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POWER TRAINING: SPECIFICITY OF THE EXERCISE MODE IN PERFORMANCE TRANSFER, EXTERNAL LOAD CONTROL AND USE OF THE STRETCH-SHORTENING CYCLE

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POWER TRAINING: SPECIFICITY OF THE EXERCISE MODE IN PERFORMANCE TRANSFER, EXTERNAL LOAD CONTROL AND USE OF THE STRETCH-SHORTENING CYCLE

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O presente trabalho em nível de doutorado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Este trabalho é dedicado aos meus queridos pais e minha família.

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RESUMO

Esta tese foi dividida em quatro estudos, os quais tiveram como objetivos: a) investigar o efeito de modelos específicos de treinamento de *sprint* e salto vertical sobre parâmetros de velocidade-potência e transferência de treinamento; b) analisar a validade e reprodutibilidade de um transdutor de posição linear (enconder *Ergonauta*) para avaliar o desempenho do salto vertical; c) analisar a carga ótima para potência (0, 10, 20, 30, 40 e 50% da massa corporal) no *squat jump* (SJ) e no *countermovement jump* (CMJ) e investigar a associação entre o perfil força-velocidade (indivíduos equilibrados ou desequilibrados) e a condição ótima de carga externa (com carga ou sem carga); d) comparar diferentes métodos para avaliação da utilização do ciclo alongamento-encurtamento (CAE) em atletas de diferentes esportes. Para o primeiro objetivo (estudo 1) foi realizado um estudo de revisão sistemática, seguindo as recomendações do PRISMA. Para testar a validade e reprodutibilidade do encoder (estudo 2) na avaliação do CMJ foram avaliados 23 participantes, no qual foram analisadas as medidas de altura do salto e velocidade média propulsiva, obtidas pelo encoder e por uma plataforma de força. No estudo 3 participaram 22 homens praticantes de diferentes esportes que realizaram o SJ e CMJ com diferentes cargas (0 a 50% da massa corporal) para avaliar a carga ótima. Além disso, foi calculado o perfil força-velocidade (perfil F-v). Para atender ao último objetivo (estudo 4) foram avaliados 341 atletas (esportes de combate, esportes coletivos, corredores velocistas), aplicados os testes CMJ e SJ para identificar a utilização do CAE usando três métodos: índice de força reativa (IFR), porcentagem de pré-alongamento (PA) e taxa de utilização excêntrica (TUE). Análises estatísticas utilizadas nos estudos foram: estudo 2 – ANOVA para medidas repetidas usada para comparar as métricas do CMJ e SJ (pico de potência, altura e velocidade propulsiva média – VPM) entre diferentes condições de carga externa e teste Kappa para testar o nível de concordância entre zona de carga de potência ótima e os grupos do perfil F-v; estudo 3: coeficiente de correlação intraclasse (CCI) para testar a reprodutibilidade entre medidas e Bland-Altman para verificar concordância entre medidas (encoder e plataforma de força); estudo 4: ANOVA *one way* foi usada para comparar utilização do CAE em diferentes esportes. Em todos os testes foi considerado valor de $p<0,05$. Os resultados do estudo 1 indicaram que os treinamentos de salto vertical e sprint induziram melhorias específicas, bem como a transferência do treinamento para o desempenho de velocidade e potência, com maiores efeitos específicos e de transferência de treinamento para o treinamento com salto vertical. Em relação encoder *Ergonauta*, os resultados mostraram excelente reprodutibilidade para ambas as métricas (altura do salto e VMP), considerando os dois instrumentos de avaliação. Além disso, a altura do salto e a VMP, obtidas pelo *Ergonauta* e plataforma de força, foram fortemente correlacionadas. O gráfico de Bland-Altman mostrou boa concordância para ambas às métricas. No estudo 3, de forma geral, houve uma diminuição do desempenho em todas as métricas (altura do salto, potência e VPM) no CMJ e SJ em cargas mais altas (melhor desempenho sem carga – somente a massa corporal). Não foi encontrada concordância significativa entre o perfil F-v e as métricas do CMJ e SJ. O último estudo demonstrou correlações muito grandes entre os métodos para altura do salto e potência, concordância quase perfeita para altura do salto e para potência. Os resultados indicaram que a utilização do CAE é maior em esportes coletivos do que esportes de combate. A partir da revisão sistemática conclui-se que as intervenções de treinamento de salto vertical e sprint são eficazes no aumento de ações específicas; no entanto, o treinamento de salto vertical produz maiores efeitos específicos e de transferência de treinamento para o sprint linear do que o treinamento de *sprint*. Em relação ao encoder *Ergonauta*, conclui-se que o equipamento é reprodutível e válido para medir as variáveis de desempenho do CMJ (altura do salto e VPM). No estudo 3, conclui-se que o desempenho no CMJ e SJ é maior na condição de 0% de carga externa, e o perfil F-v não está relacionado com a carga externa ótima no CMJ e SJ. E por fim, no estudo 4 conclui-se que os diferentes métodos para calcular o CAE são fortemente correlacionados e apresentam excelente concordância entre eles considerando a altura do salto e a potência produzida.

Palavras-chave: Potência muscular; Salto vertical; Carga ótima; Ciclo-alongamento-encurtamento.

ABSTRACT

This thesis was divided into four studies, which aimed to: a) investigate the effect of specific sprint and vertical jump training models on velocity-power parameters and training transfer; b) analyze the validity and reliability of a linear position transducer (Ergonauta encoder) to evaluate the vertical jump performance; c) analyze the optimum load for power (0, 10, 20, 30, 40 and 50% of body mass) in the squat jump (SJ) and countermovement jump (CMJ) and investigate the association between the force-velocity profile (individuals balanced or unbalanced) and the optimal external load condition (loaded or unloaded); d) compare different methods for evaluating the use of the stretch-shortening cycle (SSC) in athletes from different sports. For the first objective, a systematic review study was carried out, following the PRISMA recommendations. To test the validity and reliability of the encoder (study 3) in the evaluation of the countermovement jump (CMJ), 23 participants were evaluated, in which the measures of jump height and mean propulsive velocity (VPM), obtained by the encoder and by a force platform, were analyzed. In the study 3, 22 men practicing different sports participated in the SJ and CMJ with different loads (0 to 50% of body mass) to evaluate the optimal load, in addition, the strength-velocity profile (F-v profile) was calculated. In the study 4, 341 athletes (combat sports, team sports, sprinters) were evaluated, applying the CMJ and SJ tests to identify the use of the SSC using three methods: reactive strength index (RSI), pre-stretch augmentation percentage (PSA), and eccentric utilization ratio (EUR). Statistical analyzes used in the studies: Study 2: Intraclass correlation coefficient (ICC) to test the reliability between measurements and Bland-Altman to verify agreement between measurements (encoder and force platform); study 3 - repeated measures ANOVA used to compare CMJ and SJ metrics (peak power, height, and VPM) between different external load conditions, and Kappa test was used to test the agreement between optimal power load zone and F-v profile groups; Study 4: One way ANOVA was used to compare CAE use in different sports. In all tests, the level of significance was set at $p<0.05$. Study 1 results indicated that vertical jump and sprint training induced specific improvements as well as transfer from training to velocity and power performance, with greater specific and transfer effects from training to vertical jump training. Regarding the Ergonauta encoder (study 2), the results show excellent reliability for both metrics (jump height and VMP) considering the two instruments. In addition, the jump height and the VMP, obtained from Ergonauta and force platform, were strongly correlated. The Bland-Altman plot showed good agreement for both metrics. In study 3, in general, there was a decrease in the performance of metrics (jump height, power and VPM) in CMJ and SJ at higher loads (better performance with subject' body mass). No significant agreement was found between the F-v profile and the CMJ and SJ metrics. The study 4 demonstrated very large correlations between methods for jump height and power, almost perfect agreement for jump height and output power. The results indicated that the use of SSC is greater in team sports than combat sports. From the systematic review (study 1), it is concluded that the vertical jump and sprint training are effective in increasing specific actions; however, vertical jump training produces greater transfer training effects for linear sprint than sprint training. Regarding the study 2, it is concluded that the Ergonauta equipment is reliable and valid for measuring the CMJ performance variables (jump height and VPM). In the study 3, it is concluded that the performance in CMJ and SJ is higher in the condition of 0% external load (body mass), and the F-v profile is not related to the optimal external load in CMJ and SJ. Finally, it is concluded that the different methods to calculate the SSC are strongly correlated and show excellent agreement between them considering the jump height and power output (study 4).

Keywords: muscle power; vertical jump; optimal load; stretch-shortening cycle.

RESUMO EXPANDIDO

Introdução

Em grande parte dos esportes a potência muscular é essencial para a execução de diversas ações motoras, as quais estão envolvidas em atividades técnicas e locomotoras específicas do esporte, como saltos e *sprints* com ou sem mudança de direção e acelerações, as quais estão diretamente relacionadas ao desempenho esportivo. A identificação da carga ótima ou ideal para treinamento de potência é considerada um aspecto importante para a preparação física de atletas, no entanto, a carga ideal para ser utilizada em treinamentos permanece ambíguo. Outro aspecto importante no treinamento de potência é investigar se ganhos específicos a partir de um modelo de treino, por exemplo com saltos verticais pode ser transferidos para habilidades de velocidade de sprint e vice-versa. Além disso, o uso de transdutor de posição linear (TPL) pode ser uma ferramenta mais prática para avaliar as variáveis de desempenho do salto vertical, pois é portátil e não precisa ser conectado a uma corrente elétrica. No entanto, não foram encontrados estudos anteriores testando a validade e confiabilidade de medidas como velocidade média propulsiva durante o salto vertical. Nos treinamentos envolvendo saltos verticais ou sprints, apresenta-se um fenômeno denominado ciclo alongamento-encurtamento (CAE), Para avaliar a habilidade de usar o SSC, existem vários métodos indiretos, a maioria dos quais envolve cálculos baseados no desempenho no countermovement jump (CMJ) e squat jump (SJ), entretanto, treinamentos específicos podem induzir a diferentes adaptações musculoesqueléticas de acordo com as exigências do CAE.

Objetivos

A tese foi dividida em quatro estudos, os quais tiveram os seguintes objetivos: a) Investigar, por meio de uma revisão sistemática, o efeito de modelos específicos de treinamento de sprint e salto vertical nos parâmetros velocidade-potência; b) Investigar a validade e confiabilidade de um transdutor de posição linear (codificador) para avaliar o desempenho do salto vertical; c) Analisar a carga externa ótima (0, 10, 20, 30, 40 e 50% da massa corporal) para produção de potência em protocolos de saltos verticais e verificar sua associação com o perfil força-velocidade; d) Comparar diferentes métodos para avaliar o ciclo alongamento-encurtamento obtido a partir dos protocolos Squat Jump e Countermovement Jump em atletas de diferentes modalidades.

Método

Para o primeiro objetivo (estudo 1) foi realizado um estudo de revisão sistemática, seguindo as recomendações do PRISMA. Foram utilizados os seguintes termos para as buscas: “plyometric training,” “sprint training,” “jump,” “vertical jump,” “jump height,” “speed,” “velocity,” and “sprint time”. Foram analisadas as mudanças percentuais entre pré e pós-treinamento e o efeito de transferência de treinamento. Para testar a validade e reprodutibilidade do encoder (estudo 2) na avaliação do CMJ foram avaliados 23 participantes, no qual foram analisadas as medidas de altura do salto e velocidade média propulsiva (VMP), obtidas pelo encoder e por uma plataforma de força durante a realização do CMJ. No estudo 3 participaram 22 homens praticantes de diferentes esportes que realizaram o SJ e CMJ com diferentes cargas (0 a 50% da massa corporal) para avaliar a carga ótima. Além disso, foi calculado o perfil força-velocidade (perfil F-v) e analisada a concordância entre zona de carga de potência ótima e os grupos do perfil F-v Para atender ao último objetivo (estudo 4) foram avaliados 341 atletas (esportes de combate, esportes coletivos, corredores velocistas), aplicados os testes CMJ e SJ para identificar a utilização do

CAE usando três métodos: índice de força reativa (IFR), porcentagem de pré-alongamento (PA) e taxa de utilização excêntrica (TUE).

Resultados e discussão

Os resultados do estudo 1 indicaram que os treinamentos de salto vertical e sprint induziram melhorias específicas, bem como ocorre a transferência do treinamento para o desempenho de velocidade e potência, entretanto, os maiores efeitos específicos e de transferência de treinamento ocorrem para o treinamento com salto vertical quando comparado ao treinamento de *sprint*. Em relação encoder Ergonauta, os resultados mostraram excelente reprodutibilidade para ambas as métricas altura do salto e VMP (ICC = 0,99 e 0,99; erro técnico = 1,02 e 2,14; respectivamente), considerando os dois instrumentos de avaliação. Além disso, a altura do salto e a VMP, obtidas pelo Ergonauta e plataforma de força, foram fortemente correlacionadas (altura r = 0,95; VMP r = 0,90). O gráfico de Bland-Altman mostrou boa concordância para ambas às métricas. No estudo 3, de forma geral, houve uma diminuição do desempenho em todas as métricas (altura do salto, potência e VPM) no CMJ e SJ em cargas mais altas (melhor desempenho sem carga – somente a massa corporal). Não foi encontrada concordância significativa entre o perfil F-v e as métricas do CMJ e SJ. O último estudo demonstrou correlações muito grandes entre os métodos, para altura do salto, TUE foi relacionada com PA ($r=0,98$; $p<0,01$) e IFR ($r=0,97$; $p<0,01$), e PA foi relacionado com IFR ($r=0,98$; $p<0,01$). Para a potência, a TUE foi relacionada com PA ($r=0,98$; $p<0,01$) e IFR ($r=0,96$; $p<0,01$), e o PA foi relacionado com IFR ($r=0,95$; $p<0,01$). Os resultados indicaram que a utilização do CAE é maior em esportes coletivos do que esportes de combate.

Considerações finais

A partir da revisão sistemática conclui-se que as intervenções de treinamento de salto vertical e sprint são eficazes no aumento de ações específicas; no entanto, o treinamento de salto vertical produz maiores efeitos específicos e de transferência de treinamento para o sprint linear do que o treinamento de sprint. Em relação ao encoder Ergonauta, o mesmo é confiável e válido para medir as variáveis de desempenho do CMJ (altura do salto e velocidade média propulsiva). Assim, o Ergonauta pode ser usado para avaliar e monitorar mudanças no desempenho do CMJ ao longo do tempo; no entanto, deve-se ter cuidado ao comparar as métricas com outros dispositivos de medição. No estudo 3, conclui-se que a carga de potência ideal para CMJ e SJ estava em 0% da massa corporal, (ou seja, condição descarregada), considerando a potência de pico e a potência média como variáveis de resultado. A VMP relacionada à zona de carga de potência ideal foi, em média, 1,61 m/s e diferiu entre CMJ e SJ. O perfil F-v (indivíduo equilibrado ou desequilibrado) parece não influenciar a zona ótima de produção de potência no CMJ e SJ. E por fim, no estudo 4, conclui-se que os diferentes métodos de cálculo do CAE (baseados nas diferenças entre os desempenhos do CMJ e do SJ) são fortemente correlacionados e apresentam excelente concordância entre eles considerando a altura do salto e a potência produzida. Atletas de esportes coletivos apresentaram maiores valores de CAE em comparação aos esportes de combate, independentemente do método, principalmente quando a altura do salto é usada como métrica.

