupos realizaron 2 sesiones (martes y jueves) de 2 series de 5 repeticiones de 30m, con la diferencia de que los grupos experimentales las realizaron con la carga optima para la producción de P_{max} durante el sprint (1s líneas= 89.1±6.4% y 2s líneas=80.5±6.7% del peso corporal) [12,13].

La comparación pre-test vs post-test para cada grupo reveló diferencias significativas triviales y pequeñas en peso corporal, sprint 5m y 20m en el grupo control. En las 1s líneas se encontró diferencias significativas moderadas en sprint 5m y 20m, F_0, P_{max} y Rf_{max}. Mientras que en las 2s líneas se encontraron diferencias significativas triviales y pequeñas en BM, S_{fv}, V_0 y D_{rf}; moderadas en 20m sprint, F_0 y P_{max} y grandes y muy grandes en Rf_{max} y 5m sprint, respectivamente.

En la comparación entre grupos de los cambios pre-test vs post-test, el grupo control mostró diferencias significativas con ambos grupos experimentales; sin embargo, no se observaron diferencias en la comparación entre estos últimos. Control vs 1s líneas: Se encontraron diferencias significativas muy grandes en BM, sprint 5m y 20m, F_0, P_{max}, Rf_{max} y D_{rf}. Mientras que fueron encontradas diferencias significativas grandes en la S_{fv}. Control vs 2s líneas: Fueron encontradas diferencias significativas muy grandes en BM, sprint 5m y 20m, P_{max}, Rf_{max} y D_{rf}. Mientras que fueron encontradas diferencias significativas moderadas y grandes en la S_{fv} y la F_0 respectivamente.

Por otra parte, fueron encontradas correlaciones significativas grande y muy grande entre la Sfv y la magnitud de mejora de P_{max} (Δ-P_{max}) de primeras y segundas líneas respectivamente.

El último estudio que cierra este compendio, **estudio IV** [8], es un estudio descriptivo correlacional. Los objetivos del mismo fueron (I) proporcionar valores de referencia de las variables mecánicas del perfil *F-V* (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg) y $F\text{-}V_{IMB}$ (%) y el perfil *F-V-P* en 20m sprint (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg), S_{fv} , RF_{max} (%) y D_{rf} (%) y (II) observar la asociación entre las variables mecánicas del perfil *F-V* y el perfil *F-V-P* en 20m sprint (F_0 (N/kg), V_0 (m/s) y P_{max} (W/kg), así como su rendimiento en ambos test en jugadoras de netball amateur. Se midió la altura del CMJ, los tiempos en 30m sprint (y los tiempos parciales en 5m, 10m, 15, 20m, 25 y 30m), y las variables mecánicas correspondientes al perfil *F-V* y *F-V-P* con My jump 2 [9] y My sprint [11], respectivamente, a 28 jugadoras de amateurs de netball (edad: 24.3±3.2 años, peso: 64.5±5Kg y altura: 172.5±6.2cm).

Fueron encontradas correlaciones significativas moderadas para el rendimiento en salto vertical y 20m sprint, además de las variables mecánicas de V_0 y P_{max}. Sin embargo, no se encontró asociación entre la aplicación vertical y horizontal de F_0 entre ambos test.

La presente Tesis Doctoral, reporta una serie de hallazgos que pueden ser útiles para las poblaciones involucradas en nuestros estudios u otras disciplinas que quieran hacer uso del perfil *F-V* y *F-V-P* para la individualización y control del entrenamiento.

De manera más específica, se ha observado que independientemente de la posición en ballet clásico, las practicantes de esta disciplina presentan déficit de fuerza [5]. Dicho déficit puede ser corregido con un entrenamiento individualizado basado en la mejora de la F_0, afectando positivamente al rendimiento en CMJ [6]. Teniendo en cuenta la importancia del salto vertical en danza [14], estos hallazgos podrían ser de gran utilidad para la preparación física de los bailarines.

Por otro lado, nuestros hallazgos también sugieren que la utilización de la carga óptima para la producción de P_{max} con trineos es una manera efectiva de mejorar la aceleración (5m y 20m sprint), además de las variables mecánicas del perfil *F-V-P* en jugadoras amateur de rugby [7]. Además de lo anterior, los resultados sugieren que mayores niveles iniciales de fuerza horizontal determinan mejores adaptaciones al entrenamiento resistido con trineos mientras que los niveles de fuerza vertical no [7]. Por lo tanto, debido a la importancia de las acciones balísticas en rugby [15,16], esto hallazgos proporcionan información útil para mejorar el rendimiento y el acondicionamiento físico de las deportistas.

Por último, las asociación observada entre CMJ y 20m sprint en jugadoras de netball amateur [8] sugiere que la mejora en una de las acciones supondrá también la mejora en la otra. Sin embargo, la ausencia de asociación en los niveles de fuerza, nos lleva a recomendar el entrenamiento de ambas acciones de manera específica [17], ya que el salto vertical y el sprint son acciones muy comunes y relevantes en el netball [18–20].

Las conclusiones expuestas anteriormente son incluso más relevantes debido a la facilidad y accesibilidad de utilizar estos métodos de campo con tecnología económica, valida, fiable y manejable, como la tecnología Smartphone. Teniendo conocimiento de las variables mecánicas que definen el rendimiento de nuestros deportistas tanto en salto como en sprint,

obtendremos una visión más completa e individualizada de las necesidades de cada individuo. Por lo tanto, podríamos diseñar planes de entrenamiento que se ajusten más a las necesidades individuales de cada uno de ellos.

ABSTRACT

The main objective of this Doctoral Thesis has been to deepen the monitoring and use of the vertical force-velocity profile (F-V profile) [1,3] and horizontal force-velocity-power profile (F-V-P profile) [4] to improve ballistic actions such as the vertical jump and sprint in different sports populations. This Thesis has been carried out through a compendium of four publications [5–8], among which a descriptive-comparative study, two quasi-experimental studies and a descriptive-correlational study can be identified.

Study I was a descriptive-comparative investigation. The objective was to compare and analyze the mechanical variables of the F-V profile and the height of the countermovement jump (CMJ) of classical ballet dancers based on their position [5]. A sample of 87 professional ballet dancers (age: 18.94-1.32 years, height: 164.41±8.2cm and weight: 56.3±5.86Kg) participated in this study, divided according to their position (41 "corps de ballet", 30 second soloists and 16 soloists). The height of the CMJ and the mechanical variables of the F-V profile ($F\text{-}V_{\mathrm{IMB}}$, F_0, V_0, P_{max}) were measured using a valid and reliable mobile application based on video analysis (My jump 2) [9], which uses Samozino's method [1,3]. All the participants showed high (HFD) and low (LFD) force deficits according to the thresholds proposed in previous research [2,10]. Significant differences were found in CMJ, V_0 and P_{max}, between the different subgroups, being the soloists and second soloists the ones that showed higher values respectively.

Once the tendency of the F-V profile was observed in ballet dancers, study II was performed. In this sense, a quasi-experimental study was designed to observe the effectiveness of an individualized training based on the reduction of the $F\text{-}V_{\mathrm{IMB}}$ of 9 weeks for the improvement of CMJ in this population [6]. The height of the vertical jump and the mechanical variables of the F-V profile were measured in a pre-test prior to 9 weeks of intervention and a subsequent post-test with My Jump 2 [9] to 47 dancers (age: 18.9±1.1 years, weight: 54.8±6.1Kg and height: 163.7±8.4 cm), divided into a control group (n=10) and an experimental group (n=36). At the third and the sixth week of intervention, the F-V profile of the participants was measured to observe the evolution of the $F\text{-}V_{\mathrm{IMB}}$ and adjust the training according to the

thresholds proposed in the scientific literature [2,10]. All the participants in the study showed Force deficits [2,5,10]. The intra-group comparison did not reveal significant differences in the control group between pre-test and post-test after 9 weeks following their normal training routine, except in Pmax, although with a trivial effect size. On the contrary, the experimental group showed significant changes with a large effect size in CMJ improvement, with reduction of F-V_{IMB} and V_0. At the same time, very large significant differences were found in the increase of F_0. In the comparison between the control group and the experimental group, no significant differences were found in the pre-test for any of the study variables. On the contrary, in the post-test, significant differences were found with a large effect size in CMJ, F-V_{IMB} and V_0, and very large for F_0.

Study III [7] was a quasi-experimental study with two main objectives: (I) To observe the effect of an 8-week horizontal resistance training with sleds with the optimal load for the production of Pmax in amateur rugby players and (II) observe if the initial level of horizontal force determine the magnitude of improvement in sprint performance. 31 amateur rugby players (age: 23.7±3.3 years, weight: 69±9Kg and height: 167.5±5.2cm) were measured for CMJ height, 30m sprint times (and split times in 5m, 10m, 15, 20m, 25 and 30m), and the mechanical variables corresponding to the F-V and F-V-P profile, with My jump 2 [9] and My sprint [11] respectively. The participants were divided into a control group (n=10) and two experimental groups based on the position of the players: forwards (n=13) and backs (n=8). During eight weeks, all groups performed two sessions (Tuesday and Thursday) of 2 sets of 5 repetitions of 30m, with the difference that the experimental groups performed them with the optimal load for the production of P_{max} during the sprint (Forwards=89.1±6.4% and backs=80.5±6.7% of body weight) [12,13].

The pre-test vs post-test comparison for each group displayed trivial and small significant differences in body weight, 5m sprint and 20m in the control group. Moderate significant differences were found in sprint 5m and 20m, F_0, P_{max} and RF_{max} in forwards. While in backs, trivial and small significant differences were found in BM, S_{fv}, V_0 and D_{rf}; moderate in 20m sprint, F_0 and P_{max} and large and very large in $R\text{F}_{max}$ and 5m sprint, respectively.

On the other hand, large and very large significant correlations were found between S_{fv} and the magnitude of improvement of P_{max} (Δ-P_{max}) in forwards and backs respectively.

The last study that closes this compendium, study IV 8, is a correlational descriptive study. Its objectives were (I) to provide reference values of the mechanical variables of the F-V profile (F0 (N / kg), V0 (m / s), Pmax (W / kg) and F-VIMB (%) and the F-V-P profile in 20m sprint (F0 (N / kg), V0 (m / s), Pmax (W / kg), Sfv, RFmax (%) and Drf (%) and (II) observe the association between the mechanical variables of the F-V profile and the F-V-P profile in 20m sprint (F0 (N / kg), V0 (m / s) and Pmax (W / kg), as well as their performance in both tests in amateur netball players. CMJ height, the times in 30m sprint (and the splits in 5m, 10m, 15, 20m, 25 and 30m), and the mechanical variables corresponding to the F-V profile and the F-V-P profile with My jump 2 9 and My sprint 11, respectively, to 28 players of netball amateurs (age: 24.3±3.2 years, weight: 64.5±5Kg and height: 172.5±6.2cm).

Moderate significant correlations were found for performance in vertical jump and 20m sprint, in addition to the mechanical variables of V_0 and P_{max}. However, no association was found between the vertical and horizontal application of F_0 between both tests.

This Doctoral Thesis reports a series of findings that may be useful for the populations involved in our studies or other disciplines that want to make use of the F-V and F-V-P profile for the individualization and control of training.

More specifically, it has been observed that regardless of the position in classical ballet, the practitioners of this discipline present strength deficits [5]. This deficit can be corrected with individualized training based on the improvement of F_0, positively affecting performance in CMJ [6]. Taking into consideration the importance of vertical jump in dance [14], these findings could be very useful for the physical preparation of dancers.

On the other hand, our findings also suggest that the use of the optimal load for the production of P_{max} with sleds is an effective way to improve acceleration (5m and 20m sprint), in addition to the mechanical variables of the F-V-P profile in amateur rugby players [7]. In addition to the above, the results suggest that higher initial horizontal force levels determine better adaptations to resistance training with sleds while vertical force levels do not [7]. Therefore, due to the importance of ballistic actions in rugby [15,16], these findings provide useful information to improve performance and physical conditioning of athletes.

Finally, the association observed between CMJ and 20m sprint in amateur netball players [8] suggests that an improvement in one of the actions will also mean an improvement in the other. However, the absence of association in force levels leads us to recommend training both actions specifically [17], since vertical jump and sprint are very common and relevant actions in netball [18-20].

The conclusions set out above are even more relevant due to the ease and accessibility of using these field methods with low cost, valid, reliable, and manageable technology, such as Smartphone technology. Knowing the mechanical variables that define the performance of our athletes both in jumping and sprinting, we will obtain a more complete and individualized view of the needs of each individual. Therefore, we could design training plans that are more tailored to the individual needs of each of them.

CAPÍTULO 1. INTRODUCCIÓN

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CAPÍTULO 1. INTRODUCCIÓN

La presente Tesis Doctoral tiene por título "Uso del perfil Fuerza-Velocidad para la individualización del entrenamiento en acciones balísticas", la cual ha sido presentada por compendio de publicaciones.

Este compendio de estudios científicos ha pretendido profundizar en la monitorización y utilización del perfil Fuerza-Velocidad (perfil *F-V*) en acciones balísticas como el salto vertical y el sprint en diferentes poblaciones deportivas. Las acciones balísticas pueden ser definidas como aquellas habilidades en las que se produce una aceleración máxima del cuerpo o de un implemento en el menor tiempo posible [21]. Acciones como el salto vertical, aceleraciones o cambios de dirección están muy presentes en deportes como rugby, voleibol, fútbol, atletismo [22,23], netball [18–20] e, incluso, disciplinas artísticas de alta exigencia física como la danza [14,24].

Según la literatura científica, dichas acciones balísticas son parámetros determinantes del rendimiento deportivo y requieren la producción de altos valores de potencia máxima (P_{max}) [17,22,23,25]. La P_{max} generada por los miembros inferiores es dependiente de la fuerza (*F*) y de la velocidad (*V*) que el sistema neuromuscular y osteo-articular de cada deportista es capaz de generar [26,27] durante la ejecución de dichas acciones específicas (salto vertical y sprint). Dicha relación entre *F* y *V* es conocida como el perfil *F-V* [21,28,29].

Han sido desarrollados métodos de campo y validados a través de la relación lineal entre *F y V* durante el salto vertical (perfil F-V vertical) [1,3] y sprint (perfil F-V-P horizontal) [4] para observar la producción de *F*, *V* y P_{max} de los miembros inferiores. Para la computación de las variables mecánicas durante dichas acciones balísticas, es necesario conocer la masa corporal, la distancia de los miembros inferiores, la altura de salto con diferentes cargas (individualizadas según la masa corporal del sujeto) y los tiempos de ejecución en sprint (tiempo de al menos 5 distancias parciales, por ejemplo: 5m, 10m, 15m, 20m y 30m) [3,4,17]. Tanto el perfil F-V vertical, como el perfil *F-V-P* horizontal pueden ser calculados de manera sencilla utilizando aplicaciones móviles válidas y fiables basadas en video análisis [9,11], las cuales han sido utilizadas para las investigaciones que componen el presente compendio.

Investigaciones previas han sugerido que el rendimiento en acciones balísticas, como el salto, está determinado por la P_{max} generada por los miembros inferiores [3,22,25,30–32]; sin embargo, para un mismo valor de P_{max} existen diferentes combinaciones de F y V ($P_{max} = F \cdot V/4$), aunque un mismo valor de P_{max} no necesariamente resulta en la misma altura de salto durante un test de salto vertical [33]. Además de lo mencionando anteriormente, se ha demostrado que para cada sujeto existe una relación óptima entre F y V que maximiza el rendimiento durante el salto vertical, conocido como el perfil óptimo *F-V* [17,21,34].

Estudios sobre la estimación teórica a través de un modelo matemático de este perfil óptimo de *F-V*, han sido publicados [3,21] y puestos en práctica [2,10,34,35] con resultados que sugieren que la individualización del entrenamiento en función del déficit de *F-V* (basado en la reducción de dicho déficit) es una manera más efectiva que el entrenamiento tradicional (sin considerar el déficit de F o V) para la mejora de producción de P_{max} de los miembros inferiores durante acciones balísticas.

El Perfil *F-V* nos informa de la relación de cada sujeto en cuanto a la fuerza y la velocidad generada se refiere, por lo que, en función de la misma, podremos observar si el deportista en cuestión tiene un perfil *F-V* óptimo o, en cambio, tiene un déficit de fuerza o velocidad. Este posible déficit o desequilibrio ($F\text{-}V_{IMB}$) nos permitirá individualizar el entrenamiento de nuestros deportistas de manera más óptima, ya que no se estará trabajando la mejora de la P_{max} como un todo, sino de manera más independiente en función de las variables que intervienen en la producción de esta. El entrenamiento basado únicamente en la mejora de la P_{max}, sin tener en cuenta el $F\text{-}V_{IMB}$, puede dar como resultado el aumento de P_{max}, aunque el rendimiento en el salto vertical no lo haga debido a que también aumente el $F\text{-}V_{IMB}$ [2].

De igual forma, la cuantificación de las variables mecánicas que determinan el rendimiento en Sprint pueden ser monitorizadas utilizando dicho perfil *F-V-P*, lo que permite individualizar el entrenamiento según las capacidades individuales de cada deportista [13,28,36].

La presente Tesis Doctoral se compone de 9 capítulos. Al inicio del documento se presenta el resumen de la investigación en español e inglés, cumpliendo así con uno de los requisitos necesarios para la obtención del doctorado con mención internacional. El **Capítulo 1** tiene como objetivo introducir de forma genérica los contenidos de la Tesis Doctoral y exponer brevemente cada uno de los capítulos que la componen.

En el **Capítulo 2** se fundamenta teóricamente la investigación científica. En primer lugar, se definen las acciones balísticas y su implicación en acciones especificas de varias disciplinas deportivas, así como su relevancia siendo consideradas un parámetro de rendimiento deportivo. En segundo lugar, se explica la importancia del perfil *F-V* vertical y horizontal para este tipo de acciones, además de introducir los métodos que hasta el momento permiten la cuantificación de dicho parámetro y los principales estudios que se han publicado utilizando dichos métodos.

En el **Capítulo 3** se exponen en orden cronológico los objetivos e hipótesis formulados para la presente Tesis Doctoral, así como los estudios de los que formaban parte.

En el **Capítulo 4** se describen en detalle los estudios de investigación que forman parte de la presente Tesis por compendio. La primera de las publicaciones se trata de un estudio descriptivo-comparativo de las variables mecánicas durante salto vertical en contra movimiento en bailarinas de ballet. Una vez que se observó la tendencia del perfil *F-V* en esta población, se realizó un segundo estudio, en este caso cuasi-experimental, para observar la efectividad de un programa de entrenamiento basado en la reducción del $F\text{-}V_{\text{IMB}}$ en el salto vertical y las variables mecánicas de este, comparándose con un grupo control. El estudio 3 es un estudio cuasi-experimental en el que se observó el efecto de un entrenamiento resistido horizontal con trineos en jugadoras de rugby, comparando un grupo control con un grupo experimental. Mientras que para la cuarta y última investigación se realizó un estudio descriptivo correlacional para observar el nivel de asociación entre el salto vertical y el sprint, además de las variables mecánicas que se producen durante la ejecución de ambas de acciones en jugadoras de netball amateur.

En el **Capítulo 5** se ha desarrollado una discusión de los resultados obtenidos en los estudios que componen este trabajo científico y se han comparado con hallazgos de otras investigaciones.

En el **Capítulo 6** se desarrollan las conclusiones principales que se han obtenido tras la realización de la presente Tesis Doctoral, además de las aplicaciones prácticas que los hallazgos acontecidos aportan al campo de las Ciencias del Deporte.

En el **Capítulo 7** se exponen las principales fortalezas del estudio, así como las limitaciones y las prospectivas de investigación.

En el **Capítulo 8** se recogen las referencias bibliográficas utilizadas para la realización de este trabajo de investigación.

En el **Capítulo 9** se han adjuntado los anexos. En primer lugar, se ha incluido una breve descripción de las revistas en las que se han publicado los artículos científicos que han dado lugar a esta Tesis y, en segundo lugar, se han adjuntado los artículos originales.

CAPÍTULO 2.

FUNDAMENTACIÓN TEÓRICA

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CAPÍTULO 2. FUNDAMENTACIÓN TEÓRICA

2.1 Marco Teórico

2.1.1 Las acciones balísticas.

Las acciones balísticas pueden ser definidas como aquellas habilidades en las que se produce una aceleración máxima del cuerpo o de un implemento en el menor tiempo posible [21]. Acciones como saltos (verticales y horizontales), aceleraciones o incluso cambios de dirección están muy presentes en acciones deportivas, siendo a su vez extremadamente importantes para el rendimiento.

Basándonos en el modelo de Hill [37], la explosividad necesaria para este tipo de acciones está relacionada con la capacidad contráctil de los músculos involucrados en cada acción específica y consecuentemente, a la P_{max} [17,22,23,25] generada por estos. Independientemente de la acción de los miembros inferiores que estemos midiendo, ya sea sprint [4,38–42] o salto vertical [3,43–45], la P_{max} resultante es el producto de F por V ($P_{max} = F \cdot V$). Por lo tanto, la P_{max} generada por los miembros inferiores es dependiente de la F y V que el sistema neuromuscular y osteo-articular de cada deportista es capaz de generar [26,27]. La relación entre F y V durante una acción específica es conocida como el perfil F-V [21,28,29], ya que tanto el salto vertical como el sprint son acciones muy comunes y determinantes en varias disciplinas deportivas. Así, el control y monitorización de la relación entre P_{max}, F y V se constituye en un parámetro a tener en cuenta para la individualización del entrenamiento en acciones balísticas [2,17].

2.1.2 Métodos de campo para la medición del perfil Fuerza-Velocidad vertical y perfil Fuerza-Velocidad-Potencia (Horizontal).

Diferentes dispositivos como plataformas de fuerza [46] o transductores de posición lineal [47] han sido necesarios para una medición valida y precisa de la F, V y P_{max} durante el salto vertical y el sprint. Aunque estos dispositivos aportan una medición fiable de diferentes variables mecánicas y de rendimiento, algunos inconvenientes como el alto coste económico, transportabilidad o acceso al registro de los datos dificultan un uso más común de esta información por parte de entrenadores y profesionales del ámbito deportivo. Teniendo en cuenta lo anterior, el diseño y validación de tests de campo para la cuantificación de las variables mecánicas que determinan el rendimiento tanto en salto vertical, ya sea en sentadilla (SJ) [3] o en contra movimiento (CMJ) [1], como en sprint [4], podrían ser útiles para los profesionales de las ciencias del deporte.

Perfil F-V durante el salto vertical.

El uso del salto vertical, tanto SJ como CMJ, ha sido utilizado como test de referencia para medir la explosividad de los miembros inferiores [48–54]. Métodos de campo han sido desarrollados y validados a través de la relación lineal entre *F y V* durante el salto vertical para observar la producción de *F*, *V* y P_{max} [1,3].

Para la computación de las variables mecánicas durante el SJ y el CMJ, es necesario conocer la masa corporal, la altura del salto vertical con 5 cargas diferentes y la distancia de los miembros inferiores del sujeto [1,3,17]. La distancia de los miembros inferiores se mide en 2 pasos: midiendo la distancia vertical desde el trocánter mayor hasta el suelo en sentadilla de 90º y midiendo la distancia entre la punta del pie y el trocánter mayor en posición decúbito supino con las pierna y los tobillos totalmente extendidos [1,3,17]. La diferencia entre ambas mediciones de los miembros inferiores determina la distancia en la que se ejecuta el empuje balístico (h_{po}) durante el salto (ver ilustración 1) [1,3]. Las cargas establecidas para este test se individualizan en función de cada sujeto, recomendándose la utilización de una carga con el 0% de la masa corporal (propio peso del deportista) y aumentar posteriormente hasta que el deportista alcance al menos 10cm (por ejemplo 0%, 10%, 20%, 30% y 50% del peso corporal) [17]. Dado el auge de las tecnologías Smartphone, es posible utilizar un teléfono móvil o un iPad para calcular las variables mecánicas del perfil *F-V* vertical de manera sencilla [9]. La computación del perfil F-V permite obtener las siguientes variables [3,17]:

- F_0 (N/kg): máxima producción teórica de fuerza de las extremidades inferiores durante el salto.
- V_0 (m/s): máxima velocidad teórica de extensión de las extremidades inferiores durante el salto.
- P_{max} (W/kg): Potencia máxima generada por las extremidades inferiores, expresada como $P_{max} = F_0 \cdot V_0/4$.
- Sfv: Pendiente de la relación lineal *F-V* calculada como Sfv= $-F_0$ / V_0.

- Sfv_{opt}: Pendiente del perfil *F-V* óptimo para un deportista. Depende del peso corporal del deportista, P_{max} y la h_{po}.
- *F-V*$_{imb}$ (%): Magnitud de la diferencia entre el Sfv y el Sfv_{opt}, se expresa en porcentaje (%). Calculado como $FV_{imb} = (Sfv/Sfv_{opt})*100$.