Palavras-chave: Potência muscular; Salto vertical; Carga ótima; Ciclo-alongamento-encurtamento.

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LIST OF ABBREVIATIONS

BM	Body mass
CMJ	Countermovement jump
CNS	Central Nervous System
D	Displacement
F	Force
ICC	Intraclass correlation coefficient
LPT	Linear position transducers
MPV	Mean propulsive velocity
MS	Milliseconds
MU	Motor unit
PP	Peak power
RM	Repetition maximum
SJ	Squat jump
SSC	Stretch-shortening cycle
T	Time
TE	Typical error
TEC	Transfer effect coefficient

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CHAPTER I

1. INTRODUCTION

In a range of different sports, muscle power is essential for the execution of several motor actions involved in sport-specific technical and locomotor activities, such as jumps and sprints, with or without change of direction and accelerations (CRONIN; SLIVET, 2005). Power can be defined as the rate at which force (F) is developed over a displacement (d), during a given period of time (t) [P = F * d / t], that is, the power is a product of force and velocity (CORMIE, MCGUIGAN; NEWTON, 2011a), and can be represented by the force-velocity relationship proposed by Hill (1938). However, force and velocity are not independent of each other in muscle actions. As the velocity of movement increases, the force that the muscle can produce decreases during concentric muscle actions. Therefore, the maximum power is reached in an intermediate level of force and velocity (SIEGEL et al., 2002).

The literature proposed different training methods to improve muscle power, such as resistance training with weights (CORMIE; MCGUIGAN; NEWTON, 2010; SARABIA et al., 2017), training with vertical jumps (VÁCZI et al., 2013 ; RAMÍREZ-CAMPILLO et al., 2014) and with sprint (MARKOVIC et al., 2007; BACHERO-MENA; GONZÁLEZ-BADILLO, 2014). In addition, combined methods have also been used, in which power training with jumps or sprints is performed along with strength training (KOBAL et al., 2017). Despite the range of training focused on power, there is no consensus on which method is more effective to improve this physical capacity.

An important factor in the context of power training is the principle of training specificity, as the different training models have characteristics based on sport, such as, the application of force, which can be oriented vertically or horizontally, and needs to be developed through training stimuli that have the same characteristic (SALAJ; MARKOVIC, 2011; MORAN et al. 2021). However, several studies (LOTURCO et al., 2015b; MARKOVIC et al., 2007; RAMIREZ-CAMPILLO et al., 2020a; BACHERO-MENA; GONZÁLEZ-BADILLO, 2014) suggest an improvement in power levels from non-specific power training. For example, vertical jumps and sprints are widely used to develop the velocity and power capacity of athletes; however, the literature lacks information about which model of sprint or vertical jump training could have a greater effect of transferring to another task not trained specifically. In the sporting context, this aspect deserves attention, since the performance of an exercise that presents a greater training transfer could achieve the greatest performance gains for a smaller effort overload (YOUNG, 2006). Therefore, it would be important to investigate whether specific vertical jump gains can be transferred to sprint speed abilities and vice versa. For this, a systematic review is required to synthesize the existing findings in order to help coaches, athletes and practitioners.

Due to their feasibility, the squat jump (SJ) and countermovement jump (CMJ) exercises are widely used by strength and conditioning coaches in power training and assessment programs. The specificity of the mechanical characteristics of these tasks (e.g., the presence of a negative phase and elastic energy in the CMJ) may lead to different strategies for maximizing jump performance, resulting in different power load profiles. Another important aspect is the outcome variable. While peak and mean power output, collected during the upward portion of the jump, are widely used to assess sport performance and to optimize training strategies (DAL PUPO et al., 2021), the use of a fixed velocity value, obtained at the optimum power load, has been shown to be an interesting variable (LOTURCO et al., 2015; MORENO-VILLANUEVA et al., 2022). In this sense, Loturco et al. (2015) proposed the use of mean propulsive velocity (MPV), obtained from the beginning of the concentric phase of the jump to the take-off, as a parameter to control the intensity of vertical jump training protocols.

The literature has presented different methods for obtaining the variables related the vertical jump, as the derivation of the ground reaction force obtained by force platforms (DAL PUPO et al., 2012; GIROUX et al., 2015), considered the "gold standard" (GLATTHORN et al., 2011), however, other lower cost methods have been used, as the linear position transducer (LPT) (GIROUX et al., 2015; LOTURCO et al., 2015a). The MPV may be easily assessed by linear position transducers (encoders) or accelerometers to determine the optimum load at a low cost and reduced time spent assessing the power. Moreover, the use of a LPT can be a more practical tool to assess vertical jump performance variables, as it is portable and does not need to be connected to an electrical current. However, no previous studies were found testing the validity and reliability of MPV during the vertical jump.

One of the most discussed aspects in the power training is the load used, since it directly influences both components (i.e. force and velocity) and is strongly related to the training intensity. The use of external load during the vertical jump is supported by the inverse association between force (external load) and velocity (HILL, 1938). In this perspective, the search for the ideal or optimal load for the development of muscle power has been widely studied in recent years, mainly in team sports, using different analysis methods, exercises and proposals to obtain maximal power (LOTURCO et al., 2015a; MORIN; SAMOZINO, 2016).

The identification of the optimal or ideal training load is considered an important aspect for the physical preparation of athletes. However, the identification of the ideal load to be used in training has been contradictory. The literature points out optimal load values below body mass (negative external loads) during CMJ (MARKOVIC et al., 2011; VUK et al., 2012) up to positive external loads of 60% of 1RM (SMILIOS et al., 2013) and 100% of body mass (LOTURCO et al, 2015a) in jump squat exercise. Therefore, obtaining the optimal load to train power seems to be dependent on the type of exercise performed and method used to obtain power (BAKER et al., 2001; DUGAN et al., 2004; LOTURCO et al., 2015a). In general, studies have described a decrease in peak power as the external load increases (TURNER et al., 2012; SMILIOS et al., 2013; MUNDY et al., 2017; LAKE et al., 2021).

In this sense, Samozino et al. (2014) have sought to improve the effectiveness of the power training prescription, adapting it to individual needs. For this, they proposed the existence of an optimal force-velocity (F-v) profile of each individual that would maximize performance in activities, such as vertical jump. This optimal F-v profile represents the balance between force and velocity, according to the slope of the force-velocity curve. The relative difference between actual and optimal F-v profiles represents the magnitude and the direction of the unfavorable balance between force and velocity qualities (i.e. the force-velocity imbalance, in %), which allows individual determination of force or velocity deficit. The actual F-v profile can be determined from a series of loaded vertical jumps, while the optimal F-v profile can be computed using Samozino's equations (SAMOZINO et al., 2014; MORIN; SAMOZINO, 2016). Therefore, athletes who present a force deficit should prioritize the increase in force capabilities, involving the use of overload in the jump training; contrastingly, for athletes who present a velocity deficit, training should focus by improving maximal velocity capability, using low loads or negative loads (SAMOZINO et al., 2012). According to Morin et al. (2019), an athlete who has an optimal F-v profile will have his own body mass as optimal load and, thus, will produce maximum power during a vertical jump without additional load. However, this does not always occur and may be associated with an imbalance in the force-velocity curve. However, no studies were found investigating the association between Samozino's method (F-v profile) and the optimal load for power production.

In training involving vertical jumps or sprints, a phenomenon called the stretching-shortening cycle (SSC) is presented, which is a type of muscle action capable of optimizing power production (KOMI, 2000; MARKOVIC et al., 2007). During any activity involving the SSC, elastic energy is stored during the eccentric contraction and used during the following concentric contraction, being the main mechanism responsible for increasing performance in this type of activity (BOSCO; KOMI, 1979).

To assess the ability to use the SSC, there are several indirect methods, most of which involve calculations based on the performance in the CMJ and SJ (SUCHOMEL et al., 2016). Among these methods are the reactive force index (CMJ variable - SJ variable) (YOUNG, 1995); pre-stretching increase percentage ([CMJ variable - SJ variable] / [SJ variable] * 100) (WALSHE et al., 1996); and the eccentric utilization rate (CMJ variable / SJ variable) (MCGUIGAN et al., 2006). These methods present different calculations regarding performance between CMJ and SJ using measures of jump height and power output (SUCHOMEL et al., 2016).

The SSC manifests under different motor actions, but due to the specific characteristics of each sport, the demands and adaptations of the SSC can be different. Some studies (MCGUIGAN et al., 2006; GROSPRÊTRE; LEPERS, 2016) observed different adaptations regarding the use of SSC in athletes from different sports (soccer, rugby, field hockey, track and field, parkour). McGuigan et al. (2006) observed that athletes from team sports (e.g. soccer, rugby, and Australian football) seem to make better use of elastic energy during vertical jump actions. In other study, it was found that Parkour practitioners have a higher elastic energy index when compared to gymnasts (GROSPRÊTRE; LEPERS, 2016). These studies demonstrate that the specificity of training can induce different musculotendinous adaptations, which are reflections of greater dependence on SSC activities in some sports. However, it is necessary to investigate whether the methods of evaluating the use of the SSC respond similarly in different sports involving the SSC.

Considering the topics addressed, the current thesis proposed some research questions: What is the influence of the specificity of exercise (sprint vs. vertical jump on the training transfer capacity for speed-power parameters? Is the linear position transducer valid and reliable for assessing vertical jump performance variables? What is the optimal external load for power production in SJ and CMJ protocols? Is there an association between the force-velocity profile (balanced or unbalanced individuals) and the optimal external load? Is there consistency and agreement between different methods of assessing SSC in different sports? Therefore, we proposed to: a) identify the ability to transfer performance through different types of power training (vertical jump vs. sprint); b) investigate methods to assess muscle power, as well as the external loads that generate greater power production (optimum load); and finally, to identify whether different methods of evaluating the SSC show consistency and agreement in athletes from different sports.

2. OBJECTIVES

2.1 Study 1

General Objective

To investigate, through a systematic review, the effect of specific sprint and vertical jump training models on speed-power parameters.

Specific objectives

- To identify the training transfer coefficient in power-velocity parameters after vertical jump and sprint training.
- To describe percentage changes in power-velocity parameters after vertical jump and sprint training.

2.2 Study 2

General Objective

To investigate the validity and reliability of a linear position transducer (encoder) for assess vertical jump performance.

Specific objective

- To test the reliability and criterion validity of a linear position transducer to assess countermovement jump height and mean propulsive velocity.

2.3 Study 3

General Objective

To analyzed the optimal external load (0, 10, 20, 30, 40 and 50% of body mass) for power production in vertical jumps protocols and verify its association with force-velocity profile.

Specific objectives

- To test the optimal external load (0 – 50% of body mass) in the squat jump and countermovement jump protocols on the peak and mean power, jump height and mean propulsive velocity.
- To test the association between force-velocity profile (balanced or unbalanced individuals) and optimal external load condition (loaded or unloaded).

2.4 Study 4

General Objective

To compare different methods to assess the stretching-shortening cycle obtained from the squat jump and countermovement jump protocols in athletes from different sports.

Specific objectives

- To test the consistency and agreement of different methods to assess the stretching-shortening cycle.
- To compare the methods to assess the stretching-shortening cycle among athletes from different sports (team sports, individual sports and combat sports).

3. HYPOTHESES

3.1 Study 1

H1: The vertical jump training will have a higher training transfer coefficient when compared to sprint training.

H2: Percentage changes in power and speed parameters after vertical jump training will be greater when compared to sprint training.

3.2 Study 2

H1: The linear position transducer will present high reliability and validity to assess jump height and mean propulsive velocity.

3.3 Study 3

H1: The participants will perform better in the condition of 0% load (i.e. body mass).

H2: There will be an influence of the force-velocity profile on the optimal power production.

3.4 Study 4

H1: The different methods used to evaluate the stretching-shortening cycle will show consistency and agreement.

H2: Athletes in sports modalities that require greater demand from the stretching-shortening cycle (e.g. running and team sports) will have higher indexes compared to sports that demand less use of the stretching-shortening cycle (e.g. combat sports).

CHAPTER II

4. LITERATURE REVIEW

4.1. Training organization and planning

The search for better results in sports is constant and physical performance is a crucial aspect to achieve higher levels of sports performance, whether by an athlete or a team. However, the way to achieve the desired results requires a lot of effort and dedication on the part of the athletes and training planning according to the objectives and target competitions.

In order for the long, medium and short term objectives to be achieved, the organization of training must take into account the structuring, execution, control and evaluation. In general, the principles of physical training were initially based on the previous experience of successful coaches, however, in the XX century, a more scientific approach began to understand the mechanisms and adaptations caused by training (MATVEEV, 1997). In this sense, periodization emerged as a way to assist coaches in planning, including training cycles (macrocycle, mesocycle and microcycle) (MATVEEV, 1997). Since then, periodization has become an important and indispensable tool in the training process. A key feature of traditional periodization is the initial emphasis on high training volume and a transition to higher training intensity with reduced volume as competition periods approach.

Over the years, many alternative models to traditional (linear) periodization have emerged, such as undulatory periodization, block periodization, and reverse periodization, among others (ISSURIN, 2010). However, competitive schedules currently pose great challenges to coaches and athletes, as it is necessary to plan training so that physiological and neuromuscular adaptations reach peak performance at the desired moments of the competitive season. Nevertheless, team sports athletes generally must consistently deliver high levels of performance over several months (macrocycle) for competitions in league format, but also for major competitions in the format of regional, national and international tournaments (ISSURIN, 2010). In this way, the classic models of periodization are not considered adequate for the modern reality, since the competitive calendars present a high volume of competitions.

With the recent development of new areas in sports science there is a need for an integrated and multifactorial approach to periodization, which takes into account different aspects, such as training loads, recovery, nutrition, psychological dimensions, among others (MUJIKA et al. al., 2018). These new approaches became more relevant mainly after changes occurred in several sports, which includes changes in game rules as well as in competitive calendars.

4.2 Stretch-shortening cycle

An important neuromuscular factor in the generation of muscle power during various motor tasks is the stretch-shortening cycle (SSC). Athletes' ability to effectively use the stretch-shortening cycle is an important aspect of performance in many sports, as this mechanism serves to increase the mechanical efficiency of movement and improve performance in activities that require muscle power and strength (MCGUIGAN et al., 2006). In addition, the SSC is a component that is involved in many daily activities, such as running, jumping and throwing (KUBO et al., 1999).

The SSC has been defined as a natural muscle action consisting of a combination of eccentric and concentric muscle actions, in which muscle elongation or eccentric contraction initially occurs; in this phase of the movement, the stretching reflexes and the elastic elements are activated, obtaining an elastic energy storage that will potentiate the subsequent concentric action (KOMI, 2000).

However, one aspect that deserves attention for SSC to occur is the duration of the transition from eccentric action to concentric action. Because, if the passage from one phase (eccentric) to another (concentric) is slow, the elastic potential energy will be dissipated in the form of heat, not being converted into kinetic energy (CAVAGNA, 1977; GOUBEL, 1997). A factor that could explain the loss of elastic energy, due to the delay in the transition from eccentric to concentric action, would be as a result of the disconnection and reconnection of the cross bridges, since, after reconnection, the myofilaments would be less elongated (CAVAGNA, 1977).

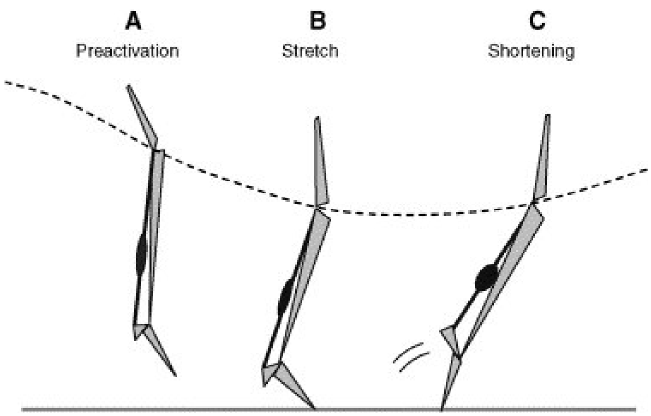


Figure 1: Occurrence of stretch-shortening cycle. A) pre-activation; B) muscle stretching or eccentric action; C) muscle shortening or concentric action. Source: Komi, 2006.

Several mechanisms have been proposed to explain the SSC; according to Enoka (2000) the capacity to use the stored elastic energy is influenced by three factors: the duration of the SSC, the joint amplitude during the displacement and the velocity of the displacement. For Komi and Gollhofer (1997), the possible mechanisms involved in the potentiation of the SSC require some fundamental conditions, such as: muscular pre-activation before the eccentric phase, short and fast eccentric phase and immediate transition between the eccentric and concentric phases.

The SSC has been classified into fast or short and slow or long. The first is characterized by presenting short or fast ground contact time (i.e. < 250 ms) and with smaller angular displacement (knee and hip); while in the second the ground contact time is long or slow (i.e. > 250 ms) and presents a greater angular displacement (KOMI; GOLLHOFER, 1997). In movements that involve long SSC, there is a smaller contribution of elastic elements, leading to a greater dependence on the contractile properties of the muscle for the production of force during the concentric phase, while in the use of short SSC, the development of force has a greater dependence on storage of elastic energy. Relating the SSC with vertical jumps, which is the object of this thesis, the jump called drop jump (DJ) is designated for presenting a fast SSC, in addition to being characterized by pre-activation and reflex activity, whereas the countermovement jump (CMJ) is characterized by duration above 250 ms and lack of pre-activation, which are characteristics of slow SSC. The squat jump (SJ) is characterized by not presenting the occurrence of the SSC. In this type of jump only the muscles concentric action is used for performance. These types of jumps are often used in training programs involving vertical jumps.

The tendon is considered a key mechanism underpinning the SSC phenomenon because it is responsible for the storage of elastic energy due to its ability to extend (store energy) and shorten (release energy) (KUBO et al., 1999). While performing activities such as jumping and running, for example, the lower limbs demonstrate characteristics similar to a spring, which is compressed in contact with the ground and stores energy, before generating impulse and releasing energy. The magnitude of the stored elastic energy is hypothesized to be proportional to the applied force and the induced deformation (TURNER et al., 2010). In this sense, a fundamental aspect for the accumulation of elastic energy is the stiffness of the tendon, which can be defined as resistance of an object or body to a change in length (McMAHON; CHENG, 1990). Because high levels of stiffness in the tendon are related to the accumulation of elastic energy and performance in the vertical jump (BRUGHELLI; CRONIN, 2008).

An estimate of the contribution of elastic energy on physical performance can be obtained by measuring the height that the individual can jump in two types of vertical jump. In this sense, Komi and Bosco (1978) tested the efficiency of the SSC by comparing the performance obtained in vertical jumps, countermovement jump (CMJ), and squat jump (SJ). In the SJ, the individual starts from a static position of knee flexion ~90° using only concentric muscle action to perform the jump, and the accumulated elastic potential energy is lost in the form of heat due to the maintenance of the assumed static position. In the CMJ, however, a countermovement (eccentric action followed by concentric action) is performed as quickly as possible and the SSC can be used to produce a greater force and power generation.

Currently, there are several methods to indirectly assess the ability to use the SSC, most of which involve calculations based on performance in the CMJ and SJ (SUCHOMEL et al., 2016). Among these methods are the reactive force index using the equation (CMJ variable - SJ variable) (YOUNG, 1995); pre-stretching increase percentage which uses the following calculation ([CMJ variable – SJ variable] / [SJ variable] * 100) (WALSHE et al., 1996); and the eccentric utilization rate, calculated from the jump performance rate (CMJ variable / SJ variable) (MCGUIGAN et al., 2006). These methods present different calculations regarding performance between CMJ and SJ, using measures of jump height and power (SUCHOMEL et al., 2016);

however, there is no consensus in the literature about which method is more effective for determining SSC usability.

As previously mentioned, in several motor actions performed in the sports there is the occurrence of SSC. However, due to the specific characteristics of each modality, the demands and adaptations of SSC can be different. Some studies (MCGUIGAN et al., 2006; GROSPRÊTRE; LEPERS, 2016) observed differences in the use of SSC between athletes from different sports (soccer, rugby, field hockey, athletics, parkour). McGuigan et al., (2006) observed that athletes from sports such as football, rugby, and Australian football seem to have greater use of elastic energy during vertical jump actions. Parkour practitioners have a higher elastic energy index when compared to gymnasts (GROSPRÊTRE; LEPERS, 2016). Therefore, the specificity of the training can induce different musculotendinous adaptations, which are reflections of the greater dependence on stretch-shortening cycle activities in some sports.

4.3 Power Training Transfer: Vertical *vs.* horizontal

The original definition postulates that transfer of training is characterized as the extent to which a response in a trained task or situation affects the response in another untrained task or situation (YOUNG, 2006). There are three types of training transfer: positive, negative, and neutral. Positive transfer means that there is a positive effect of one type of exercise on another, that is, there is an increase in the result of a trained exercise and, in parallel, there is an improvement in another exercise that was not trained. In negative transfer there is an increase in the performance of a trained exercise and a decrease in the performance of an untrained exercise. And in neutral transfer training it does not show any effect on another exercise (BONDARCHUK, 2007).

Zatsiorsky and Kraemer (2006) propose a calculation to determine the training transfer effect coefficient (TEC). For this, the effect size of the result of the trained and of the untrained exercise must be used, following the equation below:

$$TEC = \frac{Rresult\ gain\ in\ untrained\ exercise}{Result\ gain\ in\ trained\ exercise}$$

According to the authors, the higher the index, the greater the transfer of training to the non-specific exercise, on the other hand, the lower the index, the more specific the training.

Training transfer seems to be a key issue for athletes and coaches, i.e. achieving the greatest performance gains for a given amount of work effort. In this sense, it is essential to maximize the transfer of training to other untrained physical capacities (YOUNG, 2006). According to the principle of training specificity, sport-based demands that require application of vertically or horizontally oriented force need to be addressed through training stimuli that have these same characteristics. However, several studies (BACHERO-MENA; GONZÁLEZ-BADILLO, 2014; MARKOVIC, 2007; LOTURCO et al., 2015) have suggested improvement in muscle power levels from non-specific training.

Training involving sprints and vertical jumps are widely used to develop skills involving speed and power (MARKOVIC et al., 2007), which are important to determine performance in a variety of sports. During the performance of both exercise modes, the stretching and impact forces result in the storage of elastic energy during the eccentric action, allowing the increase in power during the following concentric contraction, that is, the stretch-shortening cycle (SSC) occurs (KOMI, 2000). Although both exercise modes employ SSC, there are important biomechanical differences between vertical jump and sprint. During the vertical jump, the ground reaction force is more pronounced vertically to accelerate the individual's center of gravity, causing an impulse to overcome the action of gravity, while in the sprint action the body mass must be accelerated horizontally. Therefore, there is less vertical displacement and greater horizontal ground reaction force, with smaller mechanical restriction to movement compared to the load represented by body weight during a vertical jump (SAMOZINO et al., 2014).

It is generally accepted that the more specific an exercise training is for a competitive movement or physical capacity, the greater will be the training transfer effect on performance (DELECLUSE et al., 1995). For example, sprinters, who need force to move in a horizontal plane, practice exercises that focus more on this plane, while athletes such as high jumpers and volleyball players, who need force to move in a vertical direction, train using drills vertical jump. Although athletes and coaches involved in sprint training also use plyometric exercises, as well as exercises in the horizontal plane for volleyball athletes, for example, there is little data describing the transfer of the effects of these training models (RIMMER; SLEIVERT, 2000).

According to Issurin (2010), two important characteristics of the training transfer are of particular interest: a) the transfer of technical skills is more restricted than the transfer of motor skills; b) low and medium level athletes are more sensitive to any type of training stimulus, including non-specific ones, while the transfer of training between high performance athletes is strongly restricted by the specificity of auxiliary exercises.

However, studies have shown that training models using vertical jumps or sprints can transfer training to another physical capacity even in highly trained individuals. Loturco et al. (2015) investigated the effect of training with horizontal jumps vs. vertical on sprint and vertical jump performance in high-level soccer players. The authors observed that training with vertical jumps showed a greater magnitude of improvement in vertical jump performance and 20m sprint performance. De Hoyo et al. (2016) compared the effects of vertical jump training and sprint training on vertical jump and sprint performance in elite soccer players. There was increase in CMJ performance and sprint time of 10, 20, 30 and 50m was found in both training models. However, training with vertical jumps demonstrated greater magnitudes of improvement in both CMJ and sprint performance. These studies demonstrate that a positive transfer of physical abilities can occur even in non-trained elite athletes.

4.4 Intervening factors in power production

In most sports, it is essential that athletes have a high capacity to generate muscle power. In some sports with intermittent characteristics such as volleyball, basketball, handball, soccer, among others, this physical capacity is considered a determining factor for success in sports-specific motor actions.

Power has been defined as the rate at which force (F) is developed over a displacement (d), during a given period of time (t) [$P = F * d / t$], that is, power is a product of force and velocity (CORMIE, MCGUIGAN; NEWTON, 2011b). This relationship was proven by Hill (1938), who observed that the relationship between velocity and force forms a hyperbolic curve (figure 2). According to the hyperbolic function for the force-velocity relationship observed in the isolated muscle, the ability to generate muscle force decreases as the velocity increases, just as there is a decrease in velocity with the increase in force production. Therefore, an ideal balance between both parameters corresponds to the production of maximum power (HILL, 1938).

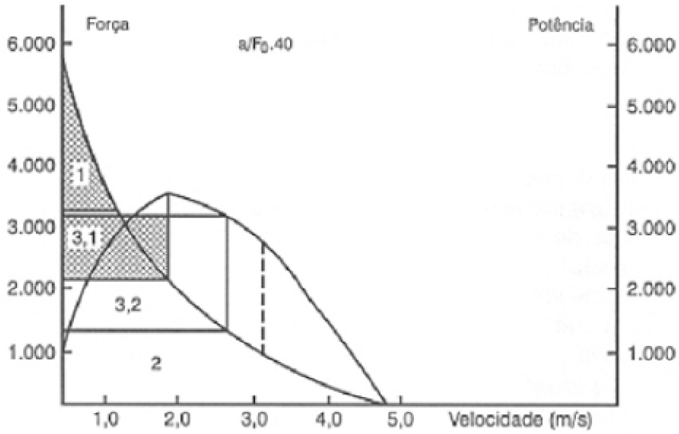


Figure 2: Hill's force-velocity curve and power. (Source: Carvalho and Carvalho, 2006).

Some neuromuscular aspects related to the ability to produce force are determinant in the production of power. In this sense, muscle force is dependent on the length of the sarcomere. The greatest force production occurs when the actin and myosin filaments are in an ideal superimposition or length written as the 'ideal length' of the muscle. In this length, the cross-bridge interaction is maximum, allowing the highest levels of active tension development (GORDON et al., 1966). However, during dynamic actions, force production can also be influenced by elastic elements, in addition to contractile ones, with a curvilinear reduction being observed in the descending phase of the force-length curve, and non-linear as seen in the production of isometric force in isolated fibers (HERZOG et al., 1988). In this way, it is expected a greater contribution of the elastic elements for the production of force in greater muscular lengths, while in smaller lengths there is a greater contribution of the contractile elements.

The muscle length can be modulated by segment placement and joint angle adjustments during motor actions. In vertical jumps, the modulation of the knee flexion level, that is, the magnitude of the jump squat alters the length of the muscles passing through the thigh. Thus, these segmental movements cause changes in the length-tension relationship and, consequently, in the generation of impulse (BOBBERT; CASIUS, 2005). Some studies observed better levels of performance in vertical jumps when they are performed from greater squat depths (KIRBY et al., 2011; GHELLER et al., 2015).

Other morphological factors can be considered important for power production, such as the composition of muscle fibers. Type II muscle fibers have a high capacity to generate strength and power, therefore, athletes who compete in sports that require velocity and/or power have a high percentage of type II fibers. In competition athletes with endurance characteristics, type I fibers predominate (PLATONOV, 2008). Bosco and Komi (1979) observed a positive relationship between percent of fast twitch fibers (type II), analyzed by means of muscle biopsy and height obtained in CMJ and SJ jumps in Physical Education students. Therefore, the type of muscle fiber can be decisive for performance in activities that require muscle power. In addition, factors related to muscle architecture influence the ability of the muscle to produce force, and therefore can influence muscle power. Among them, the cross-sectional area of the muscle, the length of the fascicle and the pennation angle of the muscle fibers (CORMIE, MCGUIGAN; NEWTON, 2011a).

The ability to generate power during a movement is not only determined by the morphology and disposition of the muscles, but also by the ability of the nervous system to adequately activate the involved muscles. The nervous system controls muscle activation primarily through changes in motor unit recruitment, firing frequency and timing, as well as intermuscular coordination. The force produced by a muscle is related to the number and type of motor units recruited. The motor units (MUs) are recruited from the principle of size and by the level of force and velocity of action (Principle of Henneman). The smaller or low-threshold MUs are initially recruited when there are smaller force demands or during submaximal actions. When there is a progressive increase in force or during the performance of faster actions, the larger MUs are activated, which innervates the fibers type IIa and IIb (ENOKA, 2000). Therefore, the gradual increase in force demands in an activity involves the progressive recruitment of the larger MUs.