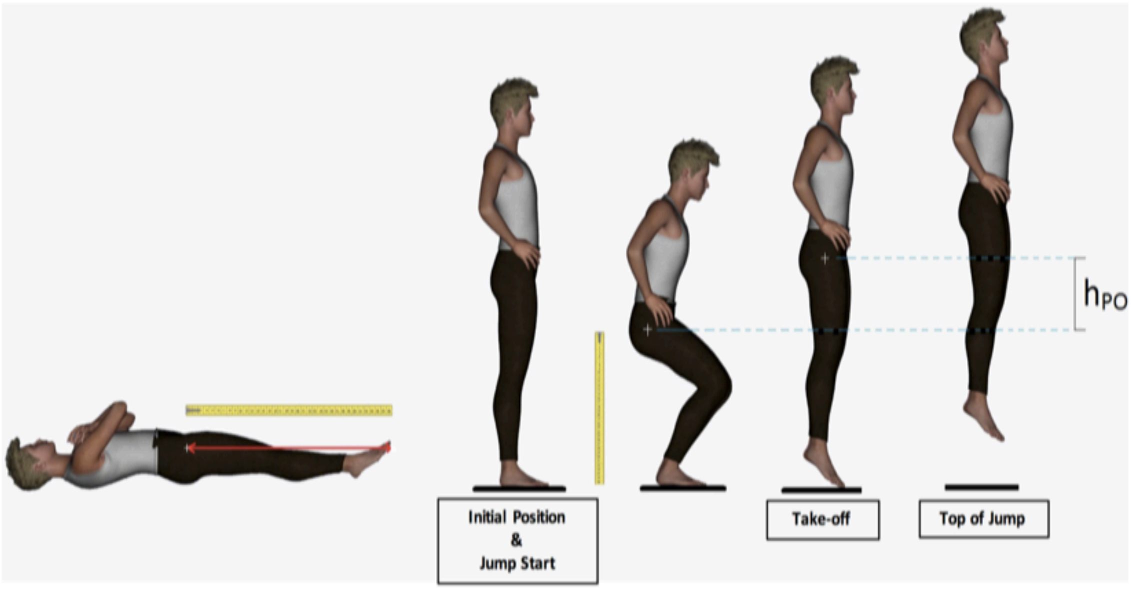

Ilustración 1: Medición de los miembros inferiores para la estimación de la distancia a la que se realiza el empuje balístico (h_{PO}). Extraído de Jiménez-Reyes y colaboradores [1].

Investigaciones previas han sugerido que el rendimiento en acciones balísticas, como el salto vertical, está determinado por la P_{max} generada por los miembros inferiores [3,22,25,30–32]. Interesantemente, para un mismo valor de P_{max} existen diferentes combinaciones de *F* y *V* ($P_{max} = F \cdot V/4$), aunque un mismo valor de P_{max} no necesariamente resulta en la misma altura de salto durante un test de salto vertical [33]. Además de lo mencionando anteriormente, se ha demostrado que para cada sujeto, existe una relación óptima entre *F* y *V* que maximiza el rendimiento durante el salto vertical, conocido como el perfil óptimo *F-V* [17,21,34].

La utilidad de cuantificar el Perfil *F-V* radica en que este parámetro nos informa de la relación de cada sujeto en cuanto a la fuerza y la velocidad generada se refiere, por lo que en función de la misma, podremos observar si el deportista en cuestión tiene un perfil *F-V* óptimo o, en cambio, tiene un déficit de fuerza o velocidad [17,21,34]. Este posible déficit o desequilibrio (*F-V*$_{IMB}$) nos permitirá individualizar el entrenamiento de nuestros deportistas de manera más óptima posible, ya que no se estará trabajando la mejora de la P_{max} como un todo, sino de manera más independiente en función de las variables que intervienen en la producción de esta.

El entrenamiento basado únicamente en la mejora de la P_{max} sin tener en cuenta el $F\text{-}V_{IMB}$, puede dar como resultado el aumento de P_{max}, aunque el rendimiento en el salto vertical no lo haga debido a que también aumente el $F\text{-}V_{IMB}$ [2].

Estudios sobre la estimación teórica a través de un modelo matemático de este perfil óptimo de *F-V*, han sido publicados [3,21] y puestos en práctica [2,10,34] con resultados que sugieren que la individualización del entrenamiento en función del déficit de *F-V* (basado en la reducción de dicho déficit) es una manera más efectiva que el entrenamiento tradicional (sin considerar el déficit de *F* o *V*) para la mejora del rendimiento en el salto vertical.

Perfil F-V-P horizontal (sprint)

Al igual que para el perfil vertical, un método de campo ha sido desarrollado y validado a través de la relación lineal entre *F* y *V* para la computación de las variables mecánicas durante el sprint, o dicho de otra forma, para la estimación del perfil *F-V-P* horizontal [4]. Para la computación de dicho perfil, es necesario conocer la masa corporal, la altura y los tiempos de ejecución del sprint (al menos 5 tiempos parciales de la distancia recorrida). Por ejemplo, para 30m: 5m, 10m, 15m, 20m y 30m de cada participante [4,17]. Para la medición de los tiempos de carrera se pueden utilizar fotocélulas, radares e, incluso, tecnología Smartphone [4,11,17]. La variables que se obtienen de la computación del perfil *F-V-P* son las siguientes [4,17]:

- F_0 (N/kg): máxima producción teórica de fuerza de las extremidades inferiores durante el sprint.
- V_0 (m/s): máxima velocidad teórica del sprint para cada individuo.
- P_{max}: Potencia máxima generada en dirección horizontal, estimada como $P_{max} = F_0 \cdot V_0/4$.
- *RF* (%): Ratio de fuerza. Efectividad mecánica en la aplicación de fuerza horizontal de cada deportista.
- RF_{max} (%): Valor máximo de ratio de fuerza. Se computa como el valor máximo de *RF* durante el sprint.
- D_{rf}: Ratio de disminución de fuerza. Describe la disminución de la eficiencia mecánica de cada deportista en la aplicación de fuerza horizontal.

2.1.3 Investigaciones relacionadas con la aplicación práctica del Perfil F-V vertical y Perfil Potencia-Fuerza-Velocidad (Horizontal).

Estudios sobre la estimación teórica a través de un modelo matemático del perfil F-V actual y óptimo durante el salto vertical (SJ y CMJ) han sido publicados [1,3,21]. Sin embargo, hasta el momento no son muy numerosas las investigaciones que han observado el efecto de un programa de entrenamiento basado en la reducción del $F\text{-}V_{\mathrm{IMB}}$ mientras aumenta el salto vertical [2,6,10,35,55]. Jiménez-Reyes y colaboradores [2] sentaron las bases para la aplicación de este método y línea de investigación. Dichos autores, en su estudio con jugadores varones semi-profesionales de rugby y fútbol, propusieron los umbrales del $F\text{-}V_{\mathrm{IMB}}$ (ver ilustración 2) y diseños de entrenamiento para corregir el déficit de cada uno de ellos. Dicha metodología, ha sido utilizada como referencia para el resto de estudios basados en la aplicación de entrenamientos basados en el perfil *F-V* publicados hasta el momento. Es importante aclarar que si el perfil *F-V* ha sido calculado con la aplicación My Jump 2 [9], los valores resultantes son interpretados de otra forma aunque con idénticas consecuencias. En el método de Samozino [1–3], los valores de $F\text{-}V_{\mathrm{IMB}}$ inferiores y superiores a 100 indican un déficit de fuerza y velocidad respectivamente, como puede apreciarse en la ilustración 1. En el caso de My Jump 2, dicha aplicación informa directamente de la dirección del déficit (entiéndase; déficit de *F* o *V*) y de la magnitud de este se expresa partiendo desde el valor 0 (lo que en la tabla 1 sería 100). Por lo tanto, un déficit del 10% de *F* equivale a un déficit del 90% en la tabla 1, mientras que un déficit del 10% de *V* equivale a un déficit del 110% en la ilustración 1.

FV_{imb} categories	F-v profile in % of optimal thresholds (%)	Training loads ratio*
High force deficit	<60	3 Strength 2 Strength-power 1 Power
Low force deficit	60–90	2 Strength 2 Strength-power 2 Power
Well-balanced	>90–110	1 Strength 1 Strength-power 2 Power 1 Power-speed 1 Speed
Low velocity deficit	>110–140	2 Speed 2 Power-speed 2 Power
High velocity deficit	>140	3 Speed 2 Power-speed 1 Power

*FV_{imb}, F-v imbalance. *Ratio based on six exercises/wk, three sets/exercise and 18 sets/wk.*

Ilustración 2: Umbrales del F-V_{IMB} para determinar la magnitud y dirección del déficit. Extraído de Jiménez-Reyes y colaboradores [2]

Una vez que los deportistas fueron clasificados en función de su déficit, se observó el efecto de un programa de entrenamiento (ver ilustración 3) basado en el perfil *F-V*, concluyendo que la individualización del entrenamiento en función del déficit actual es una manera más efectiva que el entrenamiento tradicional para la mejora del salto vertical. Lo anterior se debe a que dicha individualización permite identificar si el deportista en cuestión tiene una mayor necesidad de desarrollar entrenamientos enfocados hacia la mejora de F_0 o V_0 para mejorar la potencia óptima y, consecuentemente, su rendimiento en el salto.

Posteriormente, y para intentar abarcar ciertas limitaciones que acontecieron en los hallazgos anteriores [2], fue diseñado un estudio por el mismo grupo de investigación [10]. Para este estudio, una muestra compuesta por jugadores profesionales de fútbol sala y semi profesionales de fútbol y rugby continuaron el entrenamiento individualizado en función del F-V_{IMB} hasta que redujeron su déficit a un umbral "bien balanceado" (Well-balanced >90-110%). Las conclusiones de este estudio indican que existe una correlación positiva entre la magnitud del F-V_{IMB} y el número de semanas que se requieren para reducir el dicho déficit a un umbral óptimo, no encontrándose, además, diferencias significativas en el salto vertical y en las variables mecánicas del perfil durante las 3 semanas posteriores de finalizar la intervención para cada participante [10].

Loading focus/target	Exercises	Training loads
Strength	Back squat	80–90% 1RM
	Leg press	90–95% 1RM
	Deadlift	90–95% 1RM
Strength-power	Clean pull	80% 1RM
	Deadlift	80% 1RM
	SJ	>70% of BW
	CMJ	>80% of BW
Power	SJ	20–30% of BW
	CMJ	35–45% of BW
	Single leg SJ	BW
	Single leg CMJ	10% of BW
	Clean pull jump	65% 1RM
Power-speed	Depth jumps	
	SJ	BW
	CMJ	10% of BW
	Maximal Vertical Box Jump	
Speed	Maximal Roller Push-off	<BW
	CMJ with arms	BW

RM, repetition maximum; SJ, Squat Jump; BW, body weight; CMJ, Countermovement Jump.

Ilustración 3: Tipo de entrenamiento, ejercicios y cargas propuestas para la reducción de cada uno de los déficits. Extraído de Jiménez-Reyes y colaboradores [2].

Siguiendo las bases metodológicas de los estudios de Jiménez-Reyes [2,10], se diseñó uno de los estudios que forman parte del presente compendio [6]. En nuestro estudio se analizó el efecto de 9 semanas de un entrenamiento individualizado en un grupo de bailarinas de ballet clásico profesionales en comparación con un grupo control. Se observó que un entrenamiento basado en la reducción del déficit actual de fuerza en bailarinas se erige en una metodología útil para la mejora del salto vertical en esta población, siendo, además, que tengamos constancia según la literatura científica consultada, el único estudio hasta el momento observando el efecto de dicho método en mujeres [6].

Zabaloy y colaboradores [55] realizaron un estudio con un grupo de jugadores de rugby, en el cual reportaron que el entrenamiento individualizado basado en el perfil F-V produce mejoras en el rendimiento del sprint y modificaciones en las variables mecánicas favorables para alcanzar el perfil óptimo. Es decir, aquellos participantes que realizaron un entrenamiento para reducir la V_0 y aumentar la F_0 y viceversa, mostraron adaptaciones hacia el desarrollo de dichos componentes del espectro F-V, sin embargo estas adaptaciones no afectaron de manera significativa a la P_{max}, 1RM en sentadilla y a la altura del salto (SJ y CMJ). Por el contrario, un estudio reciente [35] comparó el efecto de 8 semanas de entrenamiento generalizado (fuerza-potencia) con un entrenamiento individualizado en función del perfil F-V en jugadores profesionales de rugby league durante la pretemporada. Los hallazgos reportaron mejores resultados del grupo que siguió un entrenamiento individualizado en la reducción del $F\text{-}V_{IMB}$, 3RM en sentadilla, P_{max} y altura de salto en SJ, mientras que no se observó diferencias significativas en 10m y 20m sprint.

En relación al perfil *F-V-P* durante el sprint [4,17], varias investigaciones han utilizado el precitado método para monitorizar y controlar el rendimiento de diferentes deportistas. El uso de este test, permite cuantificar el efecto de los programas de entrenamiento de cada individuo, observando los cambios producidos en las variables mecánicas subyacentes que determinan el rendimiento en sprint [4,17].

Investigaciones previas han observado las variables mecánicas de deportistas antes de someterlos a un programa específico de entrenamiento, como por ejemplo entrenamiento horizontal resistido con trineos (RST). Revisiones sistemáticas recientes han sugerido que este método es una de las formas más efectivas para mejorar la aceleración en varios deportes [56,57]. Diferentes investigaciones han observado las modificaciones que se producen en el perfil *F-V-P* después de varias semanas de RST en futbolistas [28], jugadores y jugadoras de rugby union [7,13,36,58] o rugby league [35]. Por otra parte, dicho método ha sido utilizado para observar las diferencias de las variables mecánicas en jugadores de fútbol y fútbol sala [59], para observar la evolución de dichas variables a lo largo de una temporada en jugadores de fútbol profesional [60] o los efectos de una sesión de sprints repetidos en jugadores de rugby 7 élite [61].

Además de las investigaciones relacionadas con la mejora del rendimiento deportivo, el uso del perfil F-V-P también ha sido utilizado para la valoración de deportistas en su proceso de recuperación después de una lesión, ya que permite observar si los valores de fuerza del deportista cumplen los requisitos necesarios para volver a la competición [62,63].

Para concluir, la asociación entre las variables mecánicas de ambos perfiles ha sido observada en numerosas poblaciones deportivas [8,64,65]. Estos estudios concluyeron que aunque en algunos casos la asociación entre el rendimiento y las variables mecánicas de ambos perfiles es existente, el uso de ambos métodos proporciona una visión más complementaría e individualizada de cada uno de los deportistas [17]. Por lo que podríamos diseñar planes de entrenamiento mas optimizados para el beneficio de estos.

CAPÍTULO 3.

OBJETIVOS E HIPÓTESIS

Facultad de Ciencias del Deporte
Universidad de Extremadura

CAPÍTULO 3. OBJETIVOS E HIPÓTESIS

En este capítulo se exponen los objetivos e hipótesis de la presente Tesis Doctoral, siguiendo la evolución en el diseño de los estudios presentados para el compendio.

1. **Analizar la el perfil F-V durante el salto vertical en bailarinas de ballet profesional.**

Hipótesis de estudio establecida:

- Las bailarinas de ballet mostrarían un perfil F-V orientado a la velocidad (déficit de fuerza), independientemente de su posición.

El anterior objetivo e hipótesis dieron lugar al estudio I, del que se derivó la siguiente publicación [5]:

Escobar Álvarez JA, Reyes PJ, Pérez Sousa MÁ, Conceição F, Fuentes García JP. Analysis of the Force-Velocity Profile in Female Ballet Dancers. *J Dance Med Sci*. 2020;24(2):59-65. doi:10.12678/1089-313X.24.2.59

2. **Observar el efecto de un programa de entrenamiento basado en el perfil F-V durante el salto vertical en bailarinas de ballet profesional.**

Hipótesis de estudio establecida:

- Un entrenamiento individualizado en el perfil F-V puede mejorar la altura del salto vertical en bailarinas de ballet clásico.

El anterior objetivo e hipótesis dieron lugar al estudio II, del que se derivó la siguiente publicación [6]:

Escobar Álvarez JA, Fuentes García JP, Da Conceição FA, Jiménez-Reyes P. Individualized Training Based on Force–Velocity Profiling During Jumping in Ballet Dancers. *Int J Sports Physiol Perform*. 2019. doi:10.1123/ijspp.2019-0492

3. **Observar el efecto de un programa de entrenamiento con trineos con una carga basada en la producción de potencia máxima.**

El anterior objetivo se desarrolló en el estudio III, del que se derivó la siguiente publicación [7]:

Escobar JA, Álvarez PJR, Da Conceição FA, Fuentes García JP. Does the Initial Level of Horizontal Force Determine the Magnitude of Improvement in Acceleration Performance in Rugby? *Eur J Sport Sci*. 2020. doi:10.1080/17461391.2020.1793004

4. **Observar si los niveles iniciales de fuerza horizontal determinan la magnitud mejora en el rendimiento en sprint.**

Hipótesis de estudio establecida:

- Las jugadoras con mayores niveles iniciales de *F* horizontal mostrarán mayor mejora después de un entrenamiento resistido con trineos.

El anterior objetivo e hipótesis dieron lugar al estudio III, del que se derivó la siguiente publicación [7]:

Escobar JA, Álvarez PJR, Da Conceição FA, Fuentes García JP. Does the Initial Level of Horizontal Force Determine the Magnitude of Improvement in Acceleration Performance in Rugby? *Eur J Sport Sci*. 2020. doi:10.1080/17461391.2020.1793004

5. Observar los niveles de asociación entre el perfil *F-V* vertical y *F-V-P* horizontal.

El anterior objetivo se desarrolló en el estudio IV, del que se derivó la siguiente publicación [8]:

Escobar-Álvarez JA, Fuentes-García JP, Viana-da-Conceição FA, Jiménez-Reyes P. Association between vertical and horizontal force-velocity-power profiles in netball players. *J Hum Sport Exerc*. 2020;17(1):1-10. doi:10.14198/jhse.2022.171.09

CAPÍTULO 4.

ESTUDIOS DESARROLLADOS

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CAPÍTULO 4. ESTUDIOS DESARROLLADOS

4.1 Investigación I: Estudio descriptivo-comparativo

"Analysis of the Force-Velocity profile in female ballet dancers"

Objetivo e hipótesis

El objetivo principal de esta investigación fue analizar el perfil *F-V* durante el salto en contra movimiento de una población poco explorada hasta el momento, como son las bailarinas de ballet. Además de lo citado anteriormente, también se comparó al salto vertical y las variables mecánicas de la bailarinas en función de su posición.

La hipótesis de estudio establecida fue la siguiente:

1- Las bailarinas de ballet mostrarían un perfil F-V orientado a la velocidad (déficit de fuerza), independientemente de su posición.

Método

Participantes

La muestra de este estudio se compuso de un total de 87 bailarinas profesionales de ballet (edad: 18.94±1.32 años, altura: 164.41±8.2cm y peso: 56.3±5.86Kg). Los subgrupos en función de la posición fueron: 41 "cuerpo de ballet", 30 segundos solistas y 16 solistas. Todas las bailarinas tenían un mínimo de 6 años de experiencia en dicha modalidad y se dedicaban exclusivamente al ballet clásico desde al menos 4 años.

Medida

Las variables de estudios fueron las siguientes:

Altura del salto vertical (CMJ) en cm. Se midió utilizando una aplicación móvil válida y fiable [9] basada en video análisis (*My jump 2*), la cual utiliza el método de Samozino para la estimación de la altura del salto [1,3].

Variables mecánicas del perfil *F-V* durante el CMJ: $F\text{-}V_{IMB}$ (%), F_0 (N/kg), V_0 (m/s), P_{max} (W/kg). Al igual que con el salto vertical, se utilizó My Jump 2 [9] para calcular las variables mecánicas de este a través de un test basado en saltos con carga [1,3,17,21,34]. Las cargas utilizadas para el test fueron el 0%, 10%, 20%, 30%, 40%, 50% y 70% del peso corporal de cada participante. Una vez analizadas y registradas las alturas de salto con las cargas citadas anteriormente, My Jump 2 calcula los parámetros mecánicos correspondientes al perfil *F-V* actual y perfil óptimo de *F-V*. Así, mediante dicho procedimiento pueden observarse la dirección (déficit de Fuerza o de Velocidad) y la magnitud del déficit de cada participante. [1,3,17,21,34].

Diseño y Procedimiento

Este estudio descriptivo-comparativo se realizó de forma transversal, ya que no se realizó ninguna intervención o se manipuló variable alguna, observándose lo que ocurre con dichas variables en un test específico. My Jump 2 se utilizó en un iPad Pro, el cual tiene una cámara capaz de realizar 240 capturas por segundo (240 fps).

Esta investigación fue realizada siguiendo las normas del Comité Ético de Investigación de South Essex College University Centre, Southend on the Sea, Reino Unido. Todas las participantes y maestros/as de danza fueron informados de los riesgos y beneficios del estudio antes de su realización. La confidencialidad y el anonimato de las bailarinas fueron rigurosamente garantizados, bajo acuerdo firmado por el doctorando y los responsables de las academias de danza participantes.

Análisis estadístico

El registro de los datos se llevó a cabo con My jump 2, el cual permite descargar los datos a una hoja de cálculo, y posteriormente se realizó el análisis mediante el programa estadístico informático IBM SPSS Statistics versión 24. No todas las variables mostraron distribución normal, por lo fueron utilizadas estadística paramétrica (ANOVA de un solo factor con una prueba Tukey) y no-paramétrica (Kruskall-Wallis con una prueba post-hoc de Mann-Whitney) para la comparación entre los 3 subgrupos. El nivel de significación fue establecido en $p \leq 0.05$.

Resultados

Estadística descriptiva y comparación entre subgrupos

En la tabla 1 se presenta mediante media y desviación típica la estadística descriptiva (total de participantes y separados por subgrupos) y la comparación entre los subgrupos para el CMJ (cm), $F\text{-}V_{IMB}$ (%), F_0 (N/kg), V_0 (m/s) y P_{max} (W/kg). Las 87 bailarinas participantes en el estudio mostraron déficit de fuerza de acuerdo a los umbrales propuestos en previas investigaciones [2,10]. Fueron encontradas diferencias significativas en CMJ, V_0 y P_{max}, entre los diferentes subgrupos, siendo las solistas y segundas solistas las que mostraron valores más altos respectivamente.

	Ballet Dancers n=87	**Artist n=41**	**First Artist n=30**	**Soloist n=16**	**P-Value (0.05*)**
CMJ (cm)	28.29±3.42	26.10±2.09	28.41±1.9	33.68±2.08	0.01*
$F\text{-}V_{IMB}$ (%)	45.60±13.54	42.28±13.33	47.37±14.08	50.78±11.34	0.06
F_0 (N/kg)	25.23±1.99	25.13±1.72	25.03±2.43	25.87±1.66	0.61
V_0 (m/s)	3.67±0.78	3.36±0.68	3.80±0.73	4.24±0.79	0.01*
P_{max} (W/kg)	22.97±4.11	20.93±3.22	23.45±2.95	27.29±4.55	0.01*

Tabla 1: Valores de media ± desviación estándar del salto vertical en contra movimiento (CMJ), diferencia entre la magnitud del el perfil F-V actual y óptimo ($F\text{-}V_{IMB}$); fuerza máxima teórica (F_0), velocidad máxima teórica (V_0) y potencia máxima teórica (P_{max}) [17].

4.2 Investigación II: Estudio cuasi-experimental

"Individualized training based on Force-Velocity profiling during jumping in ballet dancers"

Objetivo e hipótesis

El objetivo principal de esta investigación fue observar el efecto de un entrenamiento individualizado basado en la reducción del $F\text{-}V_{IMB}$ de 9 semanas de duración para la mejora del CMJ en bailarinas de ballet clásico.

La hipótesis de estudio establecida fue la siguiente:

1- Un entrenamiento individualizado en el perfil F-V puede mejorar la altura del salto vertical en bailarinas de ballet clásico.

Método

Participantes

La muestra de este estudio se compuso de un total de 47 bailarinas profesionales de ballet clásico (edad: 18.9±1.1 años, peso: 54.8±6.1Kg y altura: 163.7±8.4cm). Todas las bailarinas tenían un mínimo de 6 años de experiencia en dicha modalidad.

Medida

Las variables de estudios fueron:

Altura del salto vertical (CMJ) en cm: se midió utilizando una aplicación móvil válida y fiable [9] basada en video análisis (*My jump 2*), la cual utiliza el método de Samozino para la estimación de la altura del salto [1,3].

Variables mecánicas del perfil *F-V* durante el CMJ: $F\text{-}V_{IMB}$ (%), F_0 (N/kg), V_0 (m/s), P_{max} (W/kg). Al igual que con el salto vertical, se utilizó My Jump 2 [9], para calcular las variables mecánicas de este a través de un test basado en saltos con carga [1,3,17,21,34]. Las cargas utilizadas para el test fueron el 0%, 10%, 20%, 30%, 40%, 50% y 70% del peso corporal de cada individuo. Una vez analizadas y registradas las alturas de salto con las cargas citadas anteriormente, My Jump 2 calcula los parámetros mecánicos correspondientes al perfil *F-V* actual y perfil óptimo de *F-V*. Pudiéndose así observar la dirección (déficit de Fuerza o de Velocidad) y la magnitud del déficit de cada participante. [1,3,17,21,34].

Diseño y Procedimiento

Este estudio cuasi-experimental incluyó un grupo control (n=10) y un grupo experimental (n=36). La altura del salto vertical y las variables mecánicas del perfil *F-V* fueron medidas en un pre-test previo a las 9 semanas de intervención y un post-test posterior. A las 3 y 6 semanas de intervención se midió el perfil *F-V* de las participantes para observar la evolución del $F\text{-}V_{IMB}$ y justar el entrenamiento en función de los umbrales propuestos en la literatura [2,10]. En la tabla 2 puede observarse el plan semanal de entrenamiento (2 sesiones por semana) que siguieron las bailarinas en función de la magnitud de su déficit de fuerza.

Group		**1st Session**			**2nd Session**	
	Exercises	**Sets/repetitions**	**Training load**	**Exercises**	**Sets/repetitions**	**Training load**
	Leg press	3x6	90% 1RM	Back-Squat	3x6	3x6reps (80% 1RM)
HFD	Deadlift	3x6	90% 1RM	CMJ	3x6	3x6reps (85% BM)
	SJ	3x6	80% BM	Single leg CMJ	3x6	3x6reps (10% BM)
	Leg press	3x6	90% 1RM	Back-Squat	3x6	3x6reps (80% 1RM)
LFD	SJ	3x6	80% 1RM	CMJ	3x6	3x6reps (85% BM)
	Single leg CMJ	3x6	10% BM	Single leg SJ	3x6	3x6reps (BM)

Tabla 2: Ejercicios, series, repeticiones y cargas de entrenamiento para los subgrupos con bajo déficit de fuerza (LFD) y alto déficit de fuerza (HFD) en cada una de las sesiones semanales.

Esta investigación fue realizada siguiendo las normas del Comité ético de Investigación de South Essex College University Centre, Southend on the Sea, Reino Unido. Todas las participantes y maestros/as de danza fueron informados de los riesgos y beneficios del estudio antes de su realización. La confidencialidad y el anonimato de las bailarinas fueron rigurosamente garantizados, bajo acuerdo firmado por el doctorando y los responsables de las academias de danza participantes.

Análisis estadístico

El registro de los datos se llevó a cabo con My jump 2, el cual permite descargar los datos a una hoja de cálculo, y a continuación se procedió a realizar el análisis estadístico mediante el programa estadístico informático IBM SPSS Statistics versión 25. Las variables de estudio mostraron una distribución normal de acuerdo al test de Shapiro-Wilk. Las comparaciones intra e inter grupos se realizaron con una ANOVA de 2 factores (grupo x tiempo de medida) ajustada con un test Bonferroni. El nivel de significación fue establecido en $p \leq 0.05$. La fiabilidad del CMJ se analizó utilizando el coeficiente de correlación intraclase con un intervalo de confianza a 95%. El criterio para interpretar la magnitud de cambio entre el pre-test vs post-test y entre los diferentes grupos fue el tamaño del efecto de Cohen (ES): <0.2 = trivial, 0.2 - 0.6 = pequeño, 0.6 - 1.2 = moderado, 1.2 – 2 = grande y >2.0 = muy grande [66].

Resultados

Las 47 bailarinas participantes en el estudio mostraron déficit de fuerza de acuerdo a los umbrales propuestos en previas investigaciones [2,10].

Comparación inter grupos

En la tabla 3 se presenta la comparación de la media ± desviación típica de los valores correspondientes a las variables de estudio durante el pre-test y el post-test entre ambos grupos. No fueron encontradas diferencias significativas en el pre-test para ninguna de las variables de estudio. Por el contrario, en el post-test se encontraron diferencias significativas con un tamaño del efecto grande en CMJ, $F\text{-}V_{IMB}$ y V_0, y muy grande para F_0.

Comparación intra grupos

En la tabla 4 se presentan los valores de media ± desviación típica de la comparación pre-test vs post-test en ambos grupos. No fueron encontradas diferencias significativas en el grupo control después de 9 semanas siguiendo su rutina de entrenamiento normal, excepto en la P_{max}, aunque con un tamaño del efecto trivial. Por el contrario, el grupo experimental mostró cambios significativos con un tamaño del efecto grande en la mejora del CMJ, reducción del $F\text{-}V_{IMB}$ y V_0. mientras que fueron encontradas diferencias significativas muy grandes en el aumento de la F_0.

Variables	Control Group	Experimental Group	P	95% CI	ES
Pre-CMJ height (cm)	27.3±2	29.3±3.2	0.08	4.11-0.27	0.6 (M)
Pre-F-V_{IMB} (%)	45.1±14.6	43.8±15.3	0.8	9.55-12.33	0.08 (T)
Pre-F_0 (N/kg)	22.9±2.4	24.1±2.2	0.16	2.76-0.46	0.5 (S)
Pre-V_0 (m/s)	4.1±0.6	4±0.6	0.5	0.28-0.6	0.1 (T)
Pre-P_{max} (W/kg)	23.3±1.7	23.8±3	0.7	2.47-1.57	0.1 (T)
Post-CMJ height (cm)	27.5±2	33.5±3.7	**0.01***	8.49-3.53	1.7 (L)
Post-F-V_{IMB} (%)	45.3±14.7	24.9±8.7	**0.01***	13-27.77	1.9 (L)
Post-F_0 (N/kg)	23±2.4	29.9±2.8	**0.01***	8.78-4.92	2.5 (VL)
Post-V_0 (m/s)	4.2±0.7	3.2±0.5	**0.01***	0.59-1.36	1.8 (L)
Post-P_{max} (W/kg)	23.4±1.7	23.8±3	0.74	2.36-1.69	0.1 (T)

Tabla 3: Valores de media ± desviación estándar del grupo control y grupo experimental para la comparación de cada variable. Los datos se presentan como nivel de significación (P), intervalo de confianza al 95% (95%CI) y tamaño del efecto (ES). Resaltado en negrita y con un * aquellos valores significativos (p≤0.05).

Variables	Control Group					Experimental Group				
	Pre-Test	**Post-Test**	**P**	**95% CI**	**ES**	**Pre-Test**	**Post-Test**	**P**	**95% CI**	**ES**
CMJ height (cm)	27.3±2	27.5±2	0.9	0.60-0.35	0.1 (T)	29.3±3.2	33.5±3.7	**0.01***	4.46-3.95	1.21 (L)
F-V_{IMB} (%)	45.1±14.6	45.3±14.7	0.9	5.37-5.03	0.01 (T)	43.8±15.3	24.9±8.7	**0.01***	16.08-21.57	1.51 (L)
F_0 (N/kg)	22.9±2.4	23±2.4	0.9	0.55-0.35	0.04 (T)	24.1±2.2	29.9±2.8	**0.01***	6.04-5.56	2.3 (VL)
V_0 (m/s)	4.1±0.6	4.2±0.7	0.9	0.13-0.05	0.15 (T)	4±0.6	3.2±0.5	**0.01***	0.73-0.83	1.45 (L)
P_{max} (W/kg)	23.3±1.7	23.4±1.7	**0.02***	0.18-0.01	0.05 (T)	23.8±3	23.8±3	0.93	0.02-0.06	0 (T)

Tabla 4: Valores de media ± desviación típica de la comparación pre-test vs post-test del grupo control y el grupo experimental después de las 9 semanas de intervención.. Los datos se presentan como nivel de significación (P), intervalo de confianza al 95% (95%CI) y tamaño del efecto (ES). Resaltado en negrita y con un * aquellos valores significativos (p≤0.05).

4.3 Investigación III: Estudio cuasi-experimental

"Does the initial level of horizontal force determine the magnitude of improvement in acceleration performance in Rugby?

Objetivo e hipótesis

Los objetivos principales de esta investigación fueron:

1. Observar el efecto de un entrenamiento resistido horizontal de 8 semanas con trineos con la carga óptima para la producción de P_{max} en jugadoras de rugby amateur.

2. Observar si los valores de fuerza horizontal inicial influyen en la mejora del rendimiento en sprint.

La hipótesis de estudio establecida fue:

1. Las jugadoras con mayores niveles iniciales de *F* horizontal mostrarán mayor mejora después de un entrenamiento resistido con trineos.

Método

Participantes

La muestra de este estudio se compuso de un total de 31 jugadoras de rugby amateur (edad: 23.7±3.3 años, peso: 69±9Kg y altura: 167.5±5.2cm). Todas las jugadoras tenían más de 6 años de experiencia en dicho deporte (8±1.7).

Medida

Las variables de estudios fueron:

Altura del CMJ (en cm). Se midió utilizando *My jump 2* [9].

Velocidad (segundos-s) y variables mecánicas del perfil *F-V-P* durante un sprint de 30m. Se midió utilizando una aplicación móvil válida y fiable [11] basada en video análisis (*My Sprint*), la cual utiliza el método de Samozino [4] para la estimación de las variables mecánicas del perfil *F-V-P* (S_{fv}, F_0 (N/kg), V_0 (m/s), P_{max} (W/kg), RF_{max} (%) y D_{rf} (%)) durante un test de velocidad 30m en el que se registraron los tiempos de 5m, 10m, 15m, 20m, 25m y 30m. En los resultados solo se incluyeron los tiempos de 5m (como indicador de la aceleración) y 20m, ya que son los tiempos que más se han usado en la literatura actual y facilitaban la comparación con otros estudios.

Carga optima para el entrenamiento resistido con trineos, basada en la máxima producción de potencia [12,13,36]. Las participantes realizaron 4 sprints de 30m (5m, 10m, 15m, 20m, 25m y 30m) con un trineo atado a la cintura con las cargas correspondientes al 0%, 25%, 50% y 75% del peso corporal de cada individuo. El tiempo para cada uno de las aceleraciones con cargas fue medido con My sprint [11] y registrado en una hoja de cálculo de Excel, la cual estima la carga optima validada para la producción de P_{max} [12,13,36].

Ambas aplicaciones se utilizaron en un iPhone 7 (iPhone7: Apple, Cupertino, CA, USA) el cual tiene una cámara que graba a 240 fps.

Diseño y Procedimiento

Este estudio cuasi-experimental incluyó un grupo control (n=10) y dos grupos experimentales en función de la posición de los jugadoras, primeras líneas (n=13) y segundas líneas (n=8). La altura del salto vertical, los tiempos para el test de velocidad en 30m (5m, 10m, 15m, 20m, 25m y 30m) y la carga óptima para cada individuo fueron calculados en dos sesiones previas al comienzo de la intervención. Durante 8 semanas todos los grupos realizaron 2 sesiones (martes y jueves) de 2 series de 5 repeticiones de 30m, con la diferencia de que los grupos experimentales las realizaron con la carga optima estimada para cada individuo (1s líneas= 89.1±6.4% y 2s líneas=80.5±6.7% del peso corporal) [12,13]. Una vez finalizadas las 8 semanas (16 sesiones), se procedió con el post-test siguiendo el mismo protocolo mencionado anteriormente.

Esta investigación fue realizada siguiendo las normas del Comité ético de Investigación de South Essex College University Centre, Southend on the Sea, Reino Unido. Todas las participantes, entrenadores y preparadores físicos fueron informados de los riesgos y beneficios del estudio antes de su realización. La confidencialidad y el anonimato de las participantes fueron acordados por el doctorando y los responsables del equipo de rugby.

Análisis estadístico

El registro de los datos del salto vertical se llevó a cabo con My jump 2 [9], mientras que los tiempos en 30m sprint (con y sin carga), además de las variables mecánicas de aceleración se realizó con My sprint [11]. Ambas aplicaciones permiten descargar los datos a una hoja de cálculo y, una vez en esta, se realizó un análisis descriptivo, comparativo y correlacional con el programa estadístico informático IBM SPSS Statistics versión 25.

Las variables de estudio mostraron una distribución normal de acuerdo al test de Shapiro-Wilk. Las comparaciones intra e inter grupos se realizaron con una ANOVA de 2 factores (grupo x tiempo de medida) ajustadas con un test Bonferroni. El criterio para interpretar la magnitud de cambio entre el pre-test vs post-test y entre los diferentes grupos fue el tamaño del efecto de Cohen (ES): <0.2 = trivial, 0.2 - 0.6 = pequeño, 0.6 - 1.2 = moderado, 1.2 – 2 = grande y >2.0 = muy grande [66]. El nivel de significación fue establecido en $p \leq 0.05$.

El nivel de asociación entre los valores iniciales de CMJ con S_{fv}, y la magnitud de mejora de P_{max} (Δ-P_{max}) (calculada como $\left(\frac{Post\ Pmax}{Inicial\ Pmax}\right) - 1) * 100)$ fue analizada con la correlación de Pearson y el coeficiente de determinación (R^2) con un nivel de significación de $p \leq 0.05$. El criterio para interpretar la magnitud de las correlaciones fue : ≤ 0.1 = trivial,$> 0.1 - 0.3$ = pequeña,$> 0.3 - 0.5$ = moderada,$> 0.5 - 0.7$ = grande,$> 0.7 - 0.9$ = muy grande,$> 0.9 - 1.0$ = casi perfecta [67].

Resultados

Comparación inter grupos

En la tabla 5 se presenta la comparación entre grupos de lo cambios pre vs post (%) para cada variable de estudio.

Control vs 1s líneas: Fueron encontradas diferencias significativas muy grandes en peso corporal (BM), sprint 5m y 20m, F_0, P_{max}, Rf_{max} y D_{rf}. Mientras que fueron encontradas diferencias significativas grandes en la S_{fv}.

Control vs 2s líneas: Diferencias significativas muy grandes fueron encontradas en peso corporal (BM), sprint 5m y 20m, P_{max}, Rf_{max} y D_{rf}. Mientras que diferencias significativas moderadas y grandes fueron encontradas en la S_{fv} y la F_0, respectivamente.

1s líneas vs 2s líneas: No fueron encontradas diferencias significativas entre los cambios pre vs post de los grupos experimentales.

Groups	Variable	Pre vs Post-Test Change (%)			
		P	95% CI	ES	Inference
Control vs Forwards	**BM (Kg)**	**0.01***	8.608-4.481	6.54	Very Large
	5m (s)	**0.01***	2.799-5.775	4.28	Very Large
	20m (s)	**0.01***	2.349-5.049	3.7	Very Large
	S_{fv}	**0.01***	2.229-0.412	1.32	Large
	F_0 (N/kg)	**0.01***	3.196-1.127	2.16	Very Large
	V_0 (m/s)	1	1.053-0.061	0.22	Small
	P_{max} (W/kg)	**0.01***	5.486-2.621	4.05	Very Large
	Rf_{max} (%)	**0.01***	3.914-1.617	2.76	Very Large
	D_{rf} (%)	**0.01***	10.950-5.829	8.38	Very Large
Control vs Backs	**BM (Kg)**	**0.01***	11.048-5.371	8.2	Very Large
	5m (s)	**0.01***	2.776-6.267	4.52	Very Large
	20m (s)	**0.01***	2.223-5.307	3.76	Very Large
	S_{fv}	**0.02***	2.026-0.047	1.03	Moderate
	F_0 (N/kg)	**0.01***	2.868-0.677	1.77	Large
	V_0 (m/s)	0.77	1.372-0.509	0.43	Small
	P_{max} (W/kg)	**0.01***	4.670-1.844	3.25	Very Large
	Rf_{max} (%)	**0.01***	3.387-1.033	2.2	Very Large
	D_{rf} (%)	**0.01***	5.707-2.456	4.08	Very Large
Forwards vs Backs	**BM (Kg)**	1	0.7-1.065	0.18	Trivial
	5m (s)	1	0323-1.473	0.57	Small
	20m (s)	0,08	0.723-2.778	1.75	Large
	S_{fv}	1	0.577-1.195	0.3	Small
	F_0 (N/kg)	1	0.867-0.895	0.01	Trivial
	V_0 (m/s)	1	1.613-0.2	0.7	Moderate
	P_{max} (W/kg)	1	1.226-0.547	0.33	Small
	Rf_{max} (%)	1	0.606-1.164	0.28	Small
	D_{rf} (%)	0.95	0.512-1.264	0.37	Small

Tabla 5: Comparación entre grupos de los cambios pre vs post (%) para cada variable. Los datos se presentan como nivel de significación (P), intervalo de confianza al 95% (95%CI) y tamaño del efecto (ES). Resaltado en negrita y con un * aquellos valores significativos (p≤0.05). ***Comparación intra grupos***

En la tabla 6 se presenta los valores de media ± desviación típica de la comparación pre-test vs post-test de todos los grupos después de las 8 semanas de intervención. Grupo control: Diferencias significativas triviales y pequeñas fueron encontradas en peso corporal, sprint 5m y 20m. 1s líneas: Diferencias significativas triviales y pequeñas fueron encontradas en BM, S_{fv}, V_0 y D_{rf}. Diferencias significativas moderadas se observaron en sprint 5m y 20m, F_0, P_{max} y Rf_{max}. 2s líneas: Diferencias significativas triviales y pequeñas fueron encontradas en BM, S_{fv}, V_0 y D_{rf}. Diferencias significativas moderadas se observaron en 20m sprint, F_0 y P_{max}. Mientras que diferencias significativas grandes y muy grandes se encontraron en Rf_{max} y 5m sprint.

Groups	Variable	Pre-Test	Post-Test	P	95% CI	ES	Inference	Change (%)
Control	**BM (Kg)**	71.4±12	71.2±12	**0.01***	0.149-0.299	0.01	Trivial	-0.32±0.06
	5m (s)	1.66±0.09	1.64±0.09	**0.01***	0.015-0.025	0.22	Small	-1.23±0.71
	20m (s)	4.32±0.24	4.27±0.24	**0.01***	0.038-0.06	0.2	Small	-1.15±0.6
	S_{fv} (%)	-0.73±0.08	-0.74±0.06	0.51	0.029-0.042	0.13	Small	-0,87±6.57
	F_0 (N/kg)	5.01±0.62	5.09±0.54	0.08	0.01-0.167	0.13	Trivial	1.6±4.15
	V_0 (m/s)	6.85±0.6	6.89±0.59	0.24	0.03-0.113	0.07	Trivial	0.58±2.6
	P_{max} (W/kg)	8.62±1.53	8.81±1.51	**0.01***	0.096-0.292	0.12	Trivial	2.25±2.20
	Rf_{max} (%)	33±2.69	33.3±2.75	**0.01***	31.67-33.64	0.11	Trivial	0.88±2.04
	D_{rf} (%)	-7.09±0.8	-7.11±0.8	**0.01***	6.725-7.319	0.02	Trivial	-0.27±0.07
Forwards	**BM (Kg)**	71.8±6.5	72.3±6.5	**0.01***	0.459-0.59	0.08	Trivial	0.73±0.2
	5m (s)	1.66±0.09	1.60±0.08	**0.01***	0.053-0.062	0.66	Moderate	-3.57±0.37
	20m (s)	4.33±0.17	4.22±0.17	**0.01***	0.103-0.121	0.65	Moderate	-2.65±0.17
	S_{fv} (%)	-0.68±0.09	-0.73±0.09	**0.01***	0.044-0.052	0.54	Small	-6.63±0.95
	F_0 (N/kg)	4.82±0.39	5.21±0.43	**0.01***	0.316-0.471	0.96	Moderate	7.53±0.53
	V_0 (m/s)	7.17±0.92	7.23±0.88	**0.04***	0.003-0.129	0.07	Trivial	0.97±0.68
	P_{max} (W/kg)	8.63±1.25	9.42±1.34	**0.01***	0.706-0.878	0.61	Moderate	8.43±0.66
	Rf_{max} (%)	32.7±1.88	34.3±1.95	**0.01***	0.726-2.455	0.82	Moderate	4.64±0.32
	D_{rf} (%)	-6.59±0.93	-7.03±0.96	**0.01***	0.179-0.7	0.46	Small	-6.3±0.94
Backs	**BM (Kg)**	61.8±3.7	62.2±3.7	**0.01***	0.345-0.512	0.11	Trivial	0.69±0.17
	5m (s)	1.51±0.02	1.45±0.02	**0.01***	0.049-0.06	3.2	Very Large	-3.76±0.25
	20m (s)	4.06±0.12	3.93±0.12	**0.01***	0.109-0.133	1.02	Moderate	-3.06±0.35
	S_{fv} (%)	-0.71±0.13	-0.76±0.15	**0.01***	0.031-0.066	0.35	Small	-6.18±2.08
	F_0 (N/kg)	5.47±0.36	5.91±0.46	**0.01***	0.351-0.549	1.08	Moderate	7.51±1.82
	V_0 (m/s)	7.83±1.05	7.94±1.06	**0.01***	0.032-0.193	0.1	Trivial	1.43±0.57
	P_{max} (W/kg)	10.64±1.08	11.66±1.08	**0.01***	0.915-1-135	0.94	Moderate	8.84±1.77
	Rf_{max} (%)	36±1.16	37.7±1.24	**0.01***	0.589-2.793	1.41	Large	4.48±0.84
	D_{rf} (%)	-6.83±1.38	-7.26±1.54	**0.01***	0.102-0.767	0.29	Small	-5.76±2.03

Tabla 6: Valores de media ± desviación típica de la comparación pre-test vs post-test de todos los grupos después de las 8 semanas de intervención.. Los datos se presentan como nivel de significación (P), intervalo de confianza al 95% (95%CI), tamaño del efecto (ES) y porcentaje de cambio (Change). Resaltado en negrita y con un * aquellos valores significativos (p≤0.05).

Correlación

En la tabla 7 se presentan las asociaciones observadas entre los valores iniciales de CMJ con S_{fv}, y la magnitud de mejora de P_{max} (Δ-P_{max}). Fueron encontradas correlaciones significativas grande y muy grande entre la Sfv y Δ-P_{max} de primeras y segundas líneas respectivamente.

Groups	Variable	r	R^2	P	Inference
CG	CMJ height & Δ-P_{max}	-0.02	0.00	0.99	
	S_{fv} & Δ-P_{max}	0.37	0.139	0.31	
FG	CMJ height & Δ-P_{max}	0.18	0.033	0.59	
	S_{fv} & Δ-P_{max}	**-0.66**	**0.439**	**0.016***	Large
BG	CMJ height & Δ-P_{max}	-0.25	0.065	0.54	
	S_{fv} & Δ-P_{max}	**-0.74**	**0.541**	**0.037***	Very Large

Tabla 7: Correlación de Pearson (r), coeficiente de determinación (R^2) y nivel de significación (P). Resaltado en negrita y con un * aquellos valores significativos ($p \leq 0.05$).

4.4 Investigación IV: Estudio descriptivo-correlacional

"Association between vertical and horizontal force-velocity-power profiles in netball players"

Objetivo e hipótesis

Los objetivos de esta investigación fueron:

1. Proporcionar valores de referencia de las variables mecánicas del perfil *F-V* durante el salto en contra movimiento (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg) y $F\text{-}V_{IMB}$ (%) y el perfil *F-V-P* horizontal en 20m sprint (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg), S_{fv} , RF_{max} (%) y D_{rf} (%) en jugadoras de netball amateur.

2. Observar la asociación entre las variables mecánicas del perfil *F-V* durante el salto en contra movimiento y el perfil *F-V-P* horizontal en 20m sprint (F_0 (N/kg), V_0 (m/s) y P_{max} (W/kg)), así como su rendimiento en ambos test.

Método
Participantes

La muestra de este estudio se compuso de un total de 28 jugadoras amateurs de netball (edad: 24.3±3.2 años, peso: 64.5±5Kg y altura: 172.5±6.2cm). Todas las participantes tenían más de 6 años de experiencia en dicha modalidad (5±2).

Medida

Las variables de estudios fueron:

Altura del salto (en cm) y variables mecánicas del perfil *F-V* durante el CMJ. Se midió utilizando una aplicación móvil válida y fiable [9] basada en video análisis (*My jump 2*), la cual utiliza el método de Samozino para la estimación de la altura del salto y las variables mecánicas del perfil *F-V* (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg) y $F\text{-}V_{IMB}$ (%)) durante un test de saltos con carga. Las cargas utilizadas para el test fueron el 0%, 10%, 20%, 30%, 40%, 50% y 70% del peso corporal de cada participante. Una vez analizadas y registradas las alturas de salto con las cargas citadas anteriormente, My Jump 2 calcula las variables mecánicas correspondientes al perfil *F-V* actual y perfil óptimo de *F-V*, pudiéndose así observar la dirección (déficit de Fuerza o de Velocidad) y la magnitud del déficit de cada participante [1,3,17,21,34].