In some cases, fast UMs may be preferentially recruited, not obeying Henneman's principle. This could occur, for example, in explosive movements in which the maximum speed must occur in a short space of time, as occurs in vertical jumps. In this way, only the MUs that innervate type IIb fibers could be activated. This suggests that the Central Nervous System has mechanisms that allow the activation of MUs that innervate fast fibers without the need to activate slow fibers first. In this way, this phenomenon would be associated with the increase of the muscles' electrical activation, probably due to an increase in the frequency of the nervous impulse of the motor units that innervate the fast fibers (ENOKA, 2000).

There are three theories related to the adaptation of motor unit recruitment that can occur in response to training. It is believed that training can result in increased motor unit recruitment, preferential recruitment of high-threshold motor units, and/or reduced motor unit recruitment thresholds (SALE, 2003). All these possible adaptations would occur to increase the activation of the agonist muscles, resulting in increased development of tension by the muscle and, consequently, greater power.

The role of the stretch reflex is also considered an important mechanism for optimizing muscle power. The stretch reflex is activated by muscle spindles, which are located in the muscle belly and are responsible for monitoring the degree of stretching or muscle stretching during a given task. When a certain threshold is reached, the spindle is activated causing a reflex muscle action, concentric or isometric, as a way of protecting the structure from excessive and rapid stretching, thus increasing the force or power produced (KOMI; GOLLHOFER, 1997).

4.5 Power production during the vertical jump

Improving physical performance has been a constant target of interest for professionals linked to sports, since the physical aspects enable athletes to perform in the best possible way the motor actions specific to each sport modality. Muscle power is probably one of the most important aspects related to performance in a variety of individual and team sports, such as soccer, volleyball, handball, track and field, martial arts, among others.

Studies have suggested that athletes who produce greater power during the jump without load or during the jump with external load perform better in tasks related to sports, such as when it involves the vertical jump itself (GONZALEZ-BADILLO; MARQUES, 2010; SHEPPARD et al ., 2008) or running (NIMPHIUS, MCGUIGAN; NEWTON, 2010). In this sense, to optimize tests carried out periodically, as well as the training prescription, many researchers have focused on investigating the relationship between external load and power during vertical jumps.

The use of external load during the vertical jump to investigate power production is supported by the inverse association between force (external load) and velocity, that is, as the capacity to generate force increases, there is a decrease in the velocity of contraction and vice versa (HILL, 1938). With the use of external loads, power could be maximized, as the force-velocity ratio can be adjusted to reach an ideal balance with the production of submaximal force and submaximal velocity (CORMIE, MCGUIGAN; NEWTON, 2011b), which has also been referred to as the optimum load for power production (figure 3).

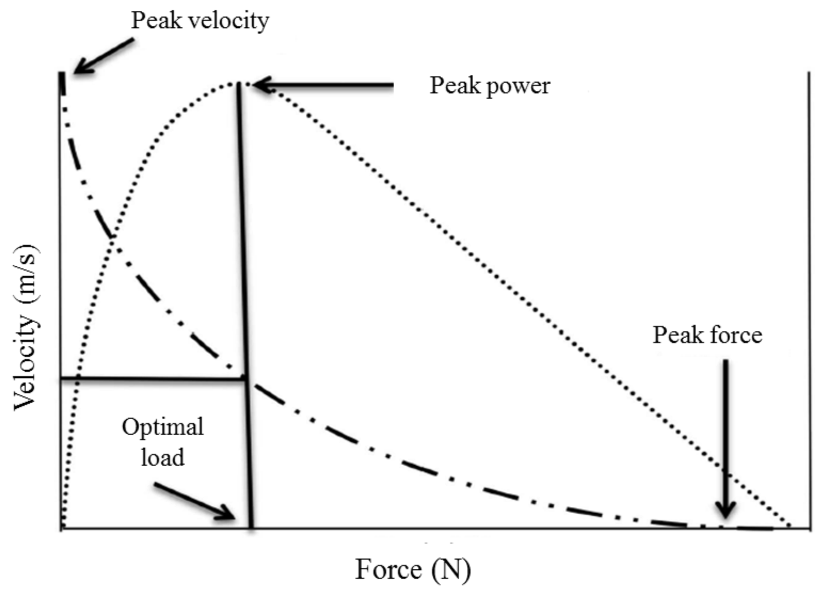


Figure 3: Force-velocity, force-power, power-velocity, and optimal load relationships (HAFF; NIMPHIUS, 2012).

The identification of the optimal or ideal training load is considered an important aspect for the physical preparation of athletes, since the training of vertical jumps with loads is an efficient method to increase the production of maximum power, as well as to improve the performance of specific motor actions of sports (CORMIE, MCGUIGAN; NEWTON, 2010). However, the ideal load to be used in vertical jumps remains ambiguous, with ideal load values being found below body mass values (negative external loads) (MARKOVIC et al., 2011; VUK et al., 2012), even loads positive external values of approximately 60% of 1RM in the squat exercise (SMILIOS et al., 2013; LAKE et al., 2021).

Vuk et al. (2012) investigated power production during CMJ with different loads, using a negative external load of 30% (0.70x body mass) to positive loads of 30% in relation to body mass (1.30x). According to the authors, there is a decrease in maximum power and average power with an increase in external load during vertical jumps, and the highest power values were found for loads below 0.7x body mass.

Mundy et al. (2017) investigated the effect of external load on CMJ power and impulse, with peak power (PP) being observed without load significantly higher than with additional loads of 25, 50, 75 and 100% of body mass. On the other hand, there were no differences in PP between load conditions of 25, 50 and 75% of MC. However, the authors observed a large intra-individual variation in the load that maximized the PP, with 12 participants reaching the PP in the no-load condition, 3 at 25% BM, 3 at 50%, 5 at 75%, and 1 at 100% BM. Bevan et al. (2010) analyzed peak power during squat jumps with loads of 0% (body mass only), 20, 30, 40, 50, and 60% of 1RM in rugby players. The results showed that peak power occurred at 0% of 1RM.

On the other hand, Loturco et al. (2015) observed that the PP obtained in the squat jump performed on the Smith machine in highly trained athletes is achieved with loads equivalent to between 69.6% and 103.4% of the subjects' body mass, depending on the sport practiced by the athletes. Turner et al. (2012) observed in rugby athletes that the PP in the squat jump is obtained with loads of 20% of 1RM, with lower values being found as the load is increased. Studies that focus on the evaluation of vertical jumps with loads report data that are somewhat inconsistent in relation to the ideal load for power production, that is, the load that maximizes power, ranging from 0% (only the subject's body mass) to high values of maximum load (% of 1RM).

Samozino et al. (2014) propose that to identify the ideal load for power training, it is necessary to determine the slope of the force-velocity curve. According to the authors, each individual has an optimal balance between force-velocity (FV), which could maximize performance in ballistic movements. Based on the slope of the actual force-velocity curve that the subject has and on the calculated optimal slope, it becomes possible to determine whether the individual has a force or velocity deficit (MORIN; SAMOZINO, 2016). Thus, an athlete with an imbalance in the FV curve related to speed must train with high loads. An athlete with an imbalance in favor of force should improve their speed through training with light loads (MCBRIDE et al., 2002; CORMIE; MCGUIGAN; NEWTON, 2010). Therefore, quantifying the imbalance of the FV ratio could improve the efficiency of power training programs, adapting them according to the individual athletes' needs (SAMOZINO et al., 2014).

CHAPTER III

5. RESULTS

The results section was divided into four parts, which correspond to the developed studies (1 to 4), according to the established objectives. The Table 1 shows the title of the articles that result from this thesis, the journal that was published or submitted, and the Qualis specification and impact factor.

Table 1. Articles developed in this thesis.

Articles title	**Journal**	**Qualis / Impact factor**
Effect of vertical jump and sprint training on power and speed performance transfer.	Motor Control (published)	A4 / 1.535
Validity and reliability of Ergonauta System to assess countermovement jump performance.	Journal of Sports Engineering and Technology (accepted)	A4 / 1.281
Optimum power-load profile in squat and countermovement jump and its association with force-velocity balance.	Sports Biomechanics (submitted)	A4 / 2.896
Methods to calculate lower-body stretch-shortening cycle utilization in the vertical jump: Which is the best for athletes of different sports?	Science & Sports (accepted)	B1 / 0.987

5.1 Study 1

EFFECT OF VERTICAL JUMP AND SPRINT TRAINING ON POWER AND SPEED PERFORMANCE TRANSFER

Published in **Motor Control**, v. 13, p. 1-29, 2022.

Abstract

The aim of this systematic review was to investigate the effect of specific sprint and vertical jump training interventions on transfer of speed–power parameters. The data search was carried out in three electronic databases (PubMed, SCOPUS, and SPORTDiscus), and 28 articles were selected (13 on vertical jump training and 15 on sprint training).We followed the PRISMA criteria for the construction of this systematic review and used the Physiotherapy Evidence Database (PEDro) scale to assess the quality of all studies. It included studies with a male population (athletes and nonathletes, n = 512) from 18 to 30 years old who performed a vertical jump or sprint training intervention. The effect size was calculated from the values of means and SDs pre and post-training intervention. The percentage changes and transfer of training effect were calculated for vertical jump training and sprint training through measures of vertical jump and sprint performance. The results indicated that both training interventions (vertical jump training and sprint training) induced improvements in vertical jump and linear sprint performance as well as transfer of training to speed–power performance. However, vertical jump training produced greater specific and training transfer effects on linear sprint than sprint training (untrained skill). It was concluded that vertical jump training and sprint training were effective in increasing specific actions of vertical jump and linear sprint performance, respectively; however, vertical jump training was shown to be a superior alternative due to the higher transfer rate.

Keywords: muscle power, stretch-shortening cycle, sports performance, running

Introduction

Sprint and vertical jumps are widely used training methods to develop speed–power abilities (MARKOVIC et al., 2007), which are important for successful performance in a range of team sports, martial arts, and track and field (DAL PUPO et al., 2021; KONS et al., 2018; LOTURCO et al., 2015; MORAN et al., 2021). In sprint and vertical jump actions, the balance between the speed and load (body mass) allows production of a high level of power output (MORIN et al., 2019), meaning that both methods (sprint and vertical jump) are commonly used in power training programs (e.g., sled sprint, drop and countermovement jumps [CMJs] protocols). The stretch and impact forces that occur during these two modes of exercise result in storage of elastic energy during the eccentric action, enabling enhancement of power during the following concentric contraction (i.e., the stretch-shortening cycle; BOSCO; KOMI, 1979; KOMI, 2000; NICOL et al., 2006).

Despite employing the same muscular action (i.e., stretch-shortening cycle), there are important biomechanical differences between vertical jump and sprints. In the first (e.g., vertical jump), the ground reaction force (GRF) is more pronounced vertically to accelerate the center of gravity of the individual, causing an impulse to overcome the action of gravity (GARCÍA-RAMOS et al., 2017; SAMOZINO et al., 2014). On the other hand, in sprint action, the body mass must be accelerated horizontally; therefore, there is lower vertical displacement and greater horizontal GRF (SAMOZINO et al., 2014).

According to the principle of training specificity, sport-based demands, which require vertically or horizontally oriented force application, segment coordination, rate of loading, and eccentric/concentric/isometric aspects, need to be addressed through training stimuli that have these same characteristics (MORAN et al., 2021; SALAJ; MARKOVIC, 2011). However, several studies (LOTURCO et al., 2015; MARKOVIC et al., 2007; BACHERO-MENA; GONZÁLEZ-BADILLO, 2014; RAMIREZ-CAMPILLO et al., 2021) have suggested improvement in muscle power levels from nonspecific training. A key aspect for athletes and coaches is efficiency of training, enabling the greatest gains in performance in different tasks to be achieved with a given amount of work effort in training. From this perspective, the concept of maximizing the transfer of training (i.e., the extent to which a response in a trained task affects the response in another untrained task; IMPELLIZZERI et al., 2008) to different performances is essential (YOUNG, 2006).

As previously mentioned, vertical jumps and sprints are widely used to develop the speed–power capacity of athletes (MORAN et al., 2021), but there have been mixed findings in the literature about the influence of exercise specificity on the power of the training methods, showing which exercise (sprint vs. vertical jump) has the greatest training transfer capability (CARLOS-VIVAS et al., 2020; DELLO IACONO et al., 2016; DE HOYO et al., 2016; RAMIREZ-CAMPILLO et al., 2021; DE VILLARREAL et al., 2008). For this, a systematic review is required to synthesize the existing findings to help practitioners. In other words, can specific vertical jump gains transfer to sprint speed abilities and vice versa? This information may be useful for coaches and strength and conditioning professionals to delineate training programs using specific (jump training to improve jump performance) or nonspecific (jump training to improve sprint performance) methods to improve speed–power capacity. The vertical jump training can be performed in a small space, showing large usability; however, it is unclear whether it can transfer gains to sports with higher horizontal force application (e.g., soccer, futsal, rugby, running, etc.). Thus, we aimed to investigate, through a systematic review, the effect of specific sprint and vertical jump training interventions on speed–power parameters considering the transfer training effects approach in a male population.

Methods

The research design, study selection, data collection, and analysis procedures were carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (MOHER et al., 2009).

Search Strategy

The PubMed, SCOPUS, and SPORTDiscus electronic databases were searched from the earliest available records up to September 22, 2021. Only articles published in the English language were considered. The terms used for the search were related to the training interventions (independent variables) and performance results of vertical jump and short sprint (dependent variables). Boolean logic using the operators "AND," "OR" was applied and used to refine the results of the searches. The following terms were used for the search: "plyometric training," "sprint training," "jump," "vertical jump,"

"jump height," "speed," "velocity," and "sprint time." For the gray literature, we used the simple Google manual search with the same words. The details of the search strategies are present in the Supplementary Material (available online). The reference lists of the articles that remained were hand searched for any further articles that met the inclusion criteria. The lists of the selected articles were also analyzed for any other potentially eligible articles.

Eligibility Criteria

The inclusion and exclusion criteria to determine the eligibility of studies for this systematic review were designed using the population, intervention, comparator, and outcome framework (PAGE et al., 2021; Table 1).

Selection Process

Two authors (Gheller and Kons) extracted the data from each article independently using a predesigned Excel spreadsheet. In cases of disagreement between the authors, a consensus meeting was held, and if necessary, a third author (Detanico) was consulted. For the study selection, Rayyan software was used. Initially, duplicate articles were identified and removed in accordance with the predefined inclusion–exclusion criteria (Table 1), based on the content of the titles and abstracts. Finally, the articles that met all inclusion criteria were read in full.

Data Extraction

The following data were identified from the studies: author; year; sample size; participant characteristics; age; training intervention characteristics (number of sessions per week, duration of training intervention, total number of training sessions, and training volume); dependent variables; and results (e.g., jump height for vertical jump performance after sprint training or time in sprint performance after vertical jump training). In cases where some information was not clearly or not completely described, the authors were contacted for elucidation. The means and SDs of the outcomes pre- and post-training intervention were extracted. For articles that did not present the means and SDs in the tables or the results section, the data were requested from the authors. If the authors did not have access to their data or did not make the data available, the required information on outcome measures was extracted from the figures using

WebPlotDigitizer (version 4.5, WebPlotDigitizer). The data were measured manually at the pixel level according to the scale provided in the study's figures.