Velocidad (segundos-s) y variables mecánicas del perfil *F-V-P* durante un sprint de 30m: se midió utilizando una aplicación móvil válida y fiable [11] basada en video análisis (*My Sprint*), la cual utiliza el método de Samozino [4] para la estimación de las variables mecánicas del perfil *F-V-P* (F_0 (N/kg), V_0 (m/s), P_{max} (W/kg), S_{fv} , RF_{max} (%) y D_{rf} (%)durante un test de velocidad 30m en el que se registraron los tiempos de 5m, 10m, 15m, 20m, 25m y 30m. En los resultados solo se incluyeron los tiempos de 5m (como indicador de la aceleración) y 20m, ya que son los tiempos que más se han usado en la literatura actual y facilitaban la comparación con otros estudios.

Diseño y Procedimiento

Este estudio descriptivo-correlacional se realizó de forma transversal. No se realizó ninguna intervención o se manipuló variable alguna, observándose lo que ocurre con dichas variables en un test específico de rendimiento. Ambas aplicaciones se utilizaron en un iPhone 7 (iPhone7: Apple, Cupertino, CA, USA) el cual tiene una cámara que graba a 240 fps.

Esta investigación fue realizada siguiendo las normas del Comité Ético de Investigación de South Essex College University Centre, Southend on the Sea, Reino Unido. Todas las jugadoras de netball participantes, entrenadores y preparadores físicos fueron informados de los riesgos y beneficios del estudio antes de su realización. La confidencialidad y el anonimato de las participantes fue acordado por el doctorando y los responsables del equipo de netball.

Análisis estadístico

El registro de los datos respecto al salto vertical y a las variables mecánicas de este se llevó a cabo con My jump 2 [9], mientras que los tiempos en 30m sprint y las variables mecánicas de este se realizó con My sprint [11]. Ambas aplicaciones permiten descargar los datos a una hoja de cálculo y, una vez en esta, el análisis descriptivo y correlación se realizó con el programa estadístico informático IBM SPSS Statistics versión 26. Las variables de estudio mostraron una distribución normal, por lo que se utilizó la correlación de Pearson y el coeficiente de determinación (R^2) con un nivel de significación de $p \leq 0.05$ para observar el nivel de asociación entre ellas. El criterio para interpretar la magnitud de las correlaciones fue : ≤ 0.1 = trivial,> 0.1 − 0.3 = pequeña,> 0.3 − 0.5 = moderada,> 0.5 − 0.7 = grande,> 0.7− 0.9 = muy grande,> 0.9 − 1.0 = casi perfecta [67].

Resultados

Estadística descriptiva y correlación entre variables.

En la tabla 8 se presenta mediante media ± desviación típica la estadística descriptiva de las variables mecánicas y rendimiento de los test de CMJ y sprint (5m y 20m).

Vertical FV profile	
CMJ (cm)	31.1±3
F_0 (N/kg)	29.71±3.4
V_0 (m/s)	3.17±0.41
P_{max} (W/kg)	23.36±2.19
F-V Deficit (%)	36.2±14.6
Horizontal FVP profile	
5 m sprint (s)	1.51±0.06
20 m sprint (s)	3.86±0.16
F_0 (N/kg)	6.51±0.6
V_0 (m/s)	7.29±0.43
P_{max} (W/kg)	11.81±1.44
Sfv	-57.82±5.9
Rf_{max} (%)	41±3
D_{RF} (%)	-0.08±0.01

Tabla 8: Valores de media ± desviación típica del rendimiento (5m y 20m) en ambos test y las variables mecánicas observadas en este estudio para el perfil vertical y horizontal.

En la tabla 9 se presentan las asociaciones observadas entre ambos test de rendimiento. Fueron encontradas correlaciones significativas moderadas para el rendimiento en salto vertical y 20m sprint (performance), además de las variables mecánicas de V_0 y P_{max}.

Variables	Vertical	Horizontal	r	R^2	p-value	Criteria
Performance	31.1±3	3.86±0.16	-0.5	0.26	**0.01***	Moderate
F_0 (N/kg)	29.71±3.4	6.51±0.6	0.27	0.08	0.15	
V_0 (m/s)	3.17±0.41	7.29±0.43	-0.4	0.17	**0.03***	Moderate
P_{max} (W/kg)	23.36±2.19	11.81±1.44	0.4	0.16	**0.04***	Moderate

Tabla 9: Valores de media ± desviación típica del rendimiento y valores de ambos perfiles, para el análisis de correlación de Pearson (r) y coeficiente de determinación (R^2). Resaltado en negrita y con un * aquellos valores significativos ($P \leq 0.05$). Para el análisis de asociación en el rendimiento se utilizó la altura del CMJ (cm) y 20m sprint (segundos).

ESTUDIO	OBJETIVO	DISEÑO	POBLACIÓN	VARIABLES	MATERIAL	CONCLUSIONES
Estudio I: ***Analysis of the Force-Velocity profile in female ballet dancers***	Analizar el perfil F-V durante el salto en contra movimiento (CMJ).	Estudio descriptivo-comparativo transversal	87 bailarinas profesionales de ballet clásico	CMJ y variables mecanicas del perfil F-V durante el salto.	Tanto las variables mecanicas del perfil F-V como la altura del CMJ se midieron utilizando My jump 2.	Todas las participantes mostraron deficit de fuerza. Esto sugiere que el entranamiento en danza desarrolla principalmente la velocidad, en terminos de perfil F-V
Estudio II: ***Individualized training based on Force-Velocity profiling during jumping in ballet dancers***	Observar el efecto de un entrenamiento individualizado basado en la reducción del $F\text{-}V_{IMB}$ (9 semanas) para la mejora del CMJ	Estudio cuasi-experimental. grupo control vs grupo experimental	46 bailarinas profesionales de ballet clásico	Salto vertical en contramovimiento y las variables mecanicas	Las variables mecanicas del perfil F-V y la altura del CMJ se midieron utilizando My jump 2.	Un entrenamiento individualizado basado en el perfil F-V es una manera efectiva de mejorar el CMJ en bailarinas de ballet
Estudio III: ***Does the initial level of horizontal force determine the magnitude of improvement in acceleration performance in Rugby?***	1. Observar el efecto de un entrenamiento con trineos de 8 semanas con la carga óptima para la producción de P_{max} 2. Observar si los valores de fuerza horizontal inicial influyen en la mejora del rendimiento en sprint.	Estudio cuasi-experimental. Un Grupo Control y dos grupos experimentales	31 jugadoras de rugby amateur	1. CMJ y variables mecanicas del perfil F-V durante el salto. 2. Variables mecanicas del perfil F-V-P y los tiempos en 5 y 20m print.	1. Variables mecanicas del perfil F-V y la altura del CMJ se midieron utilizando My jump 2 2. Variables mecanicas del perfil F-V-P y los tiempos en el print se midieron utilizando My Sprint	1. La carga óptima para Pmax, es beneficiosa para la mejora del sprint (5m y 20m), y las variables mecánicas del perfil horizontal F-V-P 2. Deportistas con mayores niveles iniciales de fuerza horizontal, desarrollaan mejores adaptaciones al entrenamiento con trineos
Estudio IV: ***Association between vertical and horizontal force-velocity-power profiles in netball players***	1. Proporcionar valores de referencia de las variables mecánicas del perfil F-V durante el salto en contra movimiento y el perfil F-V-P horizontal en 20m sprint 2. Observar la asociación entre las variables mecánicas del perfil F-V durante el salto en contra movimiento y el perfil F-V-P horizontal en 20m sprint, así como su rendimiento en ambos test.	Estudio descriptivo-correlacional	28 jugadoras amateurs de netball	1. CMJ y variables mecanicas del perfil F-V durante el salto. 2. Variables mecanicas del perfil F-V-P y los tiempos en 5 y 20m print.	1. Variables mecanicas del perfil F-V y la altura del CMJ se midieron utilizando My jump 2 2. Variables mecanicas del perfil F-V-P y los tiempos en el print se midieron utilizando My Sprint	1. Las jugadoras de netball muestran una tendencia hacia el déficit bajo de fuerza. 2. Se encontraron asociaciones significativas moderadas en el rendimiento, la V0 y la Pmax. Sin embargo, no se encontró asociación significativa entre los niveles de F0. La ausencia de correlación en la aplicación de fuerza sugiere el entrenamiento de ambas acciones balísticas, salto y sprint, de manera específica

CAPÍTULO 5.

DISCUSIÓN

Facultad de Ciencias del Deporte
Universidad de Extremadura

CAPÍTULO 5. DISCUSIÓN

El objetivo principal de esta Tesis Doctoral ha sido profundizar en el uso del perfil F-V vertical y horizontal para la monitorización e individualización del entrenamiento. A continuación, se presenta la discusión de los resultados para cada uno de los 4 estudios que componen la presente tesis.

1.1 Estudio I: *"Analysis of the Force-Velocity profile in female ballet dancers"* [5]

En primer lugar, se analizó la altura del salto vertical, además de la magnitud y dirección del perfil F-V entre diferentes posiciones de danza clásica. Los resultados obtenidos mostraron que la totalidad de las 87 bailarinas profesionales que formaron parte de la muestra, independientemente de su posición (41 "cuerpo de ballet", 30 segundos solistas y 16 solistas) presentaron déficit de fuerza (HFD y LFD). Por lo que se aceptó la hipótesis planteada: Las bailarinas de ballet mostrarían un perfil F-V orientado a la velocidad (déficit de fuerza), independientemente de su posición.

Los valores medios de cada una de las posiciones indican que las bailarinas muestran un déficit de fuerza alto, según los umbrales propuestos por investigaciones previas [2,10]. La tendencia generalizada hacia el déficit de fuerza se podría explicar debido a la gran cantidad de acciones técnicas que componen la rutina de entrenamiento en danza. Además, investigaciones previas han sugerido que el número de sesiones destinadas al entrenamiento de fuerza en esta población, son insuficientes para un desarrollo óptimo del acondicionamiento físico que optimice el rendimiento y que incluso proteja a las deportistas de potenciales lesiones [68–70].

Teniendo en cuenta el déficit mostrado por las participantes, un entrenamiento individualizado basado en el desarrollo de la F_0 sería el entrenamiento más beneficioso para reducir el $F\text{-}V_{IMB}$ y aumentar el salto vertical, como ya se había realizado con otras poblaciones [2,10]. Con relación a la comparación del CMJ, las solistas fueron las que más alto saltaron, seguidas de las segundas solistas y "cuerpos de ballet". Estos resultados coinciden con los hallazgos de Wyon y colaboradores [24].

5.2 Estudio II: *"Individualized training based on Force-Velocity profiling during jumping in ballet dancers"* [6]

Una vez que analizamos el perfil F-V durante el salto vertical en bailarinas de ballet, se observó una tendencia clara hacia el déficit de fuerza [5]. Por lo anterior, el objetivo principal del estudio 2 [6] fue observar el efecto de un entrenamiento individualizado basado en el perfil *F-V* para la mejora del CMJ en bailarinas de ballet.

Para este estudio, se dispuso de un grupo control y un grupo experimental. Ambos grupos siguieron con su rutina de entrenamiento habitual, mientras que el grupo experimental siguió un entrenamiento resistido de 2 sesiones semanales de una hora, durante 9 semanas (18 horas en total) basado en la reducción de su déficit de fuerza.

Los resultados obtenidos en este estudio mostraron un incremento significativo del grupo experimental en CMJ y F_0, mientras que se redujo el $F\text{-}V_{IMB}$ y la V_0. Sin embargo, el grupo control no mostró diferencias significativas en ninguna de las variables de estudio, excepto en la P_{max}, aunque con un tamaño del efecto trivial. Por lo tanto, se aceptó la hipótesis planteada: Un entrenamiento individualizado basado en el perfil F-V puede mejorar la altura del salto vertical en bailarinas de ballet.

Estos hallazgos coinciden con los resultados de Jiménez-Reyes y colaboradores [2,10], confirmando la efectividad de este método en una población poco explorada en función del entrenamiento resistido y con la novedad de ser el primer estudio realizado con mujeres, según la literatura científica revisada. Un entrenamiento individualizado basado en el perfil *F-V* es una manera eficiente de incrementar la altura del salto vertical en aquellas bailarinas que tienen déficit de fuerza [6]. Lo anterior puede ser muy relevante para el mundo de la danza, debido a la gran cantidad de acciones balísticas que forman parte del repertorio motor de esta población [71,72].

5.3 Estudio III: *"Does the initial level of horizontal force determine the magnitude of improvement in acceleration performance in Rugby?* [7]

El estudio III se diseñó con los objetivos de (I) observar el efecto de un entrenamiento resistido horizontal con trineos con la carga óptima para la producción de P_{max} [12,13,36] y (II) observar si los valores de fuerza horizontal inicial influyen en la mejora del rendimiento en sprint de una muestra de jugadoras de rugby amateur.

Los resultados obtenidos sugieren que el uso del entrenamiento con trineos con la carga óptima para la producción de P_{max} [12,13,36] es un método beneficioso para la mejora de 5m y 20m en sprint, además de las variables mecánicas del perfil horizontal *F-V-P*. Interesantemente, nuestros resultados también sugieren que aquellas jugadoras con un nivel de fuerza horizontal mayor, desarrollaron mayores adaptaciones al entrenamiento horizontal. Lo mencionado anteriormente nos llevó a aceptar la hipótesis de estudio: Las jugadoras con mayores niveles iniciales de *F* horizontal mostrarán mayor mejora después de un entrenamiento resistido con trineos.

Nuestros hallazgos, apoyan previas investigaciones que sugieren el uso de cargas mayores al 43% del peso corporal [12,28,73] y más concretamente de la carga óptima para la producción de P_{max} [13,36] para mejorar la aceleración, en lugar de entrenamiento horizontal no resistido.

Por otra parte, aunque estudios previos habían sugerido que los niveles de fuerza inicial podrían influenciar la magnitud de mejora en acciones balísticas [26,74–77], estos utilizaron la aplicación de fuerza vertical (SJ, CMJ, 1RM en sentadilla) como referencia. Por el contrario, nuestro estudio aporta la novedad de utilizar tanto un indicador de la aplicación de fuerza vertical como es el CMJ y el uso del perfil *F-V-P* como indicador de la aplicación de fuerza horizontal [4].

El uso del perfil *F-V-P* [4] permite cuantificar las variables mecánicas que determinan el rendimiento en sprint y por lo tanto, diseñar planes de entrenamiento más óptimos en función de las necesidades individuales de cada deportista.

5.4 Estudio IV: *"Association between vertical and horizontal force-velocity-power profiles in netball players"* [8]

El estudio IV se diseñó con los objetivos de (I) observar y proporcionar valores de referencia de las variables mecánicas del perfil *F-V* durante el salto en contra movimiento y el perfil *F-V-P* horizontal en 20m sprint (II) Observar la asociación entre las variables mecánicas del perfil *F-V* vertical y horizontal, así como su rendimiento en una muestra de jugadoras de rugby amateur.

Los hallazgos de este estudio muestran una tendencia hacia el déficit bajo de fuerza [2] por parte de las jugadoras de netball. Respecto al rendimiento en ambos test, se observó una asociación negativa moderada (r=0.5) entre el CMJ (medido en cm) y el sprint en 20m (medido en segundos), como ha sido reportado en varias ocasiones en la literatura científica [64,65,78–81]. Esta asociación en el rendimiento de ambos test puede conducirnos a hipotetizar que el entrenamiento para la mejora en uno de ellos consecuentemente nos llevará a mejorar en el otro. Sin embargo, es importante tener en cuenta que nuestras deportistas son amateur y que el nivel de asociación en un población de mayor nivel deportivo podría ser mucho menor o incluso inexistente [65].

Respecto a los niveles de asociación entre las variables mecánicas de ambos perfiles, se encontraron correlaciones significativas moderadas para la V_0 y la P_{max}. Sin embargo, no se encontró asociación significativa entre los niveles de F_0. Esta ausencia de correlación en la aplicación de fuerza apoya las recomendaciones de investigaciones previas que sugieren el entrenamiento de ambas acciones balísticas, salto y sprint, de manera específica [17,65].

Teniendo en cuenta la relevancia de acciones balísticas como el salto vertical y el sprint en netball [18–20], el uso del perfil vertical y horizontal para la monitorización y control del entrenamiento de nuestras deportistas [17] proporcionará una visión más completa e individualizada de las necesidades de cada uno de ellas. Esto, es aún más relevante cuando ambos test pueden medirse de forma válida y fiable con tecnología Smartphone [9,11], tecnología mucho más accesible económicamente que la tradicionalmente empleada para este tipo de análisis.

CAPÍTULO 6.

CONCLUSIONES Y APLICACIONES PRÁCTICAS

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CAPÍTULO 6. CONCLUSIONES Y APLICACIONES PRÁCTICAS

En el siguiente capítulo se presentan las conclusiones y aplicaciones prácticas de la presente Tesis Doctoral.

6.1 Conclusiones/conclusions

1. Bailarinas de ballet clásico profesionales tienen un déficit de fuerza en el salto vertical en CMJ.

2. Un entrenamiento basado en la reducción del déficit fuerza en bailarinas de ballet profesionales es un método útil para la mejora del salto vertical en CMJ.

3. La cuantificación del perfil F-V durante el salto vertical en bailarinas de danza es una variable útil y de fácil control para la optimización del entrenamiento de fuerza.

4. La utilización de la carga óptima para la producción de P_{max} durante el entrenamiento resistido con trineos produce mejoras en las variables mecánicas del perfil *F-V-P* y los tiempos de 5m y 20m sprint en jugadoras amateur de rugby.

5. Mayores niveles de fuerza horizontal inicial están asociados con la magnitud de mejora en el entrenamiento resistido horizontal con trineos.

6. Existe relación entre el rendimiento en CMJ y 20m sprint en jugadoras de netball amateur.

7. No existe asociación entre los niveles de fuerza durante el salto vertical y el sprint en 20m en jugadoras de netball amateur.

Conclusions

1. Professional classical ballet dancers have a strength deficit in the vertical jump in CMJ.

2. A training based on the reduction of the strength deficit in professional ballet dancers is a useful method for the improvement of vertical jump in CMJ.

3. The quantification of the *F-V* profile during the vertical jump in dancers is a useful and easily controlled variable for optimization.

4. The use of the optimal load for the production of P_{max} during the resistance training with sleds produces improvements in the mechanical variables of the profile *F-V-P* and the times of 5m and 20m sprint in amateur rugby players.

5. Higher initial horizontal force levels are associated with the magnitude of improvement in horizontal resistance sled training.

6. There is a relationship between performance in CMJ and 20m sprint in amateur netball players.

7. There is no association between the levels of force during the vertical jump and the sprint in 20m in amateur netball players.

6.2 Aplicaciones prácticas

En la presente sección se presentan las aplicaciones prácticas de la presente Tesis Doctoral.

1. La utilización del perfil *F-V* y *F-V-P* permite la monitorización y control del entrenamiento en varias disciplinas deportivas.

2. La utilización del perfil *F-V* y *F-V-P* permiten un diseño más óptimo de entrenamientos para la mejora del salto vertical y el rendimiento en sprint en función de las variables mecánicas individuales de cada deportista.

3. Las variables mecánicas del perfil *F-V* y *F-V-P* se pueden medir de forma fácil, válida y fiable con aplicaciones móviles basadas en video análisis.

Las aplicaciones prácticas de esta Tesis Doctoral nos llevan a recomendar la utilización de ambos perfiles para monitorear y controlar las variables mecánicas de acciones balísticas, como el salto vertical y el sprint, en aquellas disciplinas en las que ambas acciones estén presentes. Todo lo anterior, debido especialmente a la facilidad y accesibilidad de utilizar estos métodos de campo con tecnología económica, valida, fiable y manejable, como la tecnología Smartphone. Teniendo conocimiento de las variables mecánicas que definen el rendimiento de nuestros deportistas tanto en salto como en sprint, podríamos diseñar planes de entrenamiento que se ajusten más a las necesidades individuales de cada uno de ellos.

CAPÍTULO 7.

FORTALEZAS, LIMITACIONES Y PROSPECTIVAS

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CAPÍTULO 7. FORTALEZAS, LIMITACIONES, Y PROSPECTIVAS

En este capítulo se exponen las principales fortalezas, limitaciones y prospectivas de investigaciones derivadas de los estudios que componen la presente Tesis Doctoral.

7.1 Fortalezas

A continuación, se presentan las principales fortalezas de esta Tesis Doctoral:

1. La presente Tesis ha profundizado en el uso del perfil *F-V* vertical para monitorear y diseñar programas de entrenamiento para la mejora del salto vertical basados en la reducción del $F\text{-}V_{\text{IMB}}$. Hasta el registro de esta Tesis, tenemos constancia de solo 5 intervenciones realizadas observando el efecto de un programa de intervención basado en la reducción del déficit actual de *F-V*, siendo una de nuestras publicaciones la primera intervención con población femenina.

2. El uso de tecnología Smartphone (My Jump 2 y My sprint) para la medición del rendimiento y de las variables mecánicas durante el salto vertical y sprint, facilita la réplica de los diseños de estudio por parte de entrenadores y deportistas que deseen observar dichas variables y no tengan acceso a dispositivos de mayor coste económico o de difícil transporte, uso e instalación.

3. Los estudios que componen esta Tesis se han realizado con una muestra novedosa. Aunque en la literatura científica pueden encontrarse valores de referencia sobre las variables mecánicas del perfil F-V en diferentes deportes (rugby, fútbol, artes marciales, tenis, etc.), estaban completamente inexploradas las bailarinas y las jugadoras de netball. De forma similar, ocurre con las jugadoras de rugby, ya que solo un estudio previo se realizó con una muestra en las que se incluyeron jugadoras.

4. Nuestro estudio observando la influencia de los valores iniciales de fuerza en la mejora del sprint, es la primera investigación que observa la aplicación de fuerza de forma horizontal (perfil *F-V-P*). Así, hasta el momento los estudios realizados se habían basado en la aplicación de fuerza vertical (CMJ o SJ).

7.2 Limitaciones

A continuación, se presentan las principales limitaciones de esta Tesis Doctoral:

1. La muestra de los estudios realizados con practicantes profesionales de danza clásica no incluían bailarines masculinos. Sería interesante observar si la tendencia hacia el déficit de fuerza también está presente en bailarines masculinos de esta disciplina.

2. Aunque el entrenamiento individualizado basado en el perfil *F-V* durante el salto propició mejoras significativas en la altura del CMJ, sería interesante analizar si esta mejora tiene una transferencia positiva a acciones balísticas específicas de danza.

3. Los hallazgos de los estudios desarrollados están basados en una población muy específica. Sería interesante observar si los niveles de fuerza horizontal iniciales determinarían la magnitud de mejora en un entrenamiento con trineos de una población que tuviera un mejor acondicionamiento físico (semi profesionales, profesionales, élite).

4. De igual forma y conforme a lo citado anteriormente, sería interesante observar si la carga óptima para la producción de P_{max}, produciría las mismas adaptaciones en poblaciones con diferentes niveles de acondicionamiento físico (amateur, semi profesionales, profesionales, élite).

5. La intervención de 9 semanas realizada con las bailarinas de ballet sería potencialmente más beneficiosa si se continua con un entrenamiento individualizado hasta la consecución del perfil óptimo.

7.3 Prospectivas

A continuación, se presentan las principales prospectivas de investigación que se derivan de esta Tesis Doctoral:

1. Observar si la tendencia hacia el déficit de fuerza también está presente en bailarines masculinos de danza clásica.

2. Analizar si la influencia de la mejora del salto vertical tiene una transferencia positiva a acciones balísticas específicas de danza.

3. Observar si los valores de fuerza horizontal inicial influyen en la mejora de las variables mecánicas del perfil *F-V-P* y el rendimiento en sprint en jugadoras de rugby no amateur.

4. Realizar intervenciones basadas en la reducción del $F\text{-}V_{IMB}$ hasta que los/as participantes muestren un déficit bien balanceado.

Optimizar la planificación del entrenamiento y las propias tareas para la reducción del déficit actual de *F-V*.

CAPÍTULO 8.

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CAPÍTULO 8. REFERENCIAS BIBLIOGRÁFICAS

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CAPÍTULO 9.

ANEXOS

Facultad de Ciencias del Deporte
Universidad de Extremadura

CAPÍTULO 9. ANEXOS

CAPÍTULO 9.1 Artículos originales

A continuación, se presentan los artículos que han formado parte de la presente Tesis Doctoral por compendio de publicaciones:

Estudio I (descriptivo-comparativo):

Escobar Álvarez JA, Reyes PJ, Pérez Sousa MÁ, Conceição F, Fuentes García JP. Analysis of the Force-Velocity Profile in Female Ballet Dancers. *J Dance Med Sci*. 2020;24(2):59-65. doi:10.12678/1089-313X.24.2.59

Estudio II (cuasi-experimental):

Escobar Álvarez JA, Fuentes García JP, Da Conceição FA, Jiménez-Reyes P. Individualized Training Based on Force–Velocity Profiling During Jumping in Ballet Dancers. *Int J Sports Physiol Perform*. 2019. doi:10.1123/ijspp.2019-0492

Estudio III (cuasi-experimental):

Escobar JA, Álvarez PJR, Da Conceição FA, Fuentes García JP. Does the Initial Level of Horizontal Force Determine the Magnitude of Improvement in Acceleration Performance in Rugby? *Eur J Sport Sci*. 2020. doi:10.1080/17461391.2020.1793004

Estudio IV (descriptivo-correlacional):

Escobar-Álvarez JA, Fuentes-García JP, Viana-da-Conceição FA, Jiménez-Reyes P. Association between vertical and horizontal force-velocity-power profiles in netball players. *J Hum Sport Exerc*. 2020;17(1):1-10. doi:10.14198/jhse.2022.171.09

Estudio I.