Table Tabela 2: PICO framework for study eligibility criteria.

Category	Inclusion criteria	Exclusion criteria
Population	Male peoples (athletes or non-athletes), with an average age equal or greater than 18 years old.	Studies with rehabilitation programs or with individuals who had sustained a recent injury.
Intervention	Interventions with vertical jumps training in accordance to the following definition: "Lower body unilateral and bilateral bounds, jumps and hops that utilize a pre-stretch or countermovement that incites usage of the stretch–shortening cycle" (Ramirez-Campillo et al., 2020) and sprint training (resisted, assisted, un-resisted sprint).	Interventions carried out in water or sand, or which used additional manipulative techniques such as electrostimulation. Concurrent or combined training, plyometric training with horizontal jumps.
Comparator	The studies must have included an experimental group (vertical jumps or sprint training) and present pre- and post-intervention data.	Inappropriate study design (acute or post-activation study).
Outcome	Each study must have included at least one vertical jump performance measure (i.e. height) and one sprint measure (i.e. time or velocity) to compare specific training effect and training transfer.	Non-relevant measures of performance and physiological measures.

Data Analysis

Effect size was calculated from the values of means and SDs in the pre- and posttraining intervention. The Hopkins' criterion was used to classify the effect magnitude as follows: 0.0–0.2 = trivial, 0.21–0.6 = small, 0.61–1.2 = moderate, 1.21–2.0 = large, and 2.1–4.0 = very large (Hopkins, 2002). The percentage changes were calculated using the Hermassi et al. (2019) equation:

$$\text{Percentage changes} = \left(\frac{\text{Posttraining} - \text{Pretraining}}{\text{Pretraining}}\right) x\ 100$$

The transfer of training effect of vertical jump and sprint exercises, through measures of vertical jumps and sprint, was determined according to the equation proposed by (ZATSIORSKY; KRAEMER, 2006):

$$\text{Transfer of training effect} = \frac{\text{Result gain in untrained exercise}}{\text{Result gain in trained exercise}}$$

Transfer of training effects was calculated for variables that had an effect size of at least d = 0.2. The higher the value of the transfer of training effect, the more likely that the training exercise positively influenced the untrained performance variable. If the transfer was low, the effect of training was considered specific.

Study Risk of Bias Assessment

To assess the methodological quality of the selected studies, the Physiotherapy Evidence Database (PEDro) scale was used. This scale assesses the study in 10 domains (random allocation, concealed allocation, similarity at baseline, subject blinding, therapist blinding, assessor blinding, >85% follow-up for at least one key outcome, intention-to-treat analysis, between-group statistical comparison for at least one key outcome, and point and variability measures for at least one key outcome). Each item is scored as 1 (present) or 0 (absent), and a maximal score out of 10 is obtained by the sum of all items. For the interpretation of methodologic quality, the following scale was used: ≤3 points was considered poor quality, 4–5 points as moderate quality, and 6–10 points as high quality (STOJANOVIĆ et al., 2017), in which Item 1 was not used for the calculation of the total score.

Results

Study Selection

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram (Figure 1) shows the selection process and number of studies excluded at each stage of the systematic review. A total of 4,767 studies were initially found, and 28 (13 on vertical jump training and 15 on sprint training) were included in the systematic review. The selected studies comprised 47 intervention groups, 29 with sprint training and 18 with vertical jump training. The characteristics of the athletes (e.g., groups, sample size), training aspects (e.g., number of sets, reps), duration frequency, specific task training, measured outcomes, main findings, percentage changes, and transfer effects coefficient for sprint and vertical jump training groups are presented in Tables 2 and 3. The quality of the studies, according to the PEDro scale (Table 4), was considered as having a low risk of bias (moderate and high quality). No studies from gray literature were included in this review.

Risk of Bias in Studies

Two independent authors (Gheller and Kons) assessed each study in accordance with the PEDro scale. Agreement between reviewers was assessed using a Kappa correlation. The agreement rate between authors was k = .96. The results of the methodological quality of the selected studies are summarized in Table 4.

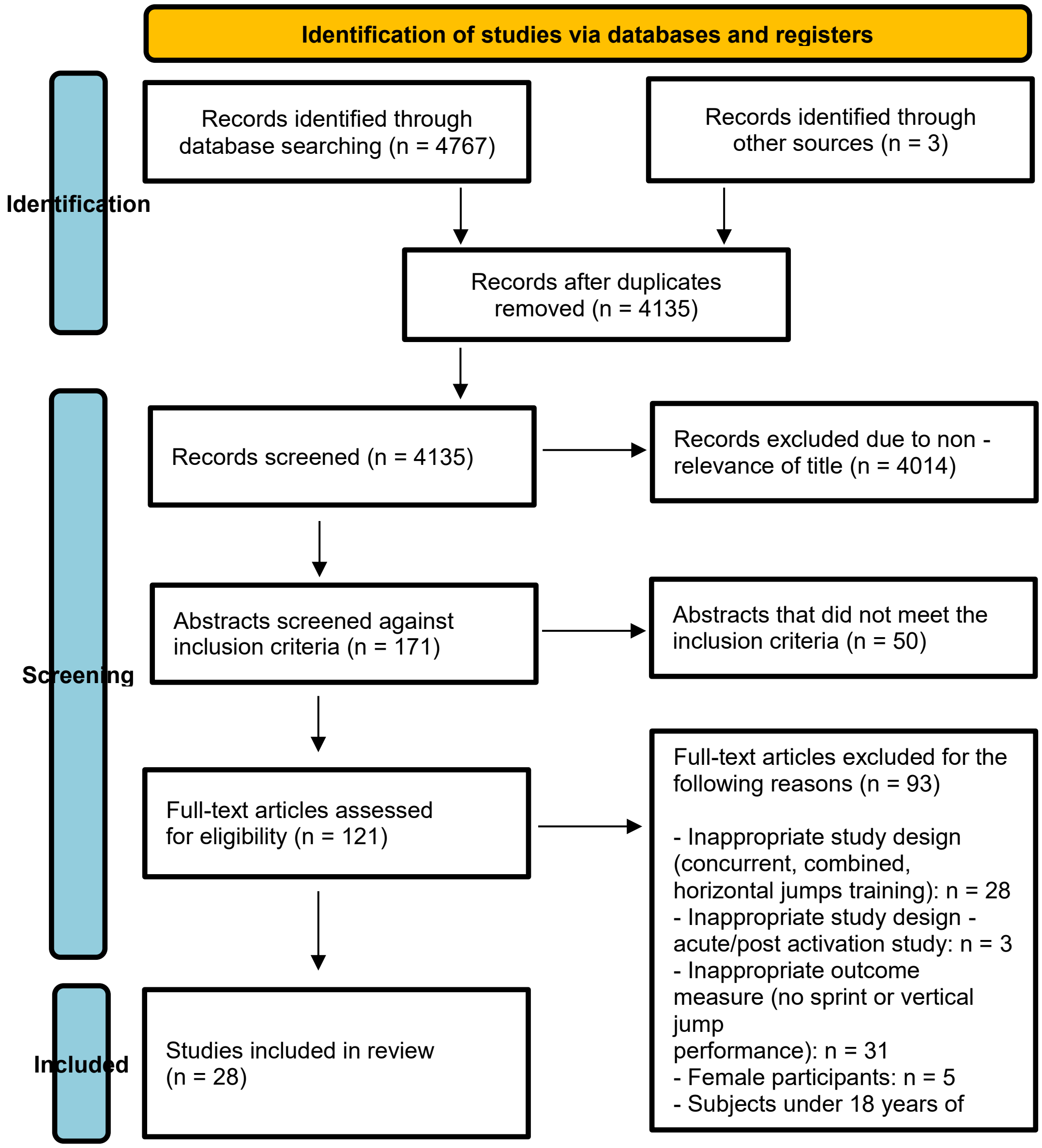


Figure 4 PRISMA flow diagram.

Table 3. Results of risk of bias analysis using the PEDro scale items for sprint and vertical jump training studies.

PEDro scale items	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Score**
Sprint training studies												
Bravo et al., (2008)	1	1	0	1	0	0	0	0	1	1	1	5
Carlos-Vivas et al., (2020)	1	1	0	1	0	0	0	0	1	1	1	5
Dello Iacono et al., (2016)	0	1	0	1	0	0	0	1	1	1	1	6
Grazioli et al., (2020)	0	1	0	1	0	0	0	0	1	1	1	5
Harrison and Bourke. (2009)	0	1	0	1	0	0	0	0	1	1	0	4
De Hoyo et al., (2016)	0	0	0	1	0	0	0	1	1	1	1	5
Krakan, Milanovic & Belcic. (2020)	0	0	0	1	0	0	0	1	1	1	1	5
Lockie et al., (2012)	1	0	0	1	0	0	0	1	1	1	1	5
Markovic et al., (2007)	1	1	0	1	0	0	0	1	1	1	1	6
Bachero-Mena and Gonzalez-Badillo (2014)	1	1	0	1	0	0	0	1	1	1	0	5
Mujika et al., (2009)	1	1	0	1	0	0	0	0	1	1	1	5
Pareja-Blanco et al., (2021)	1	1	0	1	0	0	0	1	1	1	1	6
Rey et al., (2017)	1	1	0	1	0	0	0	1	1	1	1	6
Rodríguez-Rosell et al., (2020)	1	1	0	1	0	0	0	1	1	1	1	6
Spinks et al., (2007)	1	1	0	1	0	0	0	1	1	1	1	6

Vertical jump studies											
Arazi et al., (2014)	0	1	0	1	0	0	0	1	1	1	1	6
Asadi and Ramírez-Campillo (2016)	0	1	0	1	0	0	0	1	1	1	1	6
Asadi et al., (2017)	1	1	0	1	0	0	0	1	1	1	1	6
Chelly et al., (2010)	0	1	0	1	0	0	0	1	1	1	1	6
Dello Iacono et al., (2016)	1	1	0	1	0	0	0	1	1	1	1	6
Hermassi et al., (2014)	1	1	0	1	0	0	0	1	1	1	1	6
Impellizzeri et al., (2008)	0	1	0	1	0	0	0	0	1	1	1	5
Lockie et al., (2012)	1	1	0	1	0	0	0	1	1	1	1	6
Loturco et al., (2015b)	0	1	0	1	0	0	0	1	1	1	1	6
Manouras et al., (2016)	1	1	0	1	0	0	0	1	1	1	1	6
Markovic et al., (2007)	1	1	0	1	0	0	0	1	1	1	1	6
Ramirez-Campillo et al. (2021)	1	1	0	1	0	0	0	0	1	1	1	5
De Villarreal et al., (2008)	1	1	0	1	0	0	0	1	1	1	1	6

Item 1 is not used to calculate final rating: 1. Eligibility criteria were specified; 2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received); 3. Allocation was concealed; 4. The groups were similar at baseline regarding the most important prognostic indicators; 5. There was blinding of all subjects; 6. There was blinding of all therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; 10. The results of between-group statistical comparisons are reported for at least one key outcome; 11. The study provides both point measures and measures of variability for at least one key outcome

Sprint Training Effects

A total of 324 individuals were included in the sprint training studies. Considering the effect of sprint training, only one study (LOCKIE et al., 2012) showed improvement after the sprint training session for the specific task group (e.g., improvement only in the sprint performance task). For most studies (n = 10; CARLOS-VIVAS et al., 2020; DELLO IACONO et al., 2016; HARRISON; BOURKE, 2009; DE HOYO et al., 2016; MARKOVIC et al., 2007; BACHERO-MENA; GONZÁLEZ-BADILLO, 2014; PAREJA-BLANCO et al., 2021; REY et al., 2017; RODRÍGUEZ-ROSELL et al., 2020; SPINKS et al., 2007), there was a transfer to improvement in the sprint and vertical performance tasks. One study demonstrated effects only on vertical performance (KRAKAN et al., 2020), and one study demonstrated positive effects on sprint but a decrease in vertical performance (GRAZIOLI et al., 2020). Finally, only two studies did not demonstrate effects on performance in any of the tasks (BRAVO et al., 2008; MUJIKA et al., 2009).

Table 4. Characteristics and main findings of the sprint training interventions studies.

Reference	Training experience/ group/sample size/age	Sets *x* reps *x* distance *x* recovery	Duration/ frequency	Specific Task Training	Measured outcomes	Main findings (% Change)	% Change	Transfer effect coefficient
Bravo et al., (2008)	Football players professional = 13/ 21.1 years	3 sets x 6 reps x 40 m x 4'	7 weeks, 2 times for week	Sprint training - free	CMJ, SJ and sprint 10m (s)	No effects in CMJ (0.0), SJ (-0.25) and Sprint 10m (0.0)	CMJ = 0.0 SJ = -0.25 SP10 = 0.0	Not calculated
Carlos-Vivas et al., (2020)	Soccer players; four groups: VRS: n = 11/ 18.0 years HRS: n = 13/ 18.2 years CRS: n = 12/ 18.5 years URS: n = 12/ 18.4 years	2-3 sets x 4-12 reps x 5-30m x 1-3'	8 weeks, 2 times for week	VRS - vertical resisted - 10-20% of BM; HRS - horizontal resistance - 10-20% of BM; CRS – combined (vertical and horizontal resistance); URS - without resistance	CMJ, sprint 10m (s) and 30m (s)	VRS, HRS, CRS and URS improved their sprint time by 10 (-1.42, -1.42, -1.42, -1.90) and 30m (-1.32, -1.30, -1.53, -1.54) respectively. For CMJ only the VRS group showed improves (6.95) for the other groups, no improvement (0.57, 1.13, -2.19) respectively	VRS CMJ = 6.95; SP10 = -1.43; SP30 = -1.32 HRS CMJ = 0.57; SP10 = -1.42; SP30 = -1.30 CRS CMJ = 1.13; SP10 = -1.42; SP30 = -1.53 URS CMJ = -2.19; SP10 = -1.90; SP30 = -1.54	VRS: CMJ/SP10 = 0.91 CMJ/SP30 = 1.08 HRS; CRS and URS – not calculated

Dello Iacono et al., (2016)	Elite handball players (8 years of experience) = 9/24.8 years	2 sets x 14-17 reps x 20m x 4’	8 weeks, 2 times for week	Sprint training - free	CMJ, sprint 10m (s) and 20m (s)	↓ in sprint time and ↑10 (-4.47) and 20m (-4.22) and CMJ height (8.68).	CMJ = 8.68 SP10 = -4.47 SP20 = -4.22	CMJ/SP10 = 0.65 CMJ/SP20 = 0.57
Grazioli et al., (2020)	Professional soccer players; two groups: Velocity loss 10%: n = 8/26.3 years Velocity loss 20%: n = 9/25.4 years	33.7 reps x 30” (10% loss of velocity) 48.8 reps x 30” (20% loss of velocity)	11 weeks, once a week	Sled sprint training – 45-65% of BM.	CMJ, SJ, sprint 10m (s) and 20m (s)	There was improvement in the sprint time for G10% and G20%, 10 (-5.00, -1.27) and 20m (-2.47, -1.43) and decrease in height the CMJ (-1.60, -6.58) and unclear effects for SJ (2.29, -9.43) respectively.	G10% CMJ = -1.60; SJ = 2.29; SP10m = -5.00; SP20m = -2.47 G20% CMJ = -6.58; SJ = -9.43; SP10m = -1.27; SP20m = -1.43	Not calculated
Harrison and Bourke. (2009)	Professional rugby players = 8/20.5 years	1 set x 6 reps x 20m x 4’	6 weeks, 2 times for week	Sled sprint training – 13% BM	Drop jump, sprint 10m (s)	↓ in the sprint time and 10m (-5.62) and ↑ in height for DJ (3.13).	DJ = 3.13 SP10 = -5.62	DJ/SP10 = 0.26
De Hoyo et al., (2016)	Elite soccer players = 13/18.0 years	1 set x 6-10 reps x 20m x 3’	8 weeks, 2 times for week	Resisted Sprint - sled towing 12,6% of BM	CMJ, sprint 10m, 20m, 30m and 50m (s).	↓ only in the sprint time 30 (-0.71) and 50m (-1.06) and ↑	CMJ = 4.82 SP10 = -0.58; SP20 = -0.33; SP30 = -0.71 SP50 = -1.06	CMJ/SP30 = 2.54 CMJ/SP50 = 1.85

						CMJ performance (4.82). No difference for sprint time 10 (-0.58) and 20 (-0.33)		
Krakan, Milanovic & Belcic. (2020)	Athletes amateur level over 18 years old = 20	2-3 sets x 6-10 reps x 20m x 2’	6 weeks, 3 times for week	Sprint training - free	CMJ, sprint 5m, 10m and 25m (s).	Only the height of CMJ showed improvement (2.25). No effects for sprint time 5 (-0.88), 10 (-1.06) and 25 (-1.34)	CMJ = 2.25 SP5 = -0.88; SP10 = -1.06; SP25 = -1.34	CMJ/SP10 = 0.71 CMJ/SP25 = 0.49
Lockie et al., (2012)	Football players; two groups: free sprint training n = 9/23.1 years Resisted sprint training n = 9/23.1 years	1-3 sets x 3-5 reps x 5-20m x unreported recovery	6 weeks, 2 times for week	Free sprint training (FST) Resisted sprinting (RST) with sled towing 12.6% of BM	CMJ, DJ, sprint 5m (m.s) and 10m (m.s)	Both groups (FST and RST) improvement only the 5 (6.93, 7.09) and 10m (4.57, 5.64) sprint performance. No difference for CMJ (5.56, 2.56) and DJ (3.33, 3.57) respectively.	FST CMJ = 5.56; DJ = 3.33; SP5 = 6.93; SP10 = 4.57 RST CMJ = 2.56; DJ = -3.57; SP5 = 7.09; SP10 = 5.64	FST CMJ/SP5 = 0.27 CMJ/SP10 = 0.40 RST – not calculated
Markovic et	Physically	3-4 sets x 3 reps x	10 weeks, 3	Free sprinting	CMJ, SJ,	Improvement in	CMJ = 6.51	SJ/SP20 = 1.49

al., (2007)	actives = 30/20.1 years	10-50m x 1-3’	times for week	training	sprint 20m (s)	the CMJ (6.51), SJ (9.51) and the sprint time (-2.79).	SJ = 9.51 Sprint 20m = - 2.79	CMJ/SP20 = 0.93
Mena and Gonzalez-Badillo. (2014)	Physically active; two groups: Low load (LL) = 7/21.9 Medium load (ML) = 6/20.8 High load (HL) = 6/19.8	1 set x 4-8 reps x 20-35m x 3-5’	7 weeks, 2 times for week	Sled-resisted sprint training LL – 5% BM ML – 12.5% BM HL – 20% BM	CMJ, sprint 20m (s), 30m (s) and 40m (s)	LL, ML and HL groups reduced times in sprint 40m (-1.28, 1.30, -1.10), only group HL reduced time in sprint 20 (-0.97) and 30m (-0.70). The CMJ improve only in ML (9.56) and HL (8.16).	LL CMJ = -0.76; SP20 = -1.32; SP30 = -1.18 ML CMJ = 9.56; SP20 = -0.66; SP30 = -0.71 HL CMJ = 8.16; SP20 = -0.97; SP30 = -0.70	LL - Not calculated ML CMJ/SP20 = 2.09 CMJ/SP30 = 1.82 HL CMJ/SP20 = 1.42 CMJ/SP30 = 1.53
Mujika et al., (2009)	Soccer players (7 years of experience) = 10/18.5 years	2-4 sets x 4 reps x 30m x 3’	7 weeks, once a week	Traditional sprint training - free	CMJ, sprint 15m (m.s)	No effects after sprint training in CMJ (0.71) and SP15 (-0.28).	CMJ = 0.71 SP15 = -0,28	Not calculated
Pareja-Blanco et al., (2021)	Physically actives; two groups: Heavy sled towing n = 14/21.9 years Light sled towing n = 15/22.9 years	4-7 sets x 20m x 3’	8 weeks, once a week	Resisted sprints with load of 80% BM (HST). Resisted sprints with load of 12.5% BM (LST).	CMJ, sprint 10m (s), 20m (s) and 30m (s)	Only the LST group showed improvement in the sprint time of 20m (1.59) and CMJ performance (3.24).	HST CMJ = 2.54; SP10 = -0.55; SP20 = 0.0; SP30 = -0.92 LST CMJ = 3.24; SP10 = -1.10; SP20 = 1.59; SP30 = -0.91	LST CMJ/SP10 = 0.88 CMJ/SP20 = 0.56 CMJ/SP30 = 0.51

Rey et al., (2017)	Soccer players (14.7±4 years of experience); two groups: Resisted sprint n = 10/23.6 years Unresisted n = 9/23.7 years	1-4 sets x 3-7 reps x 20m x 2-5'	6 weeks, 2 times for week	RS - Resisted sprint with weighted vests 18,9% BM US - Unresisted sprint	CMJ, sprint 10m (s) and 30m (s)	Both groups (RS and US) showed improvement only in the 10 (-9.55, -11.17) and 30m (-5.99, -5.15) in sprint performance.	RS CMJ = 0.35; SP10 = -9.55; SP30 = -5.99 US CMJ = 1.98; SP10 = -11.17; SP30 = 5.15	Not calculated
Rodríguez-Rosell et al., (2020)	Team and individual sports players; five groups: G0% = 12/21.6 G20% = 12/23.8 G40% = 12/22.1 G60% = 12/21.9 G80% = 12/22.2	6-12 sets x 20m x 2'	8 weeks, once a week	Sled-resisted sprint training G0% - without external loads G20% - 20% of BM G40% - 40% of BM G60% - 60% of BM G80% - 80% of BM	CMJ, sprint 10m (s), 20m (s) and 30m (s)	G0% improve in sprint 10m (-1.64), G40% in sprint 10m (-2.75), 20m (-1.59), 30m(-1.59), and G60% sprint 10m (-2.19), 30m(-1.14). For CMJ height all groups showed improve (G0% = 4.80, G20% = 5.79, G40% = 9.04, 60% = 6.42, G80% = 3.40).	G0% → CMJ = 4.80; SP10 = -1.64; SP20 = -1.27; SP30 = -0.92 G20% → CMJ = 5.79; SP10 = -1.11; SP20 = -0.33; SP30 = -0.23 G40% → CMJ = 9.04; SP10 = -2.75; SP20 = -1.59; SP30 = -1.59 G60% → CMJ = 6.42; SP10 = -2.19; SP20 = -1.27; SP30 = -1.14 G80% → CMJ = 3.40; SP10 = -1.63; SP20 = -0.63; SP30 = -0.68	G0% CMJ/SP10 = 0.54 CMJ/SP20 = 0.62 CMJ/SP30 = 0.97 G20% CMJ/SP10 = 1.08 G40% CMJ/SP10 = 0.58 CMJ/SP20 = 1.04 CMJ/SP30 = 1.11 G60% CMJ/SP10 = 0.67 CMJ/SP20 = 1.12 CMJ/SP30 = 1.37 G80% CMJ/SP10 = 1.00
Spinks et al., (2007)	Soccer, rugby, football players; two groups: Resisted sprint n	1-3 sets x 3-6 reps x 5-20m x 45"-2'	8 weeks, 2 times for week	Resisted sprint (RS) - Training with sled towing - load to reduce	CMJ, sprint 5m (m.s), and 15m	Both groups (RS and NRS) showed improvement in	RS CMJ = 5.88 SP5 = -9.12; SP15 = -7.81	RS CMJ/SP5 = 0.43 CMJ/SP15 = 0.37 NRS

	= 10/21.8 years Nonresisted sprint n = 10/21.8 years	running velocity by 10% of maximal; Nonresisted sprint training (NRS)	(m.s)	the 5 (-9.12, -7.98) and 15m sprint performance (-7.81, -6.24) and the height CMJ (5.88, 9.07) respectively.	NRS CMJ = 9.07 SP5 = -7.98; SP15 = 6.24	CMJ/SP5 = 0.95 CMJ/SP15 = 0.84

Notes: BM - body mass; CMJ – counter movement jump; SJ – squat jump; DJ – drop jump; SP5m – sprint 5m; SP10m – sprint 10m; SP15m – sprint 15m; SP20m - sprint 20m; SP25m – sprint 25m; SP30m - sprint 30m.

Vertical Jump Training Effects

A total of 188 individuals took part in the vertical jump training studies. The majority of studies demonstrated positive effects on sprint and vertical performance after jump training (n = 10; ARAZI et al., 2014; ASADI; RAMÍREZ-CAMPILLO, 2016; ASADI et al., 2017; CHELLY et al., 2010; DELLO IACONO et al., 2017; HERMASSI et al., 2014; LOCKIE et al., 2012; MANOURAS et al., 2016; RAMIREZ-CAMPILLO et al., 2021; DE VILLARREAL et al., 2008). Three studies showed effects only on vertical jump performance (IMPELLIZZERI et al., 2008; LOTURCO et al., 2015; MARKOVIC et al., 2007).

Table 5. Characteristics and main findings of the studies of vertical jump training interventions.

Reference	**Training experience/ Sample size/ Groups**	**Sets *x* reps *x* distance *x* recovery**	**Duration/ frequency**	**Specific Task Training**	**Measured outcomes**	**Main findings**	**% Change**	**Transfer effect coefficient**
Arazi et al., (2014)	Healthy men = 7/20.5 years	5 sets x 20 reps x 2’	6 weeks, 2 times for week	Drop jump - 45 cm height	SJ, sprint 20m (s), sprint 40m (s)	Improvement in the sprint time 20 and 40m and SJ.	SJ = 12.88 SP20m = -11.11 SP40m = -8.35	SP20m/SJ = 1.29 SP40m/SJ = 1.05
Asadi and Ramírez-Campillo. (2016)	Physically actives; two groups: Cluster group (CG) n = 6/20.5 years Traditional (TG) group: n = 7/20.2 years	CG - 5 sets x 20 reps x 2’ TG - 5 sets x 20 reps x 30-90”	6 weeks, 2 times for week	Drop jump - 45 cm height	CMJ, sprint 20m (s), sprint 40m (s)	Both training groups improved the performance after plyometric training.	CG CMJ = 12.64 SP20m = -6.36 SP40m = -7.47 TG CMJ = 12.71 SP20m = -12.15 SP40m = -9.48	CG SP20m/CMJ = 0.86 SP40m/CMJ = 0.67 TG SP20m/CMJ = 1.41 SP40m/CMJ = 1.32
Asadi et al., (2017)	Basketball players (7.5 years of experience) = 16/18.5 years	3 sets x 8-12 reps x 2’	8 weeks, 3 times for week	CMJ, Single-leg jump, Single-leg hops	CMJ, sprint 60m (s)	Improvement in the sprint time 60m and the CMJ.	CMJ = 14.25 SP60m = -16.01	SP60m/CMJ = 0.43
Chelly et al., (2010)	Soccer players (7.2 years of experience) = 12/19.1 years	4-7 sets x 10 reps x 1’	8 weeks, 2 times for week	Drop jump - 40cm height, hurdle jump	SJ, CMJ, sprint 40m (max. velocity)	Improvement in the SJ and CMJ and maximum velocity sprint	SJ = 8.33 CMJ = 2.50 SP40m (max velocity = 9.76	SP40m/SJ = 4.0 SP40m/CMJ = 12.12

						40m.		
Dello Iacono et al., (2017)	Elite handball players (8 years of experience) = 9/23.4 years	5-8 sets x 6-10 reps x 2’	10 weeks, 2 times for week	Drop jump - 25cm height	CMJ, sprint 10m (s), sprint 25m (s)	Improvement in the CMJ and sprint 10m and 25m.	CMJ = 8.68 SP10m = -3.99 SP25m = -3.71	SP10m/CMJ = 3.24 SP25m/CMJ = 1.43
Hermassi et al., (2014)	Handball players (12.4 years of experience) = 14/20.1 years	5-7 sets x 10 reps x 3’	8 weeks, 2 times for week	Drop jump - 40cm height, hurdle jump	SJ, CMJ, sprint 30m (s)	Improvement in the SJ and CMJ and sprint 30m.	SJ = 7.43 CMJ = 10.18 SP30m = -5.37	SP30m/SJ = 0.75 SP30m/CMJ = 0.43
Impellizzeri et al., (2008)	Soccer players = 18/25 years	3-15 sets x 5-15 reps x 1-2’	4 weeks, 3 times for week	Vertical jump, drop jump	CMJ, SJ, sprint 10m (s), sprint 20m (s)	Improvement only in height CMJ.	CMJ = 14.55 SJ = 5.29 SP10m = -3.70 SP20m = -2.79	SP10m/CMJ = 0.86 SP20m/CMJ = 0.98 SP10m/SJ = 1.67 SP20m/SJ = 1.91
Lockie et al., (2012)	Football players = 9/23.1 years	2-6 sets x 5-10 reps x unreported recovery	6 weeks, 2 times for week	Box jump, drop jump	CMJ, DJ 40cm, sprint 10m (m.s)	Improvement in sprint velocity 10m in all groups.	CMJ = 2.63 DJ 40cm = 0.0 SP10m = 4.16	SP10m/CMJ = 4.25
Loturco et al., (2015)	High-level soccer players = 12/18.2 years	4-6 sets x 8-10 reps x 3’	3 weeks, 2-5 times for week	Countermovemen t jumps	CMJ (cm), sprint 10m (m.s), sprint 20m (m.s)	Improvement only in CMJ.	CMJ = 6.04 SP10m = 0.52 SP20m = 3.14	SP20m/CMJ = 1.32
Manouras et al., (2016)	Soccer players (more of 3	3-5 sets x 4-10 reps x 1-2’	8 weeks, once a week	Countermovemen t jumps, obstacle	CMJ, sprint 10m (s), sprint 30m (s)	Improvement in the CMJ and	CMJ = 5.82 SP10m = -2.67	SP10m/CMJ = 2.84