Analysis of the Force-Velocity Profile in Female Ballet Dancers

Analysis of the Force-Velocity Profile in Female Ballet Dancers

Juan Antonio Escobar Álvarez, MSc, Pedro Jiménez Reyes, PhD, Miguel Ángel Pérez Sousa, PhD, Filipe Conceição, PhD, and Juan Pedro Fuentes García, PhD

Abstract

Jumping ability has been identified as one of the best predictors of dance performance. The latest findings in strength and conditioning research suggest that the relationship between force and velocity mechanical capabilities, known as the force-velocity profile, is a relevant parameter for the assessment of jumping ability. In addition, previous investigations have suggested the existence of an optimal force-velocity profile for each individual that maximizes jump performance. Given the abundance of ballistic actions in ballet (e.g., jumps and changes of direction), quantification of the mechanical variables of the force-velocity profile could be beneficial for dancers as a guide to specific training regimens that can result in improvement of either maximal force or velocity capabilities. The aim of this study was to compare the mechanical variables of the force-velocity profile during jumping in different company ranks of ballet dancers. Eighty-seven female professional ballet dancers (age: 18.94 ± 1.32 years; height: 164.41 ± 8.20 cm; weight: 56.3 ± 5.86 kg) showed high force deficits (> 40%) or low force deficits (10% to 40%) regardless of their company rank. Our results suggest that dance training mainly develops velocity capabilities, and due to the high number of dramatic elevations that dance performance requires, supplemental individualized force training may be beneficial for dancers. The individualization of training programs addressed to the direction of each individual's imbalance (high force or low force) could help dancers and their teachers to improve jump height and therefore dance performance.

Jumping ability has been identified as one of the best predictors of dance performance; those dancers who are able to jump the highest will be able to implement a greater range of skills to realize the aesthetic components of dance choreography.[1] Preceding studies have shown that jump height in dance can be affected by different factors, such as: muscle mass[2,3]; flexibility; isometric muscle strength; age, height, and weight[4]; level of expertise[5]; sex; or company rank.[6] Most ballet training classes involve complex, controlled, precise movements followed by ballistic actions (jumps, changes of direction, and so forth). These skills require high measures of strength and power.[7-9] Therefore, components aimed at improving jump height and power output of the lower limbs have been suggested as an important part of any training regimen.[10-12]

Recent research has found that jump performance is significantly determined by maximal power output of the lower limbs[13] and the relationship between force (F) and velocity (V) mechanical capabilities. This relationship is known as the force-velocity (F-V) profile during jumping performance.[14-16] Different combinations of F and V ($P_{max} = F_0 \cdot V_0 / 4$) can result in the same P_{max} (theoretical maximal power), although the same value of P_{max} does not necessarily result in the same jump height.[17] Interestingly, it has been suggested that there is an optimal F-V relationship for each individual that maximizes jump performance for the same value of P_{max}.[14-16] Previous studies have reported a lack of change, or even a decrease in jumping performance, after training planned specifically to improve P_{max}, due to a detrimental increase of imbalance between F and V during jumping.[18] Therefore, for the improvement of jump performance, quantification of both the actual

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and optimal F-V profile is required, which provides information about the individual needs of each athlete.[15,16,18] The actual F-V profile is determined by a validated field method, based on the linear relationship of F and V values obtained during a simple test, while the optimal F-V profile can be computed using an equation based on a biomechanical model.[15,19-22] A series of loaded vertical jumps with the loads corresponding to 0%, 10%, 20%, 30%, 40%, 50%, and 70% of the participant's body weight provides the information related to theoretical maximal force (F_0), theoretical maximal velocity (V_0), slope of the F-V relationship (F-V_{slope}), and theoretical maximal power (P_{max}).[14-16,18,21,23,24] These variables determine the mechanical limitations of the neuromuscular system involved in jumping performance to produce force, velocity, and power.[17] The difference between actual and optimal F-V profile for each individual represents the magnitude and direction of the imbalance between force and velocity qualities (F-V_{IMB}), which makes possible the individual determination of F or V deficit.

Optimal F-V profiling has been related to jump performance among world class athletes in cycling, fencing, taekwondo, athletic sprinting,[22] rugby,[25] track and field,[23] volleyball,[26] elite female soccer,[27] and such specific positions as football goalkeepers.[28] Moreover, a previous study has designed a F-V_{IMB} category according to the magnitude and direction of the imbalance. This classification also provides recommendations for the design of training aimed at reducing the F-V deficit. The results of this investigation suggest that training programs intended to reduce the actual F-V deficit are more efficient at improving jumping performance than traditional resistance training that is common to all individuals regardless of their actual and optimal F-V profile.[18]

Studies of the F-V profile in dancers are sparse. Considering the multitude of ballistic movements in dance (e.g., jumps or changes of direction),[7-9] the quantification of F-V_{IMB} could be beneficial in this population if applied to the needs of individuals and the specific training prescriptions that could result in improvement of either maximal F or V capabilities. To our knowledge, this is the first study to analyze F-V profile during jumps by professional ballet dancers according to company rank. This study may provide information about the F-V properties that could be useful for the design of individualized training programs addressing the F-V_{IMB} to improve jump performance, especially in terms of time-efficiency.[18]

The purpose of this study was to compare the magnitude and direction of mechanical variables of the F-V profile during jumping in different company ranks of female professional ballet dancers. Previous investigations have reported that female dancers have insufficient resistance strength training in their weekly routine and a high amount of training hours devoted mainly to the repetition of technical skills.[6,29,30] In addition, significant differences have been found in jump height according to company rank, although no significant differences were found in the total number and type of training hours.[6] These findings led us to hypothesize that ballet dancers would show a force-velocity profile toward velocity capabilities regardless of their company rank.

Methods and Materials

This study was approved by the ethics board at South Essex College in agreement with the Declaration of Helsinki. All participants were informed of the benefits and risks of the research and provided written consent.

Eighty-seven professional female ballet dancers (age: 18.94 ± 1.32 years; height: 164.41 ± 8.20 cm; weight: 56.3 ± 5.86 kg), representing three different dance companies, participated in this study. Each dancer had a minimum of 6 years experience (mean ± SD = 9 ± 2.6 years), and all were exclusively involved in classical ballet training and performance for the last 4 years. The number of hours per week of choreographic rehearsal and supplemental training are detailed in Table 1.

Weight (kg), height (cm), and measures for lower-limb length (cm) in fully extended position from iliac crest to toes with plantar flexed ankle, and starting height in 90° squat from iliac crest to ground vertical distance (Fig. 1), were measured prior to any physical testing on the morning of

Table 1 Mean and Standard Deviation Hours of Rehearsal and Training Type, Grouped by Company Rank

Training hours per week	Corps de Ballet (N = 41)	Second Soloists (N = 30)	Soloists (N = 16)	P-value (0.05*)
Rehearsal	17.1 ± 2	17 ± 1.8	17.3 ± 1.7	0.45
Technique	6 ± 1	6.1 ± 1.2	6.3 ± 0.9	0.86
Pilates	2 ± 0.6	2.2 ± 0.4	2.3 ± 0.2	0.12
Gyrokinesis	2.1 ± 0.6	2.2 ± 0.3	2.5 ± 0.5	0.27
Gyrotonic	1.6 ± 0.4	1.7 ± 0.2	1.5 ± 0.5	0.32
Cardiovascular	2.5 ± 0.4	2.5 ± 0.5	2.5 ± 0.5	0.88
Resistance (Weights)	1 ± 0.0	1 ± 0.0	1 ± 0.0	0.97
Total	31.2 ± 3.1	31.7 ± 2.8	32.7 ± 2	0.052

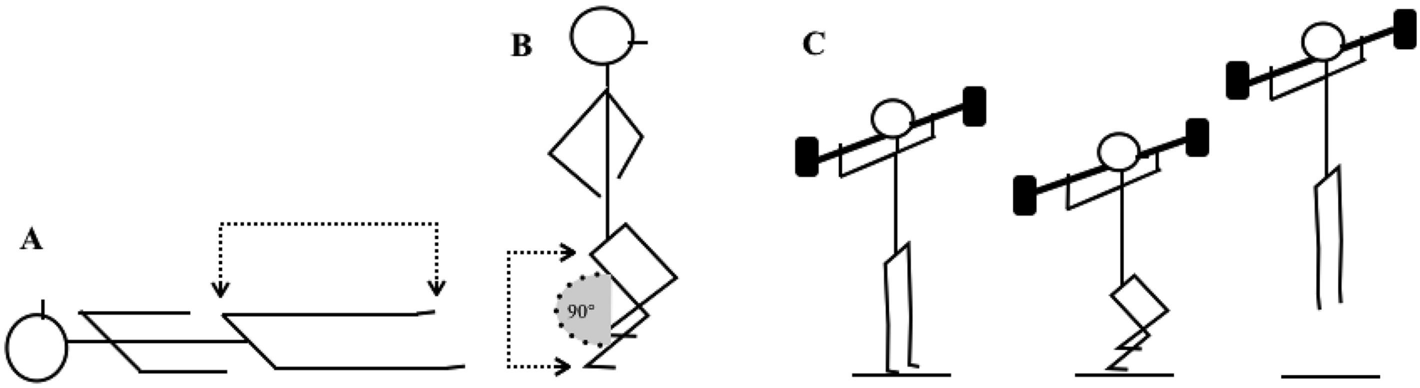

Figure 1 **A**, Measurement for lower-limb length in fully extended position from iliac crest to toes with fully plantar flexed ankle; **B**, starting height in 90° squat from iliac crest to ground vertical distance; **C**, jumping task for obtaining mechanical variables for the F-V profile.

the study. Body weight was measured using a Tanita SC-330 (Tanita Corp., Japan), height was estimated with an aluminum stadiometer (model 713, Seca, Hamburg, Germany), and the lower limb length and starting height at 90° were measured using a tape measure.[15,16] Two days prior to testing, all participants undertook a familiarization session consisting of a standardized warm up of 10 minutes of jogging, dynamic stretching, and 10 repetitions of countermovement jumps (CMJ) with variously loaded Olympic barbells on their shoulders. Participants were instructed to jump as high as possible for each CMJ, starting from a static standing position and keeping their legs straight during the flight stage of the jump. The landing was performed with full ankle dorsiflexion.[31] During the performance of each CMJ, two observers, one on each side of the participant, provided verbal feedback to establish that the starting height was at 90°. Two minutes of recovery time was provided between trials. For both the familiarization and testing session, all participants wore ballet slippers.

The required measurements for determining the optimal F-V profile during jumping performance are the athlete's body mass, jump height, and push-off distance (Hpo), as measured by the difference between the lower-limb length in fully extended position and the starting height at 90°.[14,15,20] At the beginning of the testing session, the dancers performed the standardized warm up with which they had been familiarized the day before. Then, to calculate the actual F-V profile, each dancer performed three vertical maximal CMJs with barbell loads corresponding to 0%, 10%, 20%, 30%, 40%, 50%, and 70% of their own body weight in randomized order with 2 minutes of recovery time between trials and 4 minutes between load conditions to avoid fatigue effect[15,29] (Fig. 1). The highest score of the three attempts for each load was selected for the F-V profile analysis and the 70% body weight load was included to determine if the participants were able to jump approximately 10 cm (8.48 ± 1.02 cm), as has been recommended in the literature.[16]

Jump height and the F-V profile were measured using a smartphone app (My Jump 2 available on the Apple App Store) on an iPad device that featured a camera frame rate of 240 fps.[32] My Jump 2 provided information regarding the magnitude and direction of the F-V imbalance for each dancer (F-V_{IMB}), theoretical maximal force (F_0), theoretical maximal velocity (V_0), and theoretical maximal power (P_{max}), according to Samozino's method.[14-16,23,24]

All data are presented as mean and standard deviations with IBM SPSS Statistics software version 24 (IBM, Armonk, New York, USA). Differences between the three company ranks were assessed using Kruskall Wallis test (with Mann-Whitney post hoc test) and one way ANOVA (Tukey post hoc test) according to the normal distribution of each variable presented in Tables 1 and 2, with level of significance set at $p \leq 0.05$.

Results

No significant differences between company ranks were found with regard to the number of hours per week of rehearsal and supplemental training (Table 1).

Values for all descriptive, performance, and mechanical variables are shown for all groups of the study in Table 2. Each group was subdivided according to the magnitude of F-V_{IMB} as follows: well-balanced < 10%, low force-velocity deficit 10% to 40%, and high force-velocity deficit > 40%.[18]

All 87 dancers showed a force deficit (45.60 ± 13.54%). The participants displayed a CMJ height of 28.29 ± 3.42 cm, while the values regarding the F-V profile in F_0 were 25.23 ± 1.99 N/kg, V_0 3.67 ± 0.78 m/s, P_{max} 22.97 ± 4.11 W/kg, and F-V_{IMB} 45.60 ± 13.54%.

Fifty-seven dancers presented a high force deficit (HFD = 54.08 ± 9.13%), while 33 displayed low force deficit (LFD = 31.71 ± 5.85). High and low force deficits were found for each company rank: corps de ballet (HFD N = 22; LFD N = 19), second soloists (HFD N = 20; LFD N = 10), and soloists (HFD N = 12; LFD N = 4), (Table 2).

Post hoc test showed significant differences between the three groups in CMJ. Soloists had the highest CMJ height (33.68 ± 2.08 cm), followed by the second soloists (28.41 ± 1.9 cm)

Table 2 Mean and Standard Deviation for Descriptive, Performance, and Mechanical Variables for all Participants as Grouped by Company Rank

	Ballet Dancers N = 87	Corps de Ballet N = 41	Second Soloists N = 30	Soloists N = 16	P-value (0.05*)
CMJ (cm)	28.29 ± 3.42	26.10 ± 2.09	28.41 ± 1.9	33.68 ± 2.08	0.01*
$F\text{-}V_{IMB}$ (%)	45.60 ± 13.54	42.28 ± 13.33	47.37 ± 14.08	50.78 ± 11.34	0.06
F_0 (N/kg)	25.23 ± 1.99	25.13 ± 1.72	25.03 ± 2.43	25.87 ± 1.66	0.61
V_0 (m/s)	3.67 ± 0.78	3.36 ± 0.68	3.80 ± 0.73	4.24 ± 0.79	0.01*
P_{max} (W/kg)	22.97 ± 4.11	20.93 ± 3.22	23.45 ± 2.95	27.29 ± 4.55	0.01*

The presented variables are defined as counter movement jump (CMJ), difference between the magnitude of the actual and optimal F-V profile for each individual ($F\text{-}V_{IMB}$), theoretical maximal force (F0), theoretical maximal velocity (V0), and theoretical maximal power (*P*max).[16]

and corps de ballet (26.10 ± 2.09 cm). No significant differences were found for $F\text{-}V_{IMB}$ (p = 0.06) and F_0 (p = 0.61). With regard to the V_0, significant differences were found between corps de ballet (3.36 ± 0.68 m/s) versus second soloists (3.80 ± 0.73 m/s) and between corps de ballet (3.36 ± 0.68 m/s) versus soloists (4.24 ± 0.79 m/s). Furthermore, significant differences were found for P_{max} between the three company ranks: corps de ballet versus second soloists (20.93 ± 3.22 W/kg versus 23.45 ± 2.95 W/kg), corps de ballet versus soloists (20.93 ± 3.22 W/kg versus 27.29 ± 4.55 W/kg), and second soloists versus soloists (23.45 ± 2.95 W/kg versus 27.29 ± 4.55 W/kg), (Table 3).

Discussion

The aim of this study was to compare the magnitude and direction of mechanical variables of the F-V profile during jumping of female ballet dancers in different company ranks. Such information could potentially be used to prescribe individualized training programs based on the indications of the F-V deficit.[18] As was hypothesized, the results of this investigation suggest that professional female ballet dancers, regardless of their company rank, are velocity orientated in terms of F-V profiling during jumping performance. Although all of our dancers showed the same direction in their $F\text{-}V_{IMB}$, variations in magnitude within groups are reported and dancers with HFD and LFD can be found in corps de ballet (HFD N = 22; LFD N = 19), second soloists (HFD N = 20; LFD N = 10), and soloists (HFD N = 12; LFD N = 4). Based on the results of this study, F-V imbalance is an important parameter to consider in assessing the jumping ability of ballet dancers, although previous research has pointed only toward sex, rank, and anthropometric factors in this context.[6] These results are in accordance with the movements that dance performance requires, involving both athletic and aesthetic elements.

Regarding jump height, our results show variances within the different company ranks. Wyon et al.[6] found that soloists and first artists demonstrated greater jump height compared to principals and artists, although no significant differences were found by rank in the total number and type of supplemental training hours. Previous studies have suggested that female dancers do not incorporate a sufficient number of sessions designed to develop strength into their weekly routine.[6,29,30] It is relevant to note that these studies did not take into account the influence of the F-V profile on jumping ability. Moreover, and in relation to the findings of Harley et al.[4] suggesting that, although female dancers have greater quadriceps muscle strength than physically active controls, they do not jump significantly higher, our results indicate that this may be explained by the magnitude of the $F\text{-}V_{IMB}$.

An earlier study has reported that training plans intended to improve P_{max} while increasing $F\text{-}V_{IMB}$ could result in a lack of change or even a decrease in jumping performance.[18] As has been highlighted in a previous investigation, the same P_{max} can be achieved from different combinations of F_0 and V_0 ($P_{max} = F_0 \cdot V_0 / 4$).[17] The fact that all of our participants showed F deficits regardless of their company rank may lead to the conclusion that dance training predominantly develops velocity capabilities and training plans should be designed around the magnitude and direction of $F\text{-}V_{IMB}$. According to the literature surrounding dance training, dancers must include different elements of fitness in their training routine, especially sessions focused on power output.[10] Considering the F deficit of our participants and the ballistic actions that dance performance requires, supplementary strength training based not only on increasing P_{max} of the lower limbs but also reducing the actual deficit could potentially result in an increase of jump height.[18] Based on the results of this study, dancers should increase the generation of P_{max} during jumping while decreasing $F\text{-}V_{IMB}$; therefore, their main priority should be the enhancement of force capabilities (F_0). For this purpose, strength training to include one repetition maximum with loads corresponding to 70% to 90% of body weight could be beneficial according to previous studies based on this methodology.[14,18] Dancers with HFD would focus more on the development of strength (e.g., back squat, leg press, and deadlift) and strength-power (e.g., clean pull, deadlift, and loaded squat jumps), while dancers with LFD would need a more balanced training plan between strength, strength-power, and power (e.g., loaded single leg CMJs and clean pull jumps) single training loads.[18]

Table 3 Mean and Standard Deviation for Descriptive, Performance, and Mechanical Variables for all Participants Grouped by Company Ranked and Sub-Grouped by Their F-V_{IMB}

	Total Number of Participants		Corps de Ballet		Second Soloist		Soloist	
	High Deficit N = 54	Low Deficit N = 33	High Deficit N = 22	Low Deficit N = 19	High Deficit N = 20	Low Deficit N = 10	High Deficit N = 12	Low Deficit N = 4
Age (Years)	18.78 ± 1.28	19.21 ± 1.34	18.55 ± 1.22	19.37 ± 1.42	19 ± 1.37	19.30 ± 1.33	18.83 ± 1.26	18.25 ± 0.5
Weight (kg)	55.05 ± 6	58.34 ± 5.05	51.72 ± 3.26	56.58 ± 4.59	54.84 ± 5.06	60.57 ± 3.67	61.533 ± 6.41	61.12 ± 7.7
Fat Percentage (%)	16.16 ± 1.86	16.55 ± 1.78	16.71 ± 1.43	17.26 ± 1.37	16.39 ± 1.91	16.28 ± 1.25	14.78 ± 1.93	13.9 ± 2.27
Height (cm)	164.05 ± 9.30	165 ± 6.06	158.13 ± 4.29	162.73 ± 5.56	163.5 ± 5.79	166.2 ± 4.34	175.83 ± 10.09	172.75 ± 5.73
CMJ (cm)	28.91 ± 3.62	27.29 ± 2.83	26.39 ± 1.89	25.78 ± 2.32	28.5 ± 2.17	28.24 ± 1.31	34.22 ± 2.14	32.06 ± 0.35
Force (N/kg)	24.39 ± 1.94	26.61 ± 1.12	24.21 ± 1.92	26.19 ± 0.32	23.96 ± 2.08	27.18 ± 1.48	25.44 ± 1.41	27.16 ± 1.91
Velocity (m/s)	4.11 ± 0.67	2.96 ± 0.28	3.83 ± 0.59	2.82 ± 0.22	4.16 ± 0.63	3.08 ± 0.22	4.53 ± 0.7	3.37 ± 0.05
P_{max} (W/kg)	24.93 ± 3.75	19.76 ± 2.24	23.04 ± 2.74	18.49 ± 1.63	24.72 ± 2.68	20.89 ± 1.41	28.75 ± 4.23	22.91 ± 1.95
F-V_{IMB} (%)	54.08 ± 9.13	31.71 ± 5.85	52.58 ± 8.72	30.35 ± 5.13	55.04 ± 9.66	32.04 ± 7.08	55.25 ± 9.37	37.38 ± 1.32

By way of comparison, a previous study with seven professional male rugby league players showed a F-V profile toward force capabilities. This can be explained by the force and resistance training programs that rugby players usually include in their training routine.[18] On the other hand, and in line with our results, a study conducted with 54 trained male athletes (sprinters and jumpers) showed a high homogeneity in the F-V_{IMB} toward velocity qualities (43.7 ± 16.11% vs. 45.60 ± 13.54%) due to the ballistic performance (horizontal jumps or sprints) of their sport activities and consequently the design of their training programs.[19]

In general, athletes tend to present with higher F_0 (38 ± 4.92 N/kg), V_0 (4.58 ± 0.81 m/s), P_{max} (42.9 ± 5.64 W/kg), and CMJ height values (51 ± 5 cm) than ballet dancers (F_0 = 25.23 ± 1.99 N/kg; V_0 = 3.67 ± 0.78 m/s; P_{max} = 22.97 ± 4.11 W/kg; and CMJ = 28.29 ± 3.42 cm).[19] Thus, a cohort study of 95 male and female elite athletes found that female cyclists (F_0 = 36 ± 4.4 N/kg; V_0 = 2.38 ± 0.34 m/s; P_{max} = 21.2 ± 2.7 W/kg; F-V_{IMB} = 7%), athletic sprinters (F_0 = 36 ± 4.1 N/kg; V_0 = 2.70 ± 0.22 m/s; P_{max} = 24.3 ± 4 W/kg; F-V_{IMB} = 2%), fencers (F_0 = 27.4 ± 3.2 N/kg; V_0 = 3.03 ± 0.34 m/s; P_{max} = 20.8 ± 3.1 W/kg; F-V_{IMB} = 25%), and taekwondo practitioners (F_0 = 31.8 ± 3.5 N/kg; V = 2.87 ± 0.25 m/s; P_{max} = 18.2 ± 2.5 W/kg; F-V_{IMB} = 12%) showed higher force and lower velocity and F-V_{IMB} values than ballet dancers (F_0 = 31.8 ± 3.5 N/kg; V_0 = 2.87 ± 0.78 m/s; P_{max} = 22.97 ± 4.11 W/kg; F-V_{IMB} = 45.60 ± 13.54%), while dancers displayed greater P_{max}, except for athletic sprinters.[22]

Previous investigations have also reported F-V_{IMB} toward velocity qualities in elite female soccer players (F-$V_{IMB.}$ = 64.5 ± 16.3 %; F_0 = 33.52 ± 3.61 N/kg; V_0 = 3.35 ± 0.59 m/s; and P_{max} =27.77 ± 3.79 W/kg),[27] football goalkeepers from fourth French division (F-V_{IMB} = 29.4 ± 17.8 %; F_0 = 34.3 ± 5.9 N/kg; V_0 = 3.2 ± 0.6 m/s),[28] and the majority of 73 young male and female elite and professional volleyball players (F-V_{IMB} from 37% to 34%).[26] The amount of ballistic actions (change of direction, sprinting, or jumping quickly) that goalkeepers and volleyball players require may explain the predominance of velocity qualities.