	years of experience) = 10/20.7 years			jumps, Drop jump (40cm)		sprint 30m	SP30m = -3.01	SP30m/CMJ = 2.28
Markovic et al., (2007)	Physically actives = 30/20.1 years	4-10 sets x 10 reps x 3’	10 weeks, 3 times for week	Hurdle jumps, drop jump	CMJ, SJ, sprint 20m (s)	Improvement only in CMJ and SJ.	CMJ = 6.11 SJ = 6.03 SP20m = -1.55	SP20m/CMJ = 0.69 SP20m/SJ = 0.71
Ramirez-Campillo et al. (2021)	Physically actives; three groups: 100% intensity = 10/22.0 years 80% intensity = 9/22.4 years 65% intensity = 10/21.8 years	10 sets x 4-10 reps x 2’	8 weeks, 2 times for week	Countermovement jump with arm swing. Plyometric jump training using 65, 80, and 100% of the maximal vertical jump height intensity.	CMJ, sprint 30m (s)	Improvement in CMJ height in all groups. The sprint 30m only improved in the 100% intensity group.	PT 100% CMJ = 9.21 SP30m = -3.66 PT 80% CMJ = 5.67 SP30m = -0.79 PT 65% CMJ = 2.74 SP30m = -0.19	PT 100% Sprint30m/CMJ = 1.64 PT 85% Sprint30m/CMJ = 0.63
De Villarreal et al., (2008)	Physical education students; three groups: 7 sessions (7SG) n = 10/22.4 years 14 sessions (14SG) n = 12/23.1 years 28 sessions (28SG) n = 10/21.8 years	2 sets x 10 reps x 1’	7SG - 7 weeks, once a week 14SG - 7 weeks, 2 times for week 28SG - 7 weeks, 4 times for week	Drop jump - 20-40-60cm height	CMJ, DJ 20cm, DJ 40cm, DJ 60cm, sprint 20m (s)	Improvement in the sprint 20m in all groups. Height CMJ and DJ (20, 40 and 60 cm) improve in the 14SG and 28SG groups.	7SG CMJ = 1.16 DJ 20cm = 1.30 DJ 40cm = 1.00 DJ 60cm = 4.23 SP20m = -1.08 14SG CMJ = 13.70 DJ 20cm = 10.26 DJ 40cm = 12.27 DJ 60cm = 10.76 SP20m = -0.54 28SG	7SG SP20m/DJ60 = 0.70 14SG – Not calculated 28SG SP20m/CMJ = 0.44 SP20m/DJ20 = 0.49 SP20m/DJ40 = 0.43

CMJ = 17.63 DJ 20cm = 17.21 DJ 40cm = 18.23 DJ 60cm = 18.42 SP20m = -1.88	SP20m/DJ60 = 0.40

Note. N = number; BM= body mass; CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; SP5m = sprint 5 m; SP10m = sprint 10 m; SP15m = sprint 15 m; SP20m = sprint 20 m; SP25m = sprint 25 m; SP30m = sprint 30 m; SP60m = sprint 60 m; reps = repetitions; G = groups; CG = cluster group; TG = traditional group; PT = plyometric training; s = sessions; NS = not significant.

Percentage Changes

When analyzing the percentage changes after the vertical jump training (Figure 2), there was an improvement of 8.6% (3.44 cm) in the CMJ height and 7.99% (3.22 cm) in the SJ height and decreases of 3.09% (−0.06 s), 4.48% (−0.16 s), and 2.60% (0.14 s) in sprint time for distances of 10, 20, and 30 m, respectively (Figure 3). On the other hand, sprint training promoted an increase in the CMJ height of 3.52% (1.33 cm) and in the SJ height of 0.66% (0.30 cm) and decreases of 3.0% (−0.05 s), 1.39% (−0.04 s), and 1.56% (−0.07 s) in sprint time for distances of 10, 20, and 30 m, respectively.

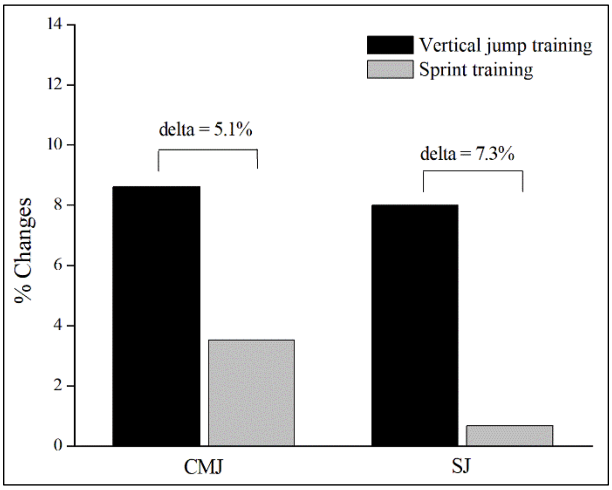


Figure 5 — Percentage performance changes after the vertical jump training. CMJ = countermovement jump; SJ = squat jump.

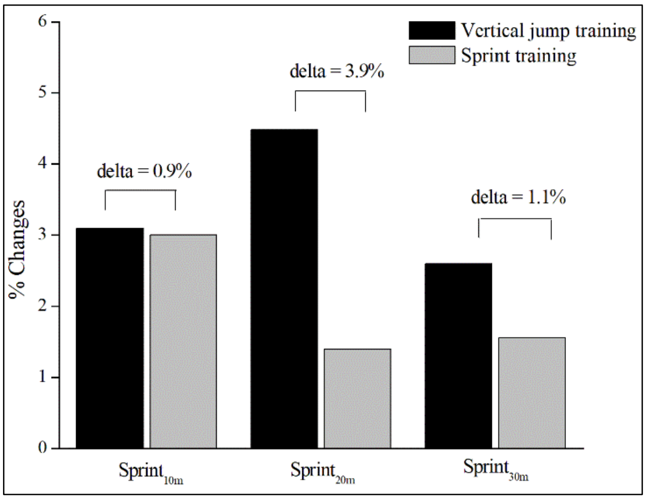


Figure 6 — Percentage performance changes after the sprint training.

Transference Effect Coefficients

Table 6 shows the transfer effect coefficients (TECs) between performance in untrained and specific trained exercises; that is, for vertical jump training, the CMJ was the specific exercise and the sprints (10, 20, and 30 m) were the untrained exercise, whereas for sprint training the sprints (10, 20, and 30 m) were the specific exercises, and the CMJ was the untrained exercise. In the vertical jump training, the TECs between CMJ and 10-, 20-, and 30-m sprint were 2.80, 1.05, and 1.25, respectively. In the sprint training, the TECs between 10-, 20-, and 30-m sprint and CMJ were 0.70, 1.04, and 1.37, respectively.

Table 6. Transference effect coefficient of jumping and sprint training.

Vertical jump training	$Sprint_{10m}$/CMJ 2.80 ± 1.42 (n = 4)	$Sprint_{20m}$/CMJ 1.05 ± 0.37 (n = 8)	$Sprint_{30m}$/CMJ 1.25 ± 0.87 (n = 4)
Sprint training	CMJ/$sprint_{10m}$ 0.70 ± 0.25 (n = 11)	CMJ/$sprint_{20m}$ 1.04 ± 0.52 (n = 8)	CMJ/$sprint_{30m}$ 1.37 ± 0.62 (n = 8)

Notes: n - number of study groups.

Discussion

The aim of this systematic review was to investigate the effects of specific sprint and vertical jump training interventions on speed–power parameters. Our results showed that both training interventions (vertical jumps and sprint) induced improvements in specific vertical jump and linear sprint performance. The transfer from one model to another occurred with both training interventions; however, we verified that vertical jump training induced greater specific and training transfer effects for the untrained skill (i.e., linear sprint). An interesting specific result of our systematic review is that vertical jump training was shown to be more effective in improving vertical performance and presented similar or superior effectiveness to sprint training to improve the horizontal performance task, as observed in 20- and 30-m sprints (vertical jump training 4.48% vs. sprint training 1.39%; vertical jump training 2.60% vs. sprint training 1.56%; respectively).

Although it is known in the current literature that vertical jumps and sprint are important training methods used to develop speed–power abilities and enhance sports performance (MARKOVIC et al., 2007; MORAN et al., 2021; RAMÍREZ-CAMPILLO et al., 2014; RAMIREZ-CAMPILLO et al., 2020; RAMIREZ-CAMPILLO et al., 2020; RAMIREZ-CAMPILLO et al., 2021; RAMÍREZ-CAMPILLO et al., 2016; SOLE et al., 2021; VAN DE HOEF et al., 2020), there is limited evidence showing which method has the greatest ability to improve aspects of specific and nonspecific speed–power capacities. In our study, we observed similar or higher TECs for vertical jump training compared with sprint training. Loturco et al. (2015) confirmed the ability of vertical and horizontal jump training to similarly transfer neuromuscular gains specific to acceleration and speed skills. A recent meta-analysis study has shown that vertical jump training induced significant improvements in both vertical jump and linear sprint performance in young male soccer players (RAMIREZ-CAMPILLO et al., 2020). In addition, improvements in jump ability, sprint, strength, and endurance were also found in individual sports (SOLE et al., 2021). In team sports, vertical jump training induced enhancements in vertical jump height in volleyball (RAMIREZ-CAMPILLO et al., 2020) and handball players (RAMIREZ-CAMPILLO et al., 2020) and improvements in vertical jump height, linear sprint speed, change of direction speed, balance, and muscle strength in basketball players (RAMIREZ-CAMPILLO et al., 2021). In our study, sprint training has shown positive effects (although lower than vertical jump training), particularly on sprints performance, suggesting that this type of training can be used in team sports where running is a crucial task (e.g., soccer and rugby).

The percentage changes showed that the CMJ and SJ performances were 5.1% and 7.3% higher, respectively, for vertical jump training compared with sprint training (Figure 3). Furthermore, the sprint performances of 10, 20, and 30 m were 0.9%, 3.9%, and 1.1% higher, respectively, after vertical jump training compared with sprint interventions, showing that the transfer effect seems more pronounced in longer sprints. Loturco et al. (2015) also found that vertically oriented training resulted in greater performance improvements over longer sprints in high-level soccer players. This may be related to the important role of vertical GRFs at longer sprints, which are more pronounced in the latter stages of a longer sprint, requiring greater participation from the stretch-shortening cycle in this phase of the sprint (NAGAHARA et al., 2018). In a recent meta-analysis, Moran et al. (2021) investigated the effect of vertical and horizontal plyometric training on both vertical (i.e., vertical jump) and horizontal (i.e., standing long jump) measures of physical performance. The results showed that horizontal plyometric training is as effective as vertical plyometric training for enhancing vertical performance but superior for enhancing horizontal performance (e.g., sprint).

The volume and frequency are very important parameters to take into account in a training program. The studies selected in the present review showed that frequency of two or three times a week generated similar improvements in vertical jump and sprint performance (ARAZI et al., 2014; ASADI; RAMÍREZ-CAMPILLO, 2016; ASADI et al., 2017; IMPELLIZZERI et al., 2008), whereas the frequency of once a week resulted in smaller improvements (MANOURAS et al., 2016; DE VILLARREAL et al., 2008). Considering the total duration of training, previous studies showed that 6 weeks of training seems to be enough to provide increases in vertical jump (ARAZI et al., 2014; ASADI; RAMÍREZ-CAMPILLO, 2016) and sprint (HARRISON; BOURKE, 2009; LOCKIE et al., 2012; REY et al., 2017) performance. Another important aspect that should be considered to analyze the training outcomes is the experience of participants. In general, it was possible to observe that regardless of training level (physically active individuals or athletes), the improvements in the vertical jump height and sprint were similar after vertical jump training (physically active, vertical jump = 9.93% and sprint −4.25%; athletes, vertical jump = 7.99% and sprint −4.38%).

Considering sprint training, previous studies have shown that there is an increase in vertical jump height after resisted (CARLOS-VIVAS et al., 2020; RODRÍGUEZ-ROSELL et al., 2020) and unresisted sprint training (CARLOS-VIVAS et al., 2020; DELLO IACONO et al., 2016). In the present study, a similar increase in CMJ performance was observed after resisted and unresisted sprint training (3.5% and 3.7%, respectively). Thus, both possibilities seem to be an effective training method to improve vertical jump abilities in athletes and moderately trained subjects. This is probably explained by the strong correlation that exists between lower limb strength (specifically assessed in hip and knee extensor muscles) and jump and sprint performance (SEITZ et al., 2014).

On the other hand, sprint performance seems to be superior when an unresisted sprint is performed compared with resisted sprint training (3.5% vs. 1.7% improvement in sprint time, respectively). According to Alcaraz et al. (2018), the resisted sprint is an effective training method for the development of sprint performance, specifically in the early acceleration phase, independent of level of training and load characteristics. However, according to the authors, when resisted and unresisted sprint training are compared, the sprint performance improvements are similar. It has been suggested that the improvements in sprints may be related to changes in specific coordination and agility rather than to improvements in explosive strength capability (BUCHHEIT et al., 2010; REY et al., 2017). However, the transfer from sprint training to other exercise modes, such as the vertical jump, appears to be more limited (BRAVO et al., 2008; GRAZIOLI et al., 2020).

Young (1992) suggested that vertical jump may be considered an appropriate exercise for the development of sprint due to the similar contact time of jump and sprint during the initial acceleration phase. Moreover, the increased step frequency, reduction in ground contact time during the support phase (MAĆKAŁA; FOSTIAK, 2015), and increase in step length (LOCKIE et al., 2012, 2014) are some of the possible adaptive mechanisms leading to the decrease in sprint time after vertical jump training. Despite the principle of training specificity, that is, the more specific a training exercise is for a sport-specific physical task, the better the improvement of the task at decisive moments of training or competition situations (SOLE et al., 2021; VAN DE HOEF et al., 2020), the vertical jump training showed higher transfer effect than sprint training, even though it is a more complex tasks skill in the performance of body movements.

An important aspect that could have influenced the transfer effect results is the discrepancy of tasks (vertical jump vs. sprint), more specifically the direction of the vector resulting from GRF. In vertical jump, the GRFs are more pronounced vertically to overcome gravity, whereas the sprint is characterized by lower vertical displacement and greater horizontal GRF (SAMOZINO et al., 2014). These characteristics of force application require different mechanical demands, which can cause different biomechanical adaptations in the musculoskeletal system (FREITAS et al., 2017). Despite these mechanical differences, we verified that vertical jump training was effective in improving the horizontal performance task. This may be explained considering that in sprint action, despite the predominance of horizontal GRF, there is a considerable presence of vertical forces during the initial acceleration and transition phases, which is a key determinant of performance (WILKAU et al., 2020).