There are several limitations to this study. Although the study provides information regarding the F-V profile of a significant number of ballet dancers (N = 87), it is important to note that all the participants were female and that the group size corresponding to the three company ranks considered (corps de ballet = 41, second soloists = 30, and soloists = 16) are not equal. It would have been interesting to have included male dancers as well as participants of different company ranks not incorporated in this investigation due to professional commitments, such as principals. The different choreographic demands and corresponding training programs of the additional ranks could have further elucidated the values in the mechanical properties that determine the F-V profile and jump height of ballet dancers.[1,6]

Conclusion

This study indicates that professional ballet dancers at all company ranks are velocity oriented and suggests that a high or low force deficit may negatively affect their jumping ability and therefore the quality of their performance.[4,18] For correction of these deficits, we suggest the prescription of training plans that address the F-V imbalance of the individual dancer. Future studies should look into the effectiveness of individualized training programs based on F-V profiling during jump performance in ballet dancers.

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Estudio II.

Individualized Training Based on Force–Velocity Profiling During Jumping in Ballet Dancers

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Human Kinetics
ORIGINAL INVESTIGATION

Individualized Training Based on Force–Velocity Profiling During Jumping in Ballet Dancers

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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, theoretical maximal velocity, theoretical maximal power, and the imbalance between force and velocity ($F\text{-}V_{IMB}$). The purpose of this study was to observe the effects of 9 wk of individualized F-V profile-based training during countermovement jumps (CMJs) in female ballet dancers. ***Methods:*** CMJ and mechanical outputs of 46 dancers (age = 18.9 [1.1] y, body mass = 54.8 [6.1] kg, height = 163.7 [8.4] cm) were estimated in a pre–post intervention. The control group (10 participants) continued with the standardized training regimen (no resistance training), whereas the experimental group (36 participants) performed 2 sessions over 9 wk of a training plan based on their F-V profile. ***Results:*** The experimental group presented significant differences with large effect sizes in CMJ height (29.3 [3.2] cm vs 33.5 [3.72] cm), theoretical maximal force (24.1 [2.2] N/kg vs 29.9 [2.8] N/kg), and theoretical maximal velocity (4 [0.6] m/s vs 3.2 [0.5] m/s). Significant differences with a very large effect size were found in $F\text{-}V_{IMB}$ (43.8% [15.3%] vs 24.9% [8.7%]). ***Conclusion:*** A training program addressing $F\text{-}V_{IMB}$ is an effective way to improve CMJ height in female ballet dancers.

Keywords: dance, performance, ballistic action, vertical jump, power output

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 (eg, 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. Nevertheless, previous studies suggest that a well-designed strength-training program is beneficial in terms of increasing muscule 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 (ie, 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 and velocity mechanical capabilities during jumping performance, known as the force–velocity profile (F-V profile).[14–18] Although the same power output (theoretical maximal power, P_{max}) can be produced with different combinations of force and velocity ($P_{max} = F_0 \cdot V_0/4$),[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 force and velocity ($F\text{-}V_{IMB}$), 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, and 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]

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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 in improving 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 6 years' experience (training volume of 9 [2] h/wk) participated in this study (age = 18.9 [1.1] y, body mass = 54.8 [6.1] kg, height = 163.7 [8.4] cm). All subjects were informed of the benefits and risks of the research through a structured consent form and the Physical Activity Readiness Questionnaire. 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 group (CG) and an experimental group (EG), was designed to observe the effects of 9 weeks of individualized training, based on the reduction of the current $F\text{-}V_{IMB}$ in the CMJ and the main variables of the F-V profile, on female ballet dancers in a pretest versus posttest comparison. The dependent variables of the study are CMJ height, and difference between the magnitude of the actual and optimal F-V profile for each individual ($F\text{-}V_{IMB}$), F_0, V_0, and P_{max}.[16]

Methodology

All subjects were asked to meet in the morning to complete the anthropometric measurements. Body weight (in kilograms) was measured using a Tanita SC-330 (TANITA Corp, Tokyo, Japan), and height (in centimeters) was estimated with an aluminum stadiometer (Seca 713 model; Seca, Postfach, Germany). Measurements for lower-limb length (in centimeters) were taken in 2 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 of jogging, dynamic stretching (plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris), and preparatory CMJs. There were 2 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 of 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 10 cm, as recommended in the 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), featuring a camera frame rate of 240 fps.[28] This app showed good validity for the CMJ height in comparison to force platform ($r = .995$, $P < .001$). The app provides information regarding the magnitude and direction of the imbalance for each dancer ($F\text{-}V_{IMB}$), the F_0, the V_0, and the 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% to 40%; and high force–velocity deficit, >40%, as suggested in a previous study.[17,18] A 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 regimen (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, dead lifts, squat jumps, back squats, CMJs, and single-leg CMJs, while the HFD subgroup performed leg presses, squat jumps, single-leg CMJs, back squats, CMJs, and single-leg squat jumps. Details for the percentages of 1-repetition maximum and body mass, in addition to sets and repetitions corresponding to each exercise, are detailed in Table 1.[17] The EG performed 2 sessions per week (1 h/session) for 9 weeks, on Tuesdays and Fridays, with 3 minutes of recovery between trials, and 5 minutes between exercises. During the third and sixth 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 9 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 (SDs) with SPSS software (version 25.0; IBM SPSS, Chicago, IL). Normal distribution for the study variables was assessed with the Shapiro–Wilk test. Intergroup and intragroup comparisons for each variable were performed using a 2-way (group × time) analysis of variance with Bonferroni

Table 1 Exercises, Sets/Repetitions, and Training Loads for LFD and HFD Groups

	First session			Second session		
Group	**Exercise**	**Sets/repetitions**	**Training load**	**Exercise**	**Sets/repetitions**	**Training load**
HFD	Leg press	3 × 6	90% 1RM	Back squat	3 × 6	3 × 6 repetitions (80% 1RM)
	Dead lift	3 × 6	90% 1RM	CMJ	3 × 6	3 × 6 repetitions (85% BM)
	SJ	3 × 6	80% BM	Single-leg CMJ	3 × 6	3 × 6 repetitions (10% BM)
LFD	Leg press	3 × 6	90% 1RM	Back squat	3 × 6	3 × 6 repetitions (80% 1RM)
	SJ	3 × 6	80% 1RM	CMJ	3 × 6	3 × 6 repetitions (85% BM)
	Single-leg CMJ	3 × 6	10% BM	Single-leg SJ	3 × 6	3 × 6 repetitions (BM)

Abbreviations: BM, body mass; CMJ, countermovement jump; HFD, high force deficit; LFD, low force deficit; 1RM, 1-repetition maximum; SJ, squat jump.

Table 2 Mean (SD) Values for Jump Performance and Mechanical Variables Over the 9 Weeks of Intervention in Control and Experimental Groups

Group	Variable[16]	Pretest	3 wk	6 wk	Posttest
Control	n	10	10	10	10
	CMJ height, cm	27.3 (2)	27.5 (1.9)	27.5 (2)	27.5 (2)
	F-V_{IMB}, %	45.1 (14.6)	45.4 (14.9)	45.3 (14.7)	45.3 (14.7)
	F_0, N/kg	22.9 (2.4)	23 (2.4)	23 (2.4)	23 (2.4)
	V_0, m/s	4.1 (0.6)	4.2 (0.7)	4.2 (0.7)	4.2 (0.7)
	P_{max}, W/kg	23.3 (1.7)	23.4 (1.7)	23.5 (1.7)	23.4 (1.7)
Low force deficit	n	16	22	24	36
	CMJ height, cm	31.2 (3.5)	31.3 (3.6)	32.8 (3.8)	33.5 (3.7)
	F-V_{IMB}, %	29.5 (5.8)	29.9 (7)	25.4 (6.4)	24.9 (8.7)
	F_0, N/kg	24.3 (2)	26.2 (2)	28.4 (2.4)	29.9 (2.8)
	V_0, m/s	4 (0.6)	3.6 (0.6)	3.3 (0.5)	3.2 (0.5)
	P_{max}, W/kg	24 (4)	23.4 (3.6)	23.3 (3.5)	23.8 (3)
High force deficit	n	20	14	12	0
	CMJ height, cm	27.8 (2.1)	28.6 (2.3)	30 (1.9)	
	F-V_{IMB}, %	55.1 (9.9)	54.7 (5.8)	45.9 (3.6)	
	F_0, N/kg	23.9 (2.4)	24.1 (2.2)	26.2 (2.8)	
	V_0, m/s	4 (0.6)	4.1 (0.5)	3.8 (0.4)	
	P_{max}, W/kg	23.6 (1.9)	24.4 (1.7)	24.7 (1.4)	

Abbreviations: CMJ, countermovement jump; F_0, theoretical maximal force; F-V, force–velocity; F-V_{IMB}, difference between the magnitude of the actual and optimal F-V profile for each individual; P_{max}, theoretical maximal power; V_0, theoretical maximal velocity.

adjustment and level of significance set at $P \leq .05$. The reliability for the CMJ pretest and posttest was analyzed using an intraclass correlation coefficient (95% confidence interval).

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 to 0.6 = small, 0.6 to 1.2 = moderate, 1.2 to 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 20 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 retests 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 and 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 analyses for the pre-CMJ height and post-CMJ height were .996 (.987–.999) and .995 (.992–.998), respectively.

The precomparison and postcomparison in the CG (expressed as a grand mean) did not show significant differences for CMJ height (27.43 [1.9] cm), F-V_{IMB} (45.2% [14.7%]), F_0 (22.9 [2.4] N/kg), or V_0 (4.1 [0.7] m/s). Significant differences with trivial ES were found for P_{max} (23.3 [1.7] W/kg vs 23.4 [1.7] W/kg; $P = .02$; ES = 0.05). After 9 weeks of intervention, the EG showed significant differences, with a large ES in CMJ height (29.3 [3.2] cm vs 33.5 [3.72] cm; $P = .01$; ES = 1.21), F_0 (24.1 [2.2] N/kg vs 29.9 [2.8] N/kg; $P = .01$; ES = 1.51), and V_0 (4 [0.6] m/s vs 3.2 [0.5] m/s; $P = .01$; ES = 1.45), while significant differences with a very large ES were found in F-V_{IMB} (43.8% [15.3%] vs 24.9% [8.7%]; $P = .01$; ES = 2.3), and no significant differences were found for P_{max} (23.8 [3] W/kg vs 23.8 [3] W/kg; $P = .93$; ES = 0) (see Table 3).

The intergroup comparison showed no significant differences for the variables observed in the pretest, although for the posttest, significant differences with large ESs were found in CMJ height (27.5 [2] cm vs 33.5 [3.7] cm; $P = .01$; ES = 1.7), $F\text{-}V_{IMB}$ (45.3% [14.7%] vs 24.9% [8.7%]; $P = .01$; ES = 1.9), and V_0 (4.2 [0.7] m/s vs 3.2 [0.5] m/s; $P = .01$; ES = 1.8). Significant differences with a very large ES were found in F_0 (23 [2.4] N/kg vs 29.9 [2.8] N/kg; $P = .01$; ES = 2.5). No significant differences were found for P_{max} (23.4 [1.7] W/kg vs 23.8 [3] W/kg; $P = .74$; 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,[17,18] suggesting that training programs, based on the reduction of the current F-V imbalance, is an effective way of improving jump performance.

As observed in the results of this study, the baseline measurements obtained in the pretest (46 out of 46 dancers showed force 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 $F\text{-}V_{IMB}$.[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, $F\text{-}V_{IMB,}$ F_0, and $V_{0,}$ although all of them increased slightly (see Table 3).

The CG increasingly displayed significant differences with a trivial ES in P_{max} (23.3 [1.7] W/kg vs 23.4 [1.7] W/kg; $P = .02$; 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 $F\text{-}V_{IMB}$, 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 EG after the 9-week intervention is equal to the pretest value, although the CMJ height was significantly higher with a larger ES at postintervention (29.3 [3.2] cm vs 33.5 [3.72] cm; $P = .01$; ES = 1.21), which provides an indication of the effectiveness of the proposed intervention in reducing $F\text{-}V_{IMB}$ 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 9-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

Table 3 Mean (SD), 95% CI, and ES for the Intragroup Comparison

	Control group					Experimental group				
Variable	**Pretest**	**Posttest**	***P***	**95% CI**	**ES**	**Pretest**	**Posttest**	***P***	**95% CI**	**ES**
CMJ height, cm	27.3 (2)	27.5 (2)	.9	0.60–0.35	0.1 (T)	29.3 (3.2)	33.5 (3.7)	.01*	4.46–3.95	1.21 (L)
$F\text{-}V_{IMB}$, %	45.1 (14.6)	45.3 (14.7)	.9	5.37–5.03	0.01 (T)	43.8 (15.3)	24.9 (8.7)	.01*	16.08–21.57	1.51 (L)
F_0, N/kg	22.9 (2.4)	23 (2.4)	.9	0.55–0.35	0.04 (T)	24.1 (2.2)	29.9 (2.8)	.01*	6.04–5.56	2.3 (VL)
V_0, m/s	4.1 (0.6)	4.2 (0.7)	.9	0.13–0.05	0.15 (T)	4 (0.6)	3.2 (0.5)	.01*	0.73–0.83	1.45 (L)
P_{max}, W/kg	23.3 (1.7)	23.4 (1.7)	.02*	0.18–0.01	0.05 (T)	23.8 (3)	23.8 (3)	.93	0.02–0.06	0 (T)

Abbreviations: CI, confidence interval; CMJ, countermovement jump; ES, effect size; F_0, theoretical maximal force; F-V, force–velocity; $F\text{-}V_{IMB}$, difference between the magnitude of the actual and optimal F-V profile for each individual; L, large; P_{max}, theoretical maximal power; T, trivial; V_0, theoretical maximal velocity; VL, very large.
*Statistically significant differences ($P \leq .05$).

Table 4 Mean (SD), 95% CI, and ES for the Intergroup Comparison

Variable	Control group	Experimental group	*P*	95% CI	ES
Pre-CMJ height, cm	27.3 (2)	29.3 (3.2)	.08	4.11–0.27	0.6 (M)
Pre-$F\text{-}V_{IMB}$, %	45.1 (14.6)	43.8 (15.3)	.8	9.55–12.33	0.08 (T)
Pre-F_0, N/kg	22.9 (2.4)	24.1 (2.2)	.16	2.76–0.46	0.5 (S)
Pre-V_0, m/s	4.1 (0.6)	4 (0.6)	.5	0.28–0.6	0.1 (T)
Pre-P_{max}, W/kg	23.3 (1.7)	23.8 (3)	.7	2.47–1.57	0.1 (T)
Post-CMJ height, cm	27.5 (2)	33.5 (3.7)	.01*	8.49–3.53	1.7 (L)
Post-$F\text{-}V_{IMB}$, %	45.3 (14.7)	24.9 (8.7)	.01*	13–27.77	1.9 (L)
Post-F_0, N/kg	23 (2.4)	29.9 (2.8)	.01*	8.78–4.92	2.5 (VL)
Post-V_0, m/s	4.2 (0.7)	3.2 (0.5)	.01*	0.59–1.36	1.8 (L)
Post-P_{max}, W/kg	23.4 (1.7)	23.8 (3)	.74	2.36–1.69	0.1 (T)

Abbreviations: CI, confidence interval; CMJ, countermovement jump; ES, effect size; F_0, theoretical maximal force; F-V, force–velocity; $F\text{-}V_{IMB}$, difference between the magnitude of the actual and optimal F-V profile for each individual; L, large; M, medium; P_{max}, theoretical maximal power; S, small; T, trivial; V_0, theoretical maximal velocity; VL, very large.
*Statistically significant differences ($P \leq .05$).

soloists). All participants in the EG (36 of 36) were sensitive to the proposed training programs (see Figure 1). 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 pretest, 10 and 16 subjects were allocated to the 2 experimental subgroups, LFD and HFD, respectively. At the end of the 9-week intervention, all the subjects in the HFD subgroup had reduced their imbalance to the threshold corresponding to LFD ($F\text{-}V_{IMB} = 10\%–40\%$), and in the same way, subjects assigned to the LFD subgroup had decreased their deficit close to the limit of well balanced ($F\text{-}V_{IMB} < 10\%$).[17,18]

The pretest 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 posttest presented a significant increase in CMJ height (27.5 [2] cm vs 33.5 [3.7] cm; $P = .01$; ES = 1.7), with a large ES, and a significant decrease in $F\text{-}V_{IMB}$ (45.3% [14.7%] vs 24.9% [8.7%]; $P = .01$; ES = 1.9) and V_0 (4.2 [0.7] m/s vs 3.2 [0.5] m/s; $P = .01$; ES = 1.8). Moreover, a significant increase was found in F_0 (23 [2.4] N/kg vs 29.9 [2.8] N/kg; $P = .01$; ES = 2.5) with a very large ES. 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 $F\text{-}V_{IMB}$ 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 et al.[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 $F\text{-}V_{IMB}$ that was reported by Jimenez-Reyes, who included athletes in subgroups according to either force and velocity deficit, as well as subjects with a well-balanced profile (something really uncommon), while the totality of our dancers showed force deficit. The intervention lasted for 9 weeks in both studies, and the design of the training sessions for our study was based on the same program proposed by Jimenez-Reyes et al to reduce $F\text{-}V_{IMB}$.

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 force deficit over 9 weeks' training has been significant in the EG, our study has only observed the effect of resistance training designed to improve force capabilities, due to the absence of dancers with velocity 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 (ie, "Sauté in first position," "Entrechats quatres," "tours en l'air," etc). Therefore, future studies could assess if the results of this 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

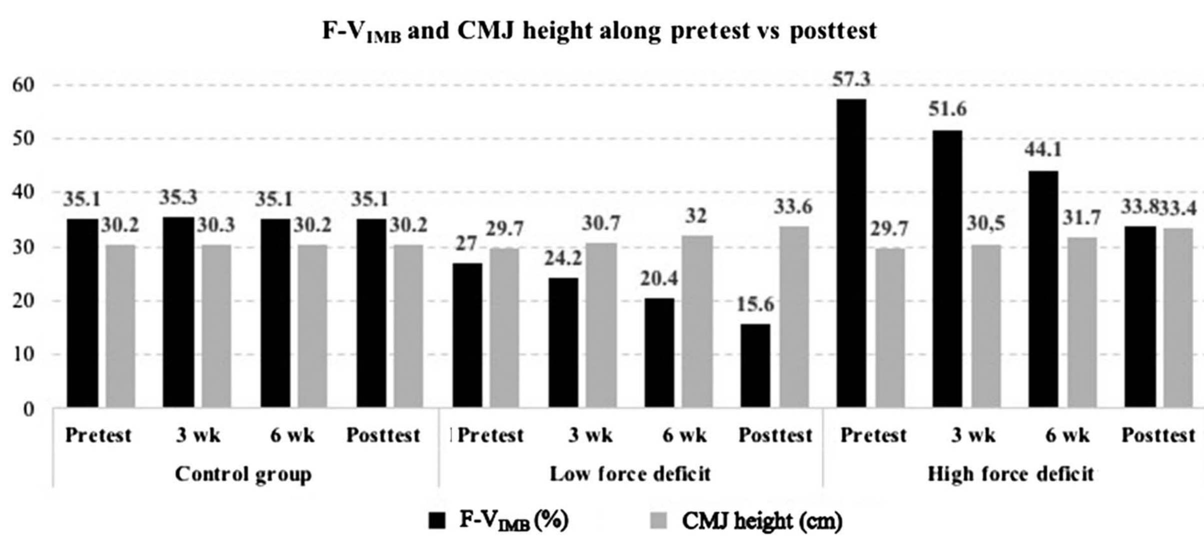

Figure 1 — Values of $F\text{-}V_{IMB}$ and CMJ height of 3 different ballet dancers (control group, low force deficit, and high force deficit) along the intervention program. CMJ indicates countermovement jump; $F\text{-}V_{IMB}$, imbalance between force and velocity.

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 CMJ 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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Estudio III.

Does the Initial Level of Horizontal Force Determine the Magnitude of Improvement in Acceleration Performance in Rugby?

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Does the initial level of horizontal force determine the magnitude of improvement in acceleration performance in rugby?

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ORIGINAL ARTICLE

Does the initial level of horizontal force determine the magnitude of improvement in acceleration performance in rugby?

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Abstract
This study aimed to observe the effect of 8 weeks of resisted sled training (RST), with optimal loading for maximal power output production and initial levels of force, on the magnitude of improvement in sprint performance and individual sprint mechanical outputs in female amateur rugby union players. The study examined the horizontal Power-Force-Velocity profile (P-F-V profile), which provides a measure of the athlete's individual balance between force and velocity capabilities (S_{fv}), theoretical maximum force (F_0), theoretical maximum velocity (V_0), maximum power (P_{max}), the maximum ratio of force (Rf_{max}) and rate of decrease in ratio of force (D_{rf}). Thirty-one participants (age = 23.7 ± 3.3years, BM = 69 ± 9Kg, height = 167.5 ± 5.2 cm) were divided into a control group and two experimental groups; forwards (FG) and backs (BG). For 8 consecutive weeks (16 sessions), all groups performed the same training programme: 2 sets of 5 × 30 m, but athletes assigned to FG and BG ran towing a resisted sled attached to their waists, with optimal loading for maximal power output production. Both FG and BG significantly improved ($p \leq 0.05$) in 5 and 20 m sprint performance, and in the mechanical properties related to the horizontal P-F-V profile. The correlation between the initial level of horizontal strength and the magnitude of improvement in P_{max} also suggests that higher levels of horizontal force may lead to greater adaptations in RST. The P-F-V profile is a useful field method for identifying the weakest mechanical variable in rugby players during sprinting and enabling the prescription of individualized raining programmes according to specific running performance.

Keywords: *Performance, acceleration, training, biomechanics*

Highlights

- The optimal loading for maximal power output production, for RST, is an effective way to improve sprint performance in 5 m and 20 m, besides the underline mechanical variables associated to sprint performance in amateur female rugby players.
- Players with higher levels of horizontal force (sprint performance) may develop greater adaptations in RST than players with high levels of vertical force application (CMJ).
- The RST may develop specific adaptations to the contextual requirements of rugby, due to the transference of similar patterns of movement during acceleration skills and consequently, the enhancement of mechanical properties.
- The horizontal Power-Force-Velocity profile is a useful and approachable field method to monitor changes in mechanical variables during the sprinting performance and to assess the effectiveness of prescribed training.

Introduction

In contact sports like rugby union, it is necessary to develop high levels of physical fitness, and the ability to accelerate is key to successful performance (Hene, Bassett, & Andrews, 2011). Players frequently need to perform multidirectional, intermittent bouts of maximal acceleration and velocity over short distances (i.e.<30 m), in reaction to opponents' movements during competition (Gabbett, 2012). Training methods such as

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plyometric training, resistance training, assisted sprint training and resisted sled training (RST) (Rumpf, Lockie, Cronin, & Jalilvand, 2016) have been used to enhance this ability.

RST has been identified as one of the most common and effective training methods for enhancing acceleration skills in a variety of sports (Alcaraz, Carlos-Vivas, Oponjuru, & Martínez-Rodríguez, 2018; Petrakos, Morin, & Egan, 2016). This methodology is based on a strong transference between resistance training and sports performance, emphasizing similar motor patterns, contraction type and therefore, mechanical properties (Buchheit et al., 2014; Kawamori, Newton, Hori, & Nosaka, 2014). One study reported that the optimal loading conditions for maximal horizontal power are between 69–91% of body mass (BM) for recreational athletes (including rugby players $n = 5$) and 70–96% of BM for highly trained sprinters (Cross, Brughelli, Samozino, Brown, & Morin, 2017a). However, to the best of our knowledge, only two studies have observed the effect of RST with optimal loading conditions for maximal power (Cross et al., 2018; Morin, Capelo-Ramirez, Rodriguez-Pérez, Cross, & Jimenez-Reyes, 2020). Cross et al. (2018) reported significant improvements in 5 and 20 m sprint performance and mechanical properties in rugby and soccer players. A recent study has also reported a clear increase in some mechanical variables of sprinting performance (30 m) in sprinters, suggesting that athletes reach their kinetic peak adaptation within a "window" of approximately 2–4 weeks post-training (Morin et al., 2020).

Previous investigations have suggested that the magnitude of improvement in ballistic actions is influenced by the initial level of strength (Cormie, McGuigan, & Newton, 2011; James et al., 2018). Cross-sectional studies have found that stronger individuals display higher maximal impulse capabilities, although the literature on the difference in adaptations between weaker and stronger individuals is limited (Cormie, Mcbride, & Mccaulley, 2009; Stone et al., 2003). The majority of the investigations in this field have observed the association between the initial levels of strength in different tests and exercises, based on the vertical application of force and maximal power output (P_{max}) of the lower limbs (including squat jump, countermovement jump, 1RM half squat and 1RM back squat) and how they affect performance tests based on the vertical and horizontal application of force and P_{max} (change of direction, horizontal squat jump or sprint ability) (Suchomel, Nimphius, & Stone, 2016). However, to the best of our knowledge, there have so far been no studies on the influence of initial levels of horizontal force on the magnitude of improvement in performance tests based on the vertical (counter movement jump-CMJ) and horizontal application of force (sprint).

Some authors have noted that the horizontal component of the total ground reaction force (GRF) is the determinant parameter for sprint acceleration performance, regardless of the athletes' level of ability (Morin et al., 2012; Morin et al., 2016; Morin, Edouard, & Samozino, 2011; Rabita et al., 2015). Athletes have to develop the ability to accelerate their body mass forward during a sprint, and this is related to the ability to produce and apply a large impulse onto the ground (Rabita et al., 2015). The magnitudes of mechanical properties related to sprinting ability have been explored through the linear force-velocity (F–V) and parabolic power–velocity (P–V) relationships (Cross, Brughelli, Samozino, & Morin, 2017b; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). The F-V profile in sprinting can be assessed using a validated and simple method in realistic conditions to determine the maximal theoretical force (F_0), maximal theoretical velocity (V_0), F-V slope, and maximal power (P_{max}).

There are few studies on the influence of initial levels of horizontal strength and the magnitude of improvement on ballistic actions, particularly with regard to the effects of RST on female participants (Alcaraz et al., 2018; Petrakos et al., 2016). As players' initial levels of force will show a wide variability due to different training backgrounds and individual characteristics (especially at amateur level), it would be useful to know whether these differences require different adaptations to training plans. Since previous studies have suggested that the initial levels of force may influence the magnitude of improvement in ballistic actions (Cormie et al., 2009; Cormie et al., 2011; James et al., 2018; Stone et al., 2003), we hypothesized that players with higher levels of horizontal force will show greater improvement following horizontal resisted training. Therefore, the purpose of this study was (i) to observe the effect of 8 weeks of sled training with optimal loading for maximal power output production on 5 and 20 m sprint performance; and (ii) to ascertain whether the initial level of force determines the magnitude of improvement in individual sprint mechanical outputs in the horizontal Power-Force-Velocity profile (P-F-V profile) and sprinting performance in amateur female rugby union players.

Material and methods

Participants

Thirty-one amateur female rugby union players (age = 23.7 ± 3.3years, BM = 69 ± 9Kg, Height = 167.5 ± 5.2 cm) with more than six years of experience (8 ±

1.7) participated in this study. All participants completed 4–5 h of training per week (Tuesday and Thursday) consisting of technical rugby training and strength, speed and aerobic endurance sessions. All players received an explanation of the research, including the risks and benefits of participation. Players were not involved in any kind of resistance training at the time of this investigation and were familiar with the tests performed. Prior to fitness testing, all players provided informed consent to participate in the study, by way of a structured consent form and a Physical Activity Readiness-Questionnaire (PAR-Q). This study was approved by the ethics board at South Essex College University Centre in agreement with the Declaration of Helsinki.

Design and procedures

Design. This was an experimental investigation with a control (5 forwards and 5 backs) and two experimental groups (FG = 13 forwards and BG = 8 backs). Forwards and backs were randomly subdivided according to their position, due to their anthropometric and performance differences. All groups performed the same training programme (Tuesdays and Thursdays): 2 sets of 5 × 30 m (2 min of recovery between trials and 5 min between sets) during eight consecutive weeks (16 sessions). The control group (CG) followed un-resisted sprint training (URS), while FG and BG ran towing a resisted sled attached to their waist, with an optimal load for FG = 89.1 ± 6.4% and BG = 80.5 ± 6.7% of their body mass. All the sessions (pre-test and post-test included) were conducted outdoors, on the same grass field where they usually trained, and all the participants wore their normal rugby footwear.

The dependent variables of the study are defined as 5 and 20 m sprint performance and the sprint mechanical outputs: the index of the athlete's individual balance between force and velocity capabilities (S_{fv}), theoretical maximal force (F_0), theoretical maximal velocity (V_0), maximal power output (P_{max}), maximal value for the ratio of force (Rf_{max}) and rate of decrease in the ratio of force (D_{rf}) (Cross et al., 2018; Morin et al., 2020; Morin & Samozino, 2016).

Procedures. The participants were asked not to participate in any physical exercise for two days before the tests. Anthropometric measurements and CMJ results were collected on the morning of the study (Thursday). Body mass (BM) was measured using a Tanita SC-330, (Tanita Corp., Japan) and height was measured using an aluminium stadiometer (Seca 713 model, Postfach, Germany). Measures for lower-limb length (cm) were taken by an experienced researcher in two steps, using a tape measure: first, with the participant lying down and the ankle plantarflexed, from the iliac crest to the toes; and second, in squatting position at 90° (knee flexion), from the iliac crest to the ground (Jiménez-Reyes et al., 2017b; Morin & Samozino, 2016; Samozino et al., 2014). CMJ height was used in this investigation as the index of performance for ballistic actions (Jones, Smith, Macnaughton, & French, 2016; McMaster, Gill, Cronin, & McGuigan, 2014). Participants performed a standardized warm-up consisting of 10 min of jogging, dynamic stretching and preparatory countermovement jumps. Vertical jump height was measured according to Samozino's method (Jiménez-Reyes et al., 2017b; Morin & Samozino, 2016; Samozino et al., 2014), using a scientifically validated smartphone app (My Jump 2) on an iPhone device (iPhone 7; Apple, Cupertino, CA, USA) (Balsalobre-Fernández, Glaister, & Lockey, 2015). Each player performed three maximal vertical CMJs with 2 min of recovery between trials. The highest score of the three attempts was selected for the correlation analysis.

After the collection of anthropometric measurements and CMJ, participants were asked to meet in the evening (18:00–21:00). A standardized 30-minute warm-up was performed prior to completion of three repetitions of a 30 m sprint test with 5 min of passive recovery between trials. An iPhone device (iPhone 7; Apple, Cupertino, CA, USA) was placed on a tripod 20 m from the track (frontal plane), using a valid and reliable app for side-on measurement of the entire sprint of each participant and estimation of the variables associated with the horizontal P-F-V profile analysis. Seven yellow fluorescent poles were used along the 30 m sprint test and players were instructed to wear black shorts to optimize the contrast and visible motion in frame by frame analysis. Poles were located at the start point, 5.57 m (for 5 m), 10.28 m (for 10 m), 15 m (for 15 m), 19.72 m (for 20 m), 24.43 m (for 25 m) and 29.15 m (for 30 m) to account for parallax. The first frame in which the participant's right thumb left the ground was the selection criterion for the start point (0 m), while the first frame in which the hips crossed the set poles was the selection criterion for the split times corresponding to 5, 10, 15, 20, 25 and 30 m (Romero-Franco et al., 2017). The best time of the three attempts was selected for the analysis of the split times and mechanical properties (S_{fv}, F_0, V_0, P_{max}, RF_{max} and D_{rf}), according to Samozino's method (Morin & Samozino, 2016; Samozino et al., 2016).

Five days after the 30 m sprint test (on Tuesday), FG and BG participants performed four sprints of 30 m (split times 0, 5, 10, 15, 20, 25 and 30 m) with a resisted sled attached to their waist corresponding to 0, 25, 50 and 75% of BM (5 min passive rest between trials), for computation of the optimal loading (kg) for maximal power output production (Cross et al., 2017a; Cross et al., 2018; Morin et al., 2020). The times for each sprint were measured using the same methodology and smartphone app on an iPhone 7 that were used on the first day of testing. The results were recorded using an Excel spreadsheet with a computation model validated in previous investigations, based on the reduction of velocity through a linear load-velocity relationship (Cross et al., 2017a; Cross et al., 2018; Morin et al., 2020). One week after the eighth week of intervention, participants were re-tested (following the same protocol that was applied in the first testing session) in a sprint test over 30 m and the variables associated with the horizontal P-F-V profile. It is important to notice that only the results corresponding to 5 and 20 m sprint are displayed in the results section.

Statistical analysis

All data are presented as mean ± SD with IBM SPSS (IBM SPSS version 25.0; SPSS, Chicago, IL, USA) software. Normal distribution for the variables of the study were assessed with the Shapiro–Wilk test. Intra- (pre vs post-test) and inter-group (percentual change between pre vs post-test-%) comparisons for each variable were performed using a two-way (group x time) ANOVA with Bonferroni adjustment. TheThe level of significance was set at $p \leq 0.05$.

The magnitudes of the changes within and between groups were calculated using Cohen's effect size (ES) (Cohen, 1988). The criteria for interpreting this magnitude were <0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2 = large and >2.0 = very large (Hopkins, Marshall, Batterham, & Hanin, 2009).

The associations between the pre-tests for CMJ height and S_{fv}, and the magnitude of improvement in P_{max} (Δ-P_{max}) (calculated as$(\text{Post } P_{max}/\text{Initial } P_{max}) - 1)*100$ were analysed using a Pearson correlation (level of significance set at $p \leq 0.05$) and the coefficient of determination (R^2). The chosen criteria to interpret the magnitude of the correlation (r) were: ≤ 0.1 = trivial, $> 0.1 - 0.3$ = small,$> 0.3 - 0.5$ = moderate,$> 0.5 - 0, 7$ = large,$> 0.7 - 0.9$ = very large,$> 0.9 - 1.0$ = almost perfect (Hopkins et al., 2009).

Results

All the results within the groups are presented in Table I. After 8 weeks of un-resisted sprint (URS) training, the control group displayed significant changes with small effect sizes in 5 and 20 m sprint. FG showed significant changes with moderate effect sizes for 5 m, 20 m, F_0, P_{max} and Rf_{max}. Significant changes with moderate effect sizes were also observed in BG in 20 m, F_0 and P_{max}, while large and very large effect sizes were observed for Rf_{max} and 5 m sprint respectively.

Intergroup comparisons between the percentual changes (%) for each variable of the study are presented in Table II. The main findings are the significant changes of both experimental groups (FG and BG) in comparison with the CG, with exception of the V_0. No significant changes were found for any variable in the comparison between FG and BG.

The associations of the pre-tests for CMJ height and S_{fv} during the pre-test and Δ-P_{max} are represented in Table III. Significant levels of association with large and very large effect sizes were found between the initial S_{fv} and Δ-P_{max} in forwards and backs respectively.

Discussion

The first purpose of this study was to observe the effect of 8 weeks of sled training with optimal loading for maximal power output production on 30 m sprint times. After 8 weeks of training, both experimental groups (FG and BG) achieved significantly improved sprint performances for each split time observed in this study (5 and 20 m), and improved mechanical properties related to sprinting ability (S_{fv}, F_0, V_0, P_{max}, RF_{max} and D_{rf}). See Table I.

The second aim was to observe whether the initial level of force determined the magnitude of improvement in individual sprint mechanical outputs for the horizontal Power-Force-Velocity profile (P-F-V profile) and sprinting performance. Our results support the previously stated hypothesis, suggesting that the initial level of horizontal force production causes greater adaptations to horizontal ballistic training (i.e. RST). This is supported by the significant correlation between the initial level of horizontal strength (represented by S_{fv}) and the improvement in Δ-P_{max} after 8 weeks of intervention with RST in both FG and BG (See Table III and Figure 1).

RST is extensively used to improve sprint ability (Alcaraz et al., 2018; Petrakos et al., 2016), although few studies have observed the use of sled training with loads greater than 43% of BM (Cross et al., 2017a; Kawamori et al., 2014; Morin et al., 2016) or with optimal loading for maximal power output (Cross et al., 2018; Morin et al., 2020). The results obtained are similar to a previous study with amateur male football players, suggesting that sled training with

Table I. Mean ± SD values for descriptive performance and mechanical variables for each group.

Groups	Variable	Pre-Test	Post-Test	*P*	95% CI	ES	Inference	Change (%)
	BM (Kg)	71.4 ± 12	71.2 ± 12	**0.01***	0.149-0.299	0.01	Trivial	−0.32 ± 0.06
	5m (s)	1.66 ± 0.09	1.64 ± 0.09	**0.01***	0.015-0.025	0.22	Small	−1.23 ± 0.71
	20m (s)	4.32 ± 0.24	4.27 ± 0.24	**0.01***	0.038-0.06	0.2	Small	−1.15 ± 0.6
	S_{fv} (%)	−0.73 ± 0.08	−0.74 ± 0.06	0.51	0.029-0.042	0.13	Small	−0,87 ± 6.57
Control	F_0 (N/kg)	5.01 ± 0.62	5.09 ± 0.54	0.08	0.01-0.167	0.13	Trivial	1.6 ± 4.15
	V_0 (m/s)	6.85 ± 0.6	6.89 ± 0.59	0.24	0.03-0.113	0.07	Trivial	0.58 ± 2.6
	P_{max} (W/kg)	8.62 ± 1.53	8.81 ± 1.51	**0.01***	0.096-0.292	0.12	Trivial	2.25 ± 2.20
	Rf_{max} (%)	33 ± 2.69	33.3 ± 2.75	**0.01***	31.67-33.64	0.11	Trivial	0.88 ± 2.04
	D_{rf} (%)	−7.09 ± 0.8	−7.11 ± 0.8	**0.01***	6.725-7.319	0.02	Trivial	−0.27 ± 0.07
	BM (Kg)	71.8 ± 6.5	72.3 ± 6.5	**0.01***	0.459-0.59	0.08	Trivial	0.73 ± 0.2
	5m (s)	1.66 ± 0.09	1.60 ± 0.08	**0.01***	0.053-0.062	0.66	Moderate	−3.57 ± 0.37
	20m (s)	4.33 ± 0.17	4.22 ± 0.17	**0.01***	0.103-0.121	0.65	Moderate	−2.65 ± 0.17
	S_{fv} (%)	−0.68 ± 0.09	−0.73 ± 0.09	**0.01***	0.044-0.052	0.54	Small	−6.63 ± 0.95
Forwards	F_0 (N/kg)	4.82 ± 0.39	5.21 ± 0.43	**0.01***	0.316-0.471	0.96	Moderate	7.53 ± 0.53
	V_0 (m/s)	7.17 ± 0.92	7.23 ± 0.88	**0.04***	0.003-0.129	0.07	Trivial	0.97 ± 0.68
	P_{max} (W/kg)	8.63 ± 1.25	9.42 ± 1.34	**0.01***	0.706-0.878	0.61	Moderate	8.43 ± 0.66
	Rf_{max} (%)	32.7 ± 1.88	34.3 ± 1.95	**0.01***	0.726-2.455	0.82	Moderate	4.64 ± 0.32
	D_{rf} (%)	−6.59 ± 0.93	−7.03 ± 0.96	**0.01***	0.179-0.7	0.46	Small	−6.3 ± 0.94
	BM (Kg)	61.8 ± 3.7	62.2 ± 3.7	**0.01***	0.345-0.512	0.11	Trivial	0.69 ± 0.17
	5m (s)	1.51 ± 0.02	1.45 ± 0.02	**0.01***	0.049-0.06	3.2	Very Large	−3.76 ± 0.25
	20m (s)	4.06 ± 0.12	3.93 ± 0.12	**0.01***	0.109-0.133	1.02	Moderate	−3.06 ± 0.35
	S_{fv} (%)	−0.71 ± 0.13	−0.76 ± 0.15	**0.01***	0.031-0.066	0.35	Small	−6.18 ± 2.08
Backs	F_0 (N/kg)	5.47 ± 0.36	5.91 ± 0.46	**0.01***	0.351-0.549	1.08	Moderate	7.51 ± 1.82
	V_0 (m/s)	7.83 ± 1.05	7.94 ± 1.06	**0.01***	0.032-0.193	0.1	Trivial	1.43 ± 0.57
	P_{max} (W/kg)	10.64 ± 1.08	11.66 ± 1.08	**0.01***	0.915-1-135	0.94	Moderate	8.84 ± 1.77
	Rf_{max} (%)	36 ± 1.16	37.7 ± 1.24	**0.01***	0.589-2.793	1.41	Large	4.48 ± 0.84
	D_{rf} (%)	−6.83 ± 1.38	−7.26 ± 1.54	**0.01***	0.102-0.767	0.29	Small	−5.76 ± 2.03

The presented variables are defined as Body Mass in kilograms (BM), 5m split time in seconds (5m), 10m split time in seconds (10m), 20m split time in seconds (20m), theoretical maximal force production in Newton per kilograms (F_0), theoretical maximal running velocity in meters per second (V_0), Maximal mechanical power output in the horizontal direction in watts per kilogram (P_{max}), maximal value for ratio of force in percentage (Rf_{max}) and rate of decrease in ratio of force in percentage (D_{rf}) (McMaster et al., 2014). Statistically significant differences ($p \leq 0.05$) denoted in bold and *.

80%BM is an effective and practical way to enhance F_0 and Rf_{max}. Morin et al. (2016) found that after 8 weeks of very heavy sled training, sprint times were improved for 5 and 20 m. The results of Morin et al. also reported that football players increased their F_0 and reduced their V_0, while the rugby players in the present study showed an improvement in both variables after the intervention. This may be a consequence of gender differences, sports-specific characteristics, the amateur status of the athletes (leading to a wider range of improvement in terms of fitness), or the use of optimal loads for maximal power output production (Spiteri, Hart, & Nimphius, 2014).

The use of optimal loading may cause development of the horizontal F-V profile, and therefore significant changes have been observed in F_0 and V_0 (Cross et al., 2018). Similarly, significant improvements on 5 and 20 m sprint performance and mechanical properties (except D_{rf}) were found in rugby and soccer players after 10 weeks of RST with optimal loading conditions for maximal power (Cross et al., 2018). A recent study by Morin et al. reported that athletes reach their peak kinetic adaptations to high RST with optimal loads between 2 and 4 weeks post-training (Morin et al., 2020). This indicates that our results and those obtained by Cross et al. (2018) might have shown even greater improvement during the following 4 weeks after the end of RST (Morin et al., 2020). In any case, our results support the use of sled training loads greater than 43% of BM to improve both sprinting performance over short distances (≤20 m) and the underlying mechanical variables associated with this ability.

Furthermore, the use of RST was more beneficial for improving acceleration (5 and 20 m) than URS, as can be observed in the effect sizes in pre–post intra-group and inter-group comparisons (see Tables I and II). Of particular note is the significant change, with a very large effect size, in the 5 m sprint in BG after the intervention.

The correlation between the initial level of horizontal strength (S_{fv}) and the Δ-P_{max} in FG and BG suggests that higher initial levels of horizontal force may produce greater adaptations to horizontal ballistic training (RST) in amateur female rugby union

Table II. Intergroup comparison between the Pre vs Post-test change (%) for each variable of the study.

		Pre vs Post-Test Change (%)			
Groups	Variable	*P*	95% CI	ES	Inference
Control vs Forwards	BM (Kg)	0.01*	8.608–4.481	6.54	Very Large
	5 m (s)	0.01*	2.799–5.775	4.28	Very Large
	20 m (s)	0.01*	2.349–5.049	3.7	Very Large
	S_{fv}	0.01*	2.229–0.412	1.32	Large
	F_0 (N/kg)	0.01*	3.196–1.127	2.16	Very Large
	V_0 (m/s)	1	1.053–0.061	0.22	Small
	P_{max} (W/kg)	0.01*	5.486–2.621	4.05	Very Large
	Rf_{max} (%)	0.01*	3.914–1.617	2.76	Very Large
	D_{rf} (%)	0.01*	10.950–5.829	8.38	Very Large
Control vs Backs	BM (Kg)	0.01*	11.048–5.371	8.2	Very Large
	5 m (s)	0.01*	2.776–6.267	4.52	Very Large
	20 m (s)	0.01*	2.223–5.307	3.76	Very Large
	S_{fv}	0.02*	2.026–0.047	1.03	Moderate
	F_0 (N/kg)	0.01*	2.868–0.677	1.77	Large
	V_0 (m/s)	0.77	1.372–0.509	0.43	Small
	P_{max} (W/kg)	0.01*	4.670–1.844	3.25	Very Large
	Rf_{max} (%)	0.01*	3.387–1.033	2.2	Very Large
	D_{rf} (%)	0.01*	5.707–2.456	4.08	Very Large
Forwards vs Backs	BM (Kg)	1	0.7–1.065	0.18	Trivial
	5 m (s)	1	0323–1.473	0.57	Small
	20 m (s)	0,08	0.723–2.778	1.75	Large
	S_{fv}	1	0.577–1.195	0.3	Small
	F_0 (N/kg)	1	0.867-0.895	0.01	Trivial
	V_0 (m/s)	1	1.613–0.2	0.7	Moderate
	P_{max} (W/kg)	1	1.226–0.547	0.33	Small
	Rf_{max} (%)	1	0.606–1.164	0.28	Small
	D_{rf} (%)	0.95	0.512–1.264	0.37	Small

Data is presented as Significance value (*P*), 95% confidence intervals (95% CI) and effect size (ES) values (<0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2 = large and >2.0 = very large). Statistically significant differences ($p \leq 0.05$) denoted in bold and *.

players (See Table III). This is also supported by the remarkable changes in the 5 m sprint times in BG (See Table I). Stronger individuals have neuromuscular adaptations that optimize their responses to ballistic resistance training, due to a greater neural drive and myofibrillar cross-sectional area, and superior intermuscular coordination (James et al., 2018). They are also able to produce higher maximal impulse capabilities (Cormie et al., 2009; Stone et al., 2003), which is extremely relevant in Rugby due to the high number of ballistic actions (sprints or changes of direction) that are required during competition (Gabbett, 2012; Hene et al., 2011).

Moreover, the absence of significant correlations between the pre-test CMJ height and the Δ-P_{max} in each group (see Table III) suggests that athletes develop specific adaptations to the contextual requirements of their sport modality. Therefore, players with high levels of vertical force application did not show greater improvements in modalities based on the horizontal application of force. These results may be explained by the transference of

Table III. Pearson's correlation (*r*), coefficient of determination (R^2), statistically significant ($p \leq 0.05$) denoted in bold and *.

Groups	Variable	*r*	R^2	*P*	Inference
CG	CMJ height & Δ-P_{max}	−0.02	0.00	0.99	
	S_{fv} & Δ-P_{max}	0.37	0.139	0.31	
FG	CMJ height & Δ-P_{max}	0.18	0.033	0.59	
	S_{fv} & Δ-P_{max}	−0.66	0.439	0.016*	Large
BG	CMJ height & Δ-P_{max}	−0.25	0.065	0.54	
	S_{fv} & Δ-P_{max}	−0.74	0.541	0.037*	Very Large

The presented variables are defined as pre-test countermovement jump height (CMJ height), index of the athlete's individual balance between force and velocity capabilities (S_{fv}), improvement on the maximal mechanical power output in the horizontal direction (Δ-P_{max}) after 8 weeks of training.

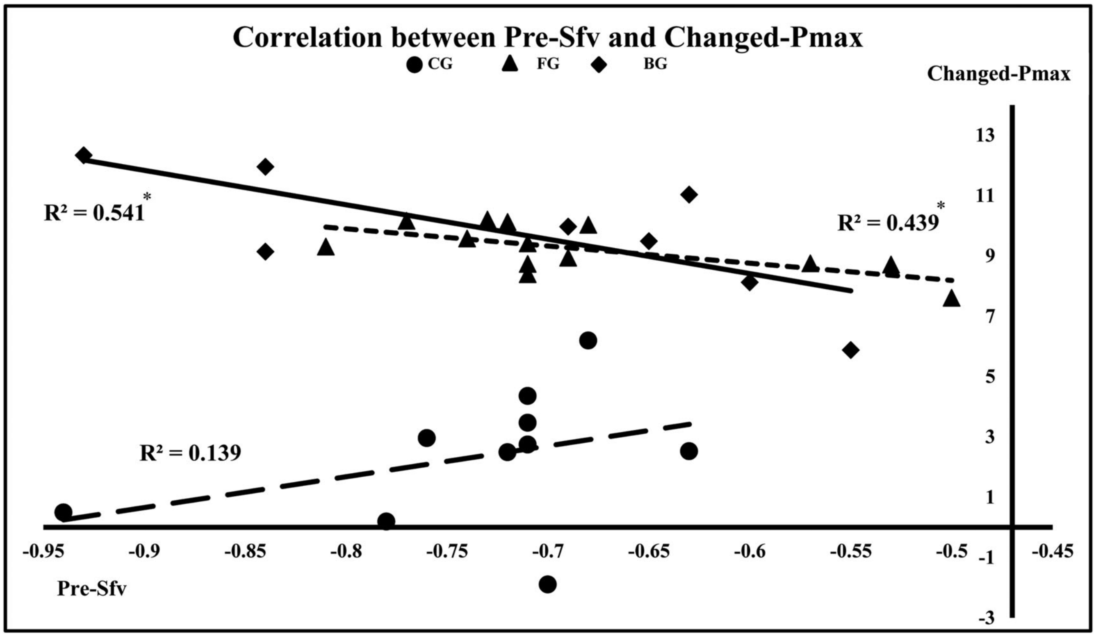

Figure 1. Coefficient of determination between Pre-S_{fv} and Changed-P_{max} for the control group (CG), forwards group (FG) and backs group (BG). Significant correlations ($p \leq 0.05$) denoted with *.

similar patterns of movement that RST provides to rugby players during acceleration skills and consequently, the enhancement of mechanical properties (Buchheit et al., 2014; Kawamori et al., 2014).

Previous investigations have suggested that the initial levels of force may influence the magnitude of improvement in ballistic actions (Cormie et al., 2009; Cormie et al., 2011; James et al., 2018; Stone et al., 2003; Suchomel et al., 2016); however, these suggestions are only based on the vertical application of force. Therefore, this study may be considered novel, due to the use of vertical (CMJ) and horizontal application of force (P-F-V profile) tests (Samozino et al., 2016). Our investigation may be useful for amateur female rugby players and coaches who want to monitor changes in mechanical variables during sprinting performance to assess the effectiveness of their training.

Limitations must be stated for a wider understanding of our results and to avoid misconceptions. The athletes who took part in this investigation are amateurs, and therefore, our results provide a reference about the effectiveness of the use of optimal loading for maximal power output (Cross et al., 2018; Morin et al., 2020) in this population. Future investigations may focus on the effect of individualized training plans based on the vertical development of strength (Escobar Álvarez, Fuentes García, Da Conceição, & Jiménez-Reyes, 2020; Jiménez-Reyes, Samozino, & Morin, 2019; Jiménez-Reyes, Samozino, Brughelli, & Morin, 2017a), horizontal strength and the combination of both on sprint performance in amateur, professional and elite rugby players. It is also important to notice that we did not monitor athletes during the 4 weeks after the end of RST, what may have provided even greater improvement according to recent findings published during the review of this manuscript (Morin et al., 2020). Lastly, observe the kinematics changes on sprinting after the RST intervention is an interesting area of study that might be relevant for strength and conditioning coaches.

Practical applications

The results obtained in this investigation suggest that the use of optimal loading for maximal power output production, based on the linear relationship of force-velocity mechanical variables using multiple trials with resistive loads (Cross et al., 2017a), is an effective way to improve sprint performance over 5 and 20 m. Optimal loading also enhanced the underlying mechanical variables associated with sprint performance in amateur female rugby players. In addition to this, our findings suggest that higher levels of horizontal force may lead to greater adaptations in RST. Therefore the P-F-V profile is a useful and approachable field method for identifying the weakest mechanical variables in rugby players during sprinting and for prescribing individualized training programmes according to specific running performance. This study provides information about the use of this field method, which is a low-cost and approachable methodology for coaches and practitioners. The design of this investigation may be useful for monitoring the sprinting ability of rugby players and allowing for the individualization of sled training and optimization of their performance.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Estudio IV.

Association between vertical and horizontal force-velocity-power profiles in netball players

Original Article

Association between vertical and horizontal force-velocity-power profiles in netball players

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ABSTRACT

Netball is a collective sport characterized by intermittent high-intensity actions. Therefore, the players must develop high levels of relative bilateral and unilateral strength and power for both improve performance and also reduce injury risk. The purpose of this study was (i) to provide a reference about the mechanical outputs obtained in the vertical (jumping) and horizontal force-velocity-power (FVP) profile and (ii) observe their relationship, besides the performance in jumping and sprinting in amateur female netball players (age = 24.3 ± 3.2 years, BM = 64.5 ± 5 Kg, height = 172.5 ± 6.2 cm). The variables for both FVP profiles (theoretical maximal force (F_0), theoretical maximal velocity (V_0) and theoretical maximal power output (P_{max})) were measured with two scientifically validated apps for iOS (My Jump 2 and My Sprint). Our results in regards to the vertical FVP suggest that netball players have low force deficit (36.2 ± 14.6%) and individualized training based on F-V profiling could be beneficial to address their deficit. The moderate correlations found for performance, V_0 and P_{max} suggest that the improvement in one of the skills (jumping or sprinting) may produce some positive adaptation to the other. However, no association was found in the force production (F_0) of the lower limbs for both FVP. Therefore, we recommend that netball players must train specifically ballistic actions in the vertical (jumping) and horizontal direction (sprinting) due to the specificity of both skills and the consequent impact of them on netball performance.
Keywords: Force; Velocity; Profile; App; Netball.

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INTRODUCTION

Netball is a collective sport characterized by intermittent high-intensity actions like sprinting, jumping, change of directions (COD), cutting and pivot movements (Fox, Spittle, Otago, & Saunders, 2013; Fox, Spittle, Otago, & Saunders, 2012; Thomas et al., 2019). A needs analysis and training recommendations study suggests that netball players must develop high levels of relative bilateral and unilateral strength and power. This is due to the high amount of ballistic actions that they perform but also to develop good control of the lower limbs and reduce the risk of common injuries (Thomas, Comfort, Jones, & Dos'Santos, 2017).

Several studies have reported a descriptive analysis of netball players or even the umpires of this sport (Spencer, McErlain-Naylor, Paget, & Kilding, 2019). Investigations have reported normative data for physical parameters and physiological characteristics of netball players according to their position (Thomas et al., 2019), level of performance and categories (Sinclair, Coetzee, & Schall, 2020; Thomas, Thomas Ismail, Comfort, Jones, & Dos'Santos, 2016) and even the umpires of this sport. The fitness testing batteries used provide the performance values based on the vertical (jumping) and horizontal (sprinting) application of strength. Interestingly, investigations have suggested that the maximal power output (P_{max}) resultant by the product between force (F_0) and velocity (V_0), is key for jumping and sprinting performance (Morin & Samozino, 2016; Samozino et al., 2016; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012) and moreover, the production of horizontal force during sprinting has been identified as an injury-related factor (Mendiguchia et al., 2016, 2014). However, to the best of our knowledge, no investigations have observed the mechanical variables underlying during sprinting and jumping in netball players.

Validated field methods developed in recent years provide a macroscopic view about the mechanical outputs during jumping (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Samozino et al., 2012) and sprinting performance (P. Samozino et al., 2016). These approaches quantify the relationship between force-velocity-power (FVP) spectrum (Morin & Samozino, 2016). Moreover, the vertical FVP allow strength and conditioning coaches the identification of the deficit in either F_0 or V_0 for the optimal production of P_{max}, known as the force-velocity imbalance (F-V_{IMB}) (Jiménez-Reyes, Samozino, Brughelli, & Morin, 2017; Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; J. B. Morin & Samozino, 2016; Pierre Samozino et al., 2012).

The relationship between jumping and sprinting performance (Comfort, Stewart, Bloom, & Clarkson, 2014; Lockie et al., 2014; Randell, Cronin, Keogh, & Gill, 2010), and the vertical and horizontal FVP profiles have been observed in female and male practitioners in a large range of sports (football, basketball, rugby, etc.) and level of practice, however, Netball has not been explored yet in this area (Jiménez-Reyes et al., 2018). The findings showed that the P_{max} and the performance variables (jumping ability and 20m sprint) were the most correlated parameters. Low correlations were found for F_0 and V_0, especially in high level and elite athletes. Therefore, the vertical and horizontal FVP profile provide distinctive information about the maximal mechanical capacities of the lower limbs, and the use of both testing methods is recommended (Jiménez-Reyes et al., 2018). Monitoring the mechanical capabilities during jumping and sprinting ability in netball players may be relevant for strength and conditioning coaches to design training sessions based on F-V profiling, as it has been already addressed in other disciplines (Escobar Álvarez, Fuentes García, Da Conceição, & Jiménez-Reyes, 2019; Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Jiménez-Reyes, Samozino, & Morin, 2019).

Due to the relevance of vertical and horizontal ballistic actions in netball performance (Sinclair et al., 2020; Thomas et al., 2017, 2019), a study observing the mechanical outputs for both FVP profiles and their level of association may be interesting for optimizing training sessions. The first aim of this study was to provide a reference about the variables of the FVP profile during jumping (F_0, V_0, P_{max} and $F\text{-}V_{IMB}$) and sprinting (F_0, V_0, P_{max}, S_{fv}, RF_{max} and D_{rf}) performance. A secondary aim was to investigate the relationship between both FVP mechanical outputs (F_0, V_0 and P_{max}) and performance variables (countermovement jump-CMJ and 20m sprint) in amateur netball players.

METHODS

Participants

Twenty-eight amateur female netball players (age = 24.3 ± 3.2 years, BM = 64.5 ± 5 Kg, height = 172.5 ± 6.2 cm) with more than five years of experience (6 ± 2) participated in this study. All participants completed 4–5 hours of training per week (Tuesday and Thursday) besides competition events during the weekend. All athletes received an explanation of the research, including the risks and benefits of participation. Prior to fitness testing, all players provided informed consent to participate in the study, by way of a structured consent form and PAR-Q. This study was approved by the ethics board at University Centre South Essex in agreement with the Declaration of Helsinki.

Instruments

Participants' body mass (BM) in Kg, and height were measured using a Tanita SC-330 (TANITA Corporation, *Itabashi-ku Tokyo*, Japan), and an aluminium stadiometer (Seca 713 model, Postfach, Germany) respectively.

My Jump 2: It is a scientifically validated smartphone app, based on video-analysis (Balsalobre-Fernández, Glaister, & Lockey, 2015). My Jump 2 provides the information regarding jump height, $F\text{-}V_{IMB}$ (%), F_0 (N/kg), V_0 (m/s) and P_{max} (W/kg), according to Samozino's method (Escobar Álvarez et al., 2019; Jiménez-Reyes et al., 2019; Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Morin & Samozino, 2016; Samozino et al., 2014).

My Sprint: It is a scientifically validated app for iOS, based on video-analysis (Romero-Franco et al., 2017). My Sprint provides information regarding 40m sprint times and its different splits. Moreover, it also calculates the mechanical variables associated with the horizontal FVP profile such as F_0 (N/kg), V_0 (m/s), P_{max} (W/kg), S_{fv}, RF_{max} and D_{rf} (J. B. Morin & Samozino, 2016; P. Samozino et al., 2014).

Procedures

This study used a descriptive correlational design, which observes the association between the vertical and horizontal mechanical variables for the F-V profile (F_0, V_0 and P_{max}), and performance for CMJ and 20m sprint (5, 10, 15 and 20m).

Subjects met in two sessions for the measurement of the vertical (Thursday) and horizontal (Monday) F-V profile. Both testing-sessions were conducted indoors, on the same court where they usually trained, and all the participants wore their normal netball footwear.

First Session (CMJ performance and Vertical FVP profile)

Players performed a standardized warm-up: 20min jogging, dynamic stretching, range of movement exercises and preparatory CMJs. The F-V profile variables were measured with a field test based on 3 maximal vertical CMJs (highest score was selected for the analysis), using an Olympic barbell with the loads corresponding to 0%, 10%, 20%, 30%, 40%, 50% and 70% of their own body mass (2 minutes' recovery between jumps, and 4 minutes between loads) (Escobar Álvarez et al., 2019; Jiménez-Reyes et al., 2019;

Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017; Morin & Samozino, 2016; Samozino et al., 2014; Samozino, Morin, Hintzy, & Belli, 2008; Samozino et al., 2012). CMJ height and the mechanical variables for the F-V profile (F_0, V_0 and P_{max}) were measured using *My Jump 2* on an iPhone device (iPhone 7; Apple, Cupertino, CA, USA) (Balsalobre-Fernández et al., 2015).

Second session (Sprint performance and Horizontal FVP profile)
A 30-minute warm-up was performed prior to completion of three repetitions of a 20m sprint test with 5min. of passive recovery between trials. The same iPhone 7 (iPhone 7; Apple, Cupertino, CA, USA) of the first day of testing was used for the measurement of sprinting performance and estimation of the variables associated with the horizontal P-F-V profile. The smartphone was placed on a tripod 20m from the track (frontal plane) using *My Sprint*, following previous recommendations (Romero-Franco et al., 2017). The best time of the three attempts was selected for the analysis of the split times (5, 10, 15 and 20m) and mechanical properties (F_0, V_0, P_{max}, S_{fv}, RF_{max} and D_{rf}) (Morin & Samozino, 2016; Samozino et al., 2016).

Statistical analysis
All data are presented as mean ± SD with IBM SPSS (IBM SPSS version 26.0; SPSS, Chicago, IL, USA) software. Normal distribution for the variables of the study were assessed with the Shapiro-Wilk test. The associations between the vertical and horizontal mechanical variables for the F-V profile, and performance variables were analysed using a Pearson correlation (level of significance set at $p \leq .05$) and the coefficient of determination (R^2). The chosen criteria to interpret the magnitude of the correlation (r) were: ≤ .1 = trivial,> .1 – .3 = small,> .3 – .5 = moderate,> .5 – .7 = large,> .7– .9 = very large,> .9 – 1.0 = almost perfect (Hopkins, Marshall, Batterham, & Hanin, 2009).

RESULTS

All the data regarding the variables of both FVP profiles are presented in Table 1. The main findings suggest that netball players have force deficit (36.2 ± 14.6%) (Jiménez-Reyes, Samozino, Brughelli, et al., 2017).

Table 1. Mean ± SD values for the CMJ and the mechanical outputs of the vertical FVP profile. Mean ± SD values for the 5m, 20m performance and the mechanical outputs of the horizontal FVP profile.

Vertical FVP profile	
CMJ (cm)	31.1 ± 3
F_0 (N/kg)	29.71 ± 3.4
V_0 (m/s)	3.17 ± 0.41
P_{max} (W/kg)	23.36 ± 2.19
F-V Deficit (%)	36.2 ± 14.6
Horizontal FVP profile	
5 m sprint (s)	1.51 ± 0.06
20 m sprint (s)	3.86 ± 0.16
F_0 (N/kg)	6.51 ± 0.6
V_0 (m/s)	7.29 ± 0.43
P_{max} (W/kg)	11.81 ± 1.44
Sfv	-57.82 ± 5.9
Rf_{max} (%)	41 ± 3
D_{RF} (%)	-0.08 ± 0.01

The associations between the performance variables (CMJ and 20m sprint) and the mechanical output for the vertical and horizontal FVP profiles (F_0, V_0 and P_{max}) can be seen in Table 2. Significant moderate correlations were found for performance (-.5), V_0 (-.4) and P_{max} (.4).

Table 2. Pearson correlation (r) and coefficient of determination (R^2) between the vertical and horizontal FVP profiles.

Variables	Vertical	Horizontal	r	R^2	p-value	Criteria
Performance	31.1 ± 3	3.86 ± 0.16	-.5	.26	.01*	Moderate
F_0 (N/kg)	29.71 ± 3.4	6.51 ± 0.6	.27	.08	.15	
V_0 (m/s)	3.17 ± 0.41	7.29 ± 0.43	-.4	.17	.03*	Moderate
P_{max} (W/kg)	23.36 ± 2.19	11.81 ± 1.44	.4	.16	.04*	Moderate

*The chosen criterion to interpret the magnitude of the correlation (r) was: ≤ .1 = trivial,> .1 – .3 = small,> .3– .5 = moderate,> .5 – .7 = large,> .7– .9 = very large,> .9 – 1.0 = almost perfect. Associations statistically significant (p ≤ .05) denoted in bold an *.The values provided for vertical and horizontal performance are based on CMJ and 20m sprint.*

DISCUSSION

The first aim of this study was to provide a reference for the mechanical variables of the vertical and horizontal FVP profile. Secondly, to observe the level of association between performance and the mechanical outputs of CMJ and 20m sprint.

The mean value for the $F\text{-}V_{IMB}$ during jumping in our participants suggest that amateur netball players have low force deficit (36.2 ± 14.6%), based on the $F\text{-}V_{IMB}$ thresholds proposed in a previous study: Well-Balanced<10%, Low Force-Velocity Deficit 10-40% and High Force-Velocity Deficit > 40% (Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Jiménez-Reyes et al., 2019). It is important to mention that of 28 players 13 had high force deficit, 13 had low force deficit, and 2 had a well-balanced profile. Athletes with a well-balanced profile are something really uncommon (Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Jiménez-Reyes et al., 2019). According to our results, Netball players must develop F_0 while reducing the $F\text{-}V_{IMB}$ to improve CMJ however, due to the differences on the magnitude of their *F-V* deficit different training plans must be designed for them (Escobar Álvarez et al., 2019; Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Jiménez-Reyes et al., 2019).

The moderate correlation (see Table 2 and Figure 1) found for performance (-.5), suggests some association between the CMJ and sprinting, as it has been previously reported in the literature for different sports (Comfort et al., 2014; Cronin, Ogden, Lawton, & Brughelli, 2007; Jiménez-Reyes et al., 2018; Lockie et al., 2014; Randell et al., 2010). This may lead us to hypothesize that training programs aimed to improve CMJ could also result in the improvement of sprinting performance with this population. However, It is important to notice that our athletes are amateur and therefore, the magnitude of the correlation with a high level or elite population may be smaller, as it was reported by Jimenez-Reyes et al., (Jiménez-Reyes et al., 2018).

Moderate correlations were found for V_0 (-.4) and P_{max} (.4) as it has been previously reported in some other modalities (Jiménez-Reyes et al., 2018) however, no association was found for the force production (F_0) of the lower limbs in the vertical and horizontal profile. The absent of correlation for F_0 suggest that both actions (jumping and sprinting) must be trained and monitored specifically, as it has been previously recommended (Morin & Samozino, 2016). Previous studies have highlighted that the horizontal production of F_0 is an injury-related factor (Mendiguchia et al., 2016, 2014), therefore assume changes in one skill due to the changes on the other can be counter-productive for the athletes, not developing an appropriated control of the lower limbs and increase the risk of common injuries (Thomas et al., 2017).

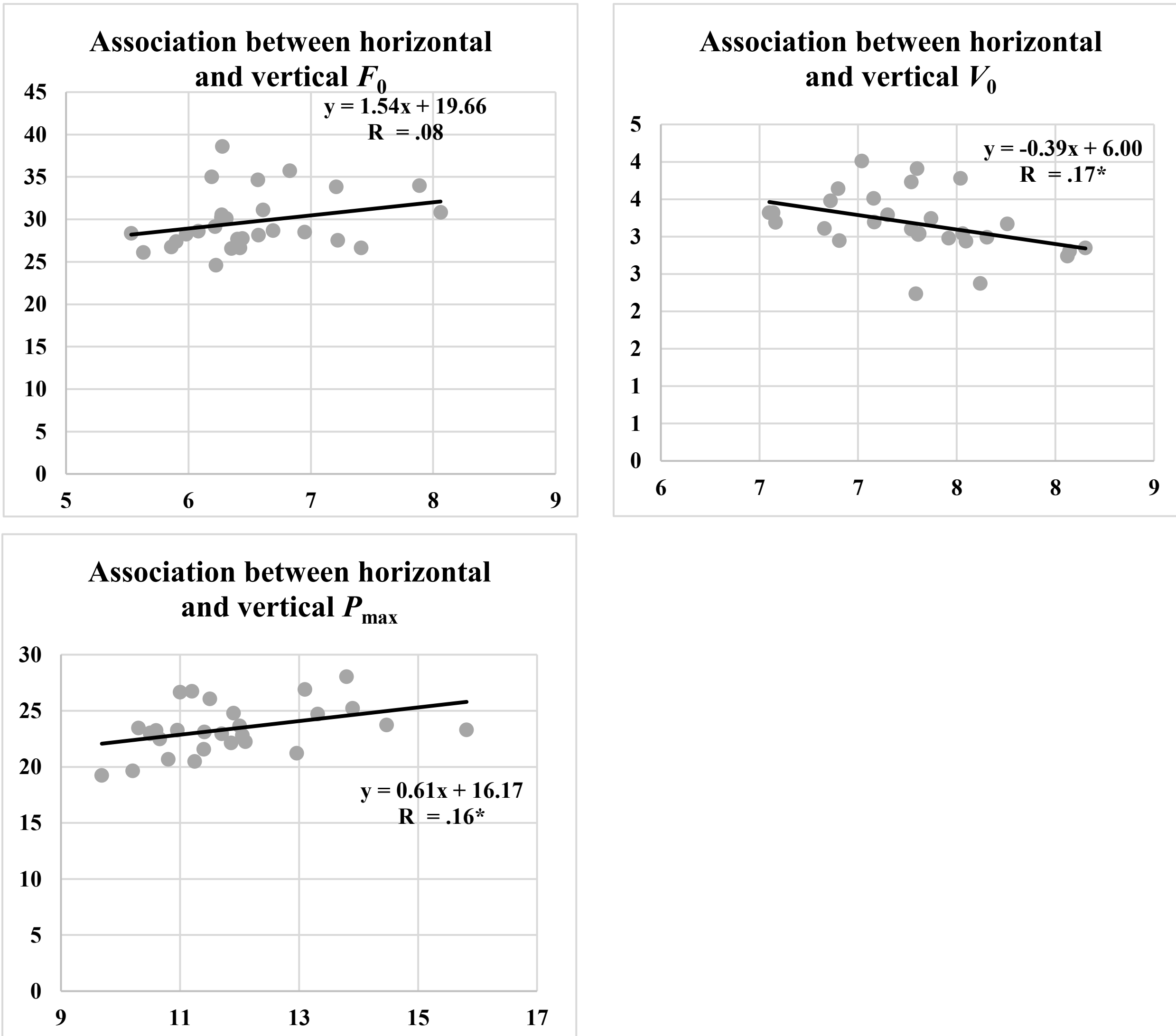

Figure 1. Coefficient of determination for the F_0, V_0 and P_{max} between the vertical and horizontal FVP profile. Associations statistically significant ($p \leq .05$) denoted with *.

Taking into consideration that jumping and sprinting skills are extremely relevant in netball performance (Fox et al., 2013; Fox et al., 2012; Thomas et al., 2019), the quantification of both FVP profiles may help to design and to monitor training programs according to the individual needs of each athlete. Therefore, we recommend specific and individualized training based on force-velocity profiling for the improvement of strength capabilities to enhance netball actions based on jumping and sprinting. Previous studies have designed training plans aimed to improve the F_0 and reduce the $F\text{-}V_{IMB}$ in jumping (Escobar Álvarez et al., 2019; Jiménez-Reyes, Samozino, Brughelli, et al., 2017; Jiménez-Reyes et al., 2019) and also improve the application of F_0 and P_{max} using horizontal resisted training (Cross et al., 2018; Morin, Capelo-Ramirez, Rodriguez-Pérez, Cross, & Jimenez-Reyes, 2020; Morin et al., 2016).

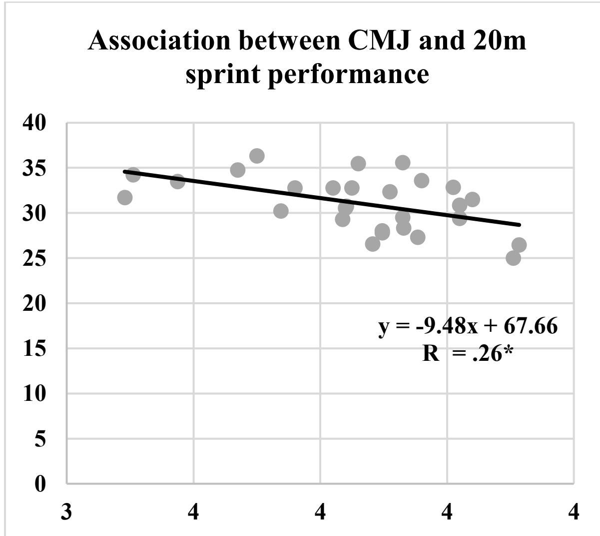

Figure 2. Coefficient of determination between the Jumping (CMJ) and sprinting performance (20m). Associations statistically significant ($p \leq .05$) denoted with *.

To the best of our knowledge, this is the first investigation observing the relationship between CMJ and sprint performance (20m) in netball players, in addition to the mechanical outputs of the vertical and horizontal FVP profile. This study might be useful for strength and conditioning coaches and practitioners, due to the use of approachable and low-cost methods (My jump 2 and My Sprint) for monitoring and assessing athletes. Moreover, the use of some other validated low-cost software can also be useful for the design of training plans (Jiménez-Olmedo, Penichet-Tomás, & Villalón-Gasch, 2021). Future studies may observe the association between sprinting and jumping performance on different levels of practice or even position within netball players, as it has been observed in other disciplines (Escobar Álvarez, Reyes, Pérez Sousa, Conceição, & Fuentes García, 2020). Also, it would be interesting to observe the effect of individualized training (based on the reduction of the actual $F\text{-}V_{IMB}$) on ballistic performance (jumping, sprinting and COD).

CONCLUSIONS

This study provides a reference about the FVP profile during CMJ, suggesting that amateurs netball players have force deficit and individualized training based on F-V profiling may be beneficial to enhance jumping ability. The moderate correlations found for performance, V_0 and P_{max} suggest that the improvement in one of the skills (jumping or sprinting) may produce some positive adaptation to the other. However, we recommend that netball players train specifically ballistic actions in the vertical (jumping) and horizontal direction (sprinting) due to the specificity of both skills and that no association was found in the force production (F_0).

AUTHOR CONTRIBUTIONS

Conceived and designed the experiments: JE, JPFG, FC, PJR. Performed experiments: JE. Analysed data: JE, JPFG, FC, PJR. Interpreted results of research: JE, JPFG, FC, PJR. Drafted manuscript and prepared tables/figures: JE, PJR. Edited, critically revised paper, and approved the final version of manuscript: JE, JPFG, FC, PJR.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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