Finally, when analyzing the methodological quality of studies included in our review, we verified that all manuscripts were considered as low risk of bias (moderate and high quality) with most studies scoring 5 points or more. Other systematic reviews with a similar approach have shown similar results considering the PEDro scale (MORAN et al., 2021; SOLE et al., 2021) with a mean score of 6 points. Studies related to sports physical performance are usually of only average quality, probably due to the difficulty in conducting studies that include a doubleblind design. Studies should also report more information on elements related to the training section, interventions, recovery, time between sets, repetitions, and so forth. The lack of details about the experimental design and participants' characteristics often leads to a low quality classification of the study.

Limitations

Some limitations and strengths can be highlighted in this study. Few studies presented the training experience of participants; only the competitive level (e.g., high level) was described in most studies, limiting the discussion considering this aspect. The lack of a subgroup analysis and consideration of different intervention variables (e.g., age, number of training sessions), groups of female athletes, and young athletes (< 18 years) may be also considered as limitations. On the other hand, although a traditional meta-analysis was not conducted, the rate of training transfer in specific and nonspecific (untrained) programs (ZATSIORSKY; KRAEMER, 2006) was analyzed; such information can be considered to be of great practical application. Finally, this study was not registered on a priori systematic review registration platforms (e.g., PROSPERO and Open Science Framework), characterizing an important limitation.

Practical Applications and Future Studies

The present systematic review showed that vertical jump and sprint training interventions are effective in increasing specific actions; however, vertical jump training produces greater specific and training transfer effects to linear sprint than sprint training. Although both training interventions can be used to improve speed–power parameters, vertical jump training proved to be a superior alternative due to the greater transfer rate. Thus, coaches can use vertical jump training even in sports where vertical jump is not a specific skill (e.g., soccer, futsal, rugby, running, etc.). In addition, vertical jump training is very useful as it can be conducted in a small space (unlike sprint training) and does not require a lot of time. We suggest vertical jumps protocols based on at least three sets, two or three times a week, as it has been verified that this is enough to promote improvements in the muscle power of lower limbs in athletes (LOTURCO et al., 2015) and physically active people (RAMIREZ-CAMPILLO et al., 2021).

References

The references of the paper are at “references section”.

5.2 Study 2

VALIDITY AND RELIABILITY OF *ERGONAUTA* ENCODER TO ASSESS COUNTERMOVEMENT JUMP PERFORMANCE

Accepted for publication in **Journal of Sports Engineering and Technology**, 2023.

Abstract

This study aimed to test the reliability and criterion validity of the *Ergonauta* encoder to assess countermovement jump (CMJ) performance, considering jump height and mean propulsive velocity metrics. Twenty-three recreationally active men participated in this study. The participants were positioned on the force plate with the *Ergonauta* individually connected through a belt. Two CMJs were performed, and the jump height and mean propulsive velocity metrics were analyzed. The intraclass correlation coefficient (ICC) and typical error (TE) were used as relative and absolute reliability indicators, respectively. The Pearson correlation was used to verify the relationship between the *Ergonauta* and force plate derived-metrics, and the Bland-Altman plot was used to verify the agreement between the metrics (*Ergonauta* encoder and force plate), with the level of significance set at $p<0.05$. The results show excellent relative reliability for both metrics, considering the two evaluation devices (ICC= 0.95 – 0.99, TE=1.02 – 2.46). The jump height and mean propulsive velocity obtained by the *Ergonauta* encoder and the force plate were strongly correlated (r= 0.95; r=0.90, respectively, $p<0.01$). The Bland-Altman plot showed good agreement for both metrics (jump height and mean propulsive power) and equipment (close to 0). We concluded that the *Ergonauta* encoder is reliable and valid for assessing CMJ performance, particularly the jump height and mean propulsive velocity metrics.

Keywords: velocity, linear position transducer, vertical jump, lower limb, devices

Introduction

The vertical jump (VJ) test is one of the main methods used to assess lower limb performance of athletes (MARKOVIC, 2007), allowing, for example, to monitor the neuromuscular status over a season, to discriminate groups of athletes, to identify inter-limb asymmetries, to detect muscular fatigue, etc. Thus, it is considered an important and practical tool for coaches and strength and conditioning professionals (BALSALOBRE-FERNÁNDEZ et al., 2015; STANTON et al., 2015). VJ tests are very used to evaluate athletes in sports in which lower limb muscle power is a mandatory factor (e.g., sprinting, kicking in soccer, jumping in volleyball/basketball or specific attacks techniques in combat sports) (DAL PUPO et al., 2021). Conventionally, the countermovement jump (CMJ) has been the most used VJ test over the years (CLAUDINO et al., 2017), showing high reliability and factorial validity (Markovic et al., 2004). Due to its practicality, the height reached in the VJ is the most commonly used metric to assess lower limb performance (CLAUDINO et al., 2017). Vertical jump height (VJH) has been associated with sport-specific tasks in different modalities (BERRIEL et al., 2020; DAL PUPO et al., 2021; HEISHMAN et al., 2020), such as judo-specific performance test, sprint performance, repeated shuttle sprint ability for futsal players (DAL PUPO et al., 2021), attack effectiveness for volleyball players (BERRIEL et al., 2020). Moreover, VJH was sensitive to detect long-term changes in sport-specific performance in basketball players (HEISHMAN et al., 2020).

It is known that VJH can be measured using different methods and devices, such as videography and force plates (considered the gold standard) (ACHE-DIAS et al., 2011), contact mats (LOTURCO et al., 2017), mobile apps (CRUVINEL-CABRAL et al., 2018), and linear transducers (MCMASTER et al., 2021). The choice of equipment is linked to several aspects, but the usability and practicality are very important, as transporting equipment to specific training locations and cost-effectiveness are mandatory factors. In this sense, several studies have focused on investigating the validity and reliability of low cost instruments (LOTURCO et al., 2017b; MCMASTER et al., 2021; O'DONNELL et al., 2017; PUEO et al., 2017; RAGO et al., 2018).

Linear transducers can be divided into two types of equipment, being linear velocity transducers and linear position transducers (MORENO-VILLANUEVA et al., 2022). Linear velocity transducers (LVT) directly measure velocity through a precision tachometer by recording electrical signals proportional to the velocity of extension of a retractable tether attached in the bar (MORENO-VILLANUEVA ET AL., 2022; COUREL-IBÁÑEZ et al., 2019; SÁNCHEZ-MEDINA; GONZÁLEZ-BADILLO, 2011). On the other hand, linear position transducers (LPT) are usually composed of a rotary encoder that directly measures the vertical displacement of the retractable tether, applying the first derivative of displacement to obtain velocity (MORENO-VILLANUEVA et al., 2022; HARRIS et al., 2010).

Regarding the aforementioned methods, LPTs provide instantaneous displacement measurements from a fixed point, and can therefore be used to obtain a direct measure of height in a vertical jump (HOJKA et al., 2022). In addition, from the change in position and time, LPTs can also provide other parameters of vertical jump, such as mean and peak velocity (O'DONNELL et al., 2017). Two critical points or limitations regarding the accuracy of LPT may be the rapid transition between the concentric and eccentric contraction phases that occur in the CMJ and plyometric exercises and the high sampling rates that seem to increase measurement errors (MORENO-VILLANUEVA et al., 2021).

However, few studies have evaluated the validity and reliability of this kind of device in estimating CMJ height and velocity metrics. O'Donnell et al. (2017) and McMaster et al. (2021) investigated the validity of a specific LPT (*Gymaware*) to assess vertical jump height and found a large correlation with the height obtained using a force plate (r=0.90; r=0.94, respectively). However, previous studies observed that LPTs overestimated the values of jump height by an average of 7.0 (O'DONNELL et al., 2017), 8.0 (MCMASTER et al., 2021) and up to 9.8 cm (HOJKA et al., 2022) when compared to the jump height obtained using a force plate. Additionally, no studies were found that tested the validity of the mean propulsive velocity (MPV) in CMJ, which is a parameter that has been strongly associated with load to control the intensity of vertical jump training protocols (LOTURCO et al., 2015). Only one study has tested the reliability and validity of a LPT to measure the MPV (MORENO-VILLANUEVA et al., 2022), however, it was obtained during the bench press exercise on the Smith machine, and the findings suggest that the encoder is a valid and reliable device for mean propulsive velocity assessment in this type of exercise.

Considering the use of LPT based-technology to assess sports performance, a new device was recently proposed, named the *Ergonauta*. The *Ergonauta* is proposed as a low-cost encoder that estimates jump height from the elevation of the subject's centre of mass, since the linear displacement is converted into rotations of the transducer axis from a retractable tether. To date, no research has still been conducted to investigate the validity and reliability of measurement of this device for vertical jump assessment. Thus, the aim of the current study is to test the reliability and criterion validity of the *Ergonauta* encoder to assess CMJ height and MPV metrics.

Methods

Participants

Twenty-three recreationally active men participated in this study, presenting the following characteristics: age 22.7 ± 4.07 years, height 179 ± 7 cm, and body mass 77.2 ± 12.19 kg. All participants were university students and were not engaged in any club, collegiate, or professional sport. Participants were physically active men who practiced physical exercises (strength training, running, and/or sports involving jump training such as: volleyball, basketball, judo, and soccer) from three to five times a week, for at least one year, and had no injuries or pathologies that would preclude maximum effort in the tests. All participants were previously familiarized with the CMJ movement in their day-by-day recreational training. The university's Institutional Review Board approved (CAEE: 57615022.7.0000.0121) all forms and experimental methods according to the declaration of Helsinki, and the participants read and signed the informed consent. During the procedures, individuals were required to wear athletic clothing and shoes.

Study design and Procedures

In our study, we aimed to assess the CMJ jump height and mean propulsive velocity through the new LPT *Ergonauta* encoder. For the criterion validity, the Ergonauta measures were compared with measures obtained from a force plate (considered as gold standard). The data reliability was verified from two assessments (test-retest) of the Ergonauta encoder on the same day.

Countermovement jump assessment

Before the CMJ assessment, the participants performed a familiarization/warmup involving 30 seconds of hopping on a trampoline, 3 series of 10 hops on the ground, and 5 submaximal countermovement vertical jumps (CMJs)

(KONS et al., 2018). The participants then performed the CMJ protocol on a force plate. *Ergonauta* encoder was connected to their bodies through a belt tied around the waist (Figure 1). This encoder was initially used to determine the squat depth position during the jump (i.e. according to the preference of each participant) as suggested by Gheller et al. (2015). The athletes started from a static standing position and were instructed to perform a countermovement (descent phase), followed by a rapid and vigorous extension of the lower limb joints (ascent phase) with legs to the width of the shoulders (see figure 1). During the jump, participants were asked to maintain their trunk as vertical as possible, with their hands remaining on their hips. After the command “jump”, participants performed a descent, followed by an ascendant phase of the jump, which was as high as possible.

The CMJs were performed on a piezoelectric force plate (model 9290AD; Kistler, Quattro Jump, Winterthur, Switzerland), which measures vertical ground reaction force (GRF), sampling at 500 Hz, with a range of 0–10 kN, overload of 15 kN, linearity of 60.5, and hysteresis of 1. The force plate was connected to a laptop equipped with the software to analyze the force data (BioWare V5.2.2.4, Kistler Holding AG, Switzerland).

The encoder *Ergonauta* (Ergonauta®, Florianópolis, Brazil) presents 400 pulses/revolution, a 1mm/pulse resolution, and variable sampling frequency, where pulses are time-stamped with a high resolution (approximately every 10µs). Data obtained in real-time by the Ergonauta were transmitted via Bluetooth to a smartphone Zenfone Maxshot – Android® 9 (ASUS®, AsusTek Computer Inc., Taipei, Taiwan). The equipment is based on the following working principle; a retractable tether is mechanically fixed to the axis of an electromechanical sensor known as a position transducer, when the retractable tether of this equipment is coupled to the object to be monitored, all variation in displacement is converted into rotation of the transducer axis, which in turn is converted into pulses, and, finally, computed as linear displacement (specific details in the flowchart, figure 1). The time at which each pulse occurs is identified by the micro-controlled encoder so that the movement speed and other kinematic and kinetic parameters can then be estimated (LI et al., 2016). The end of the cable was attached to a belt located on the individuals' hips and the device was located between the legs, trying to make the cable as vertical as possible. This procedure was made during all assessments in order to minimize the biological and technical errors according to Figure 2.

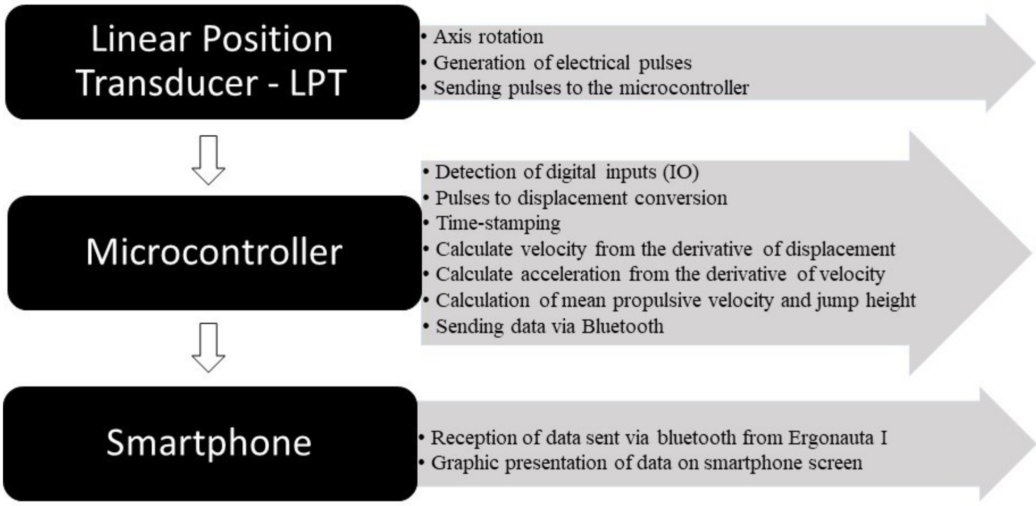


Figure 7: Specific details in the flowchart.

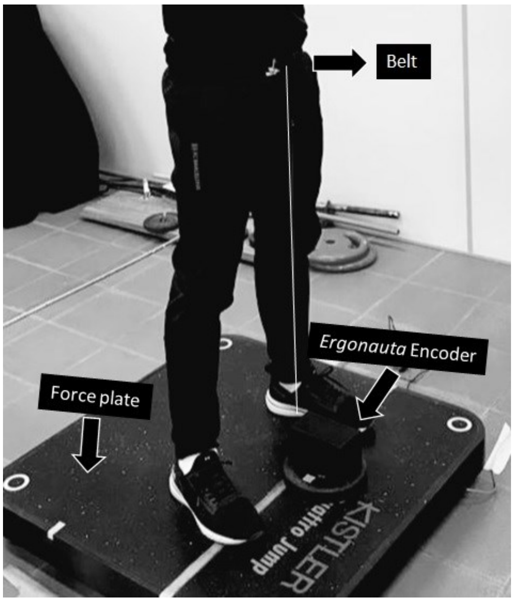


Figure 8: Ergonauta device through a belt tied around the waist over the force platform.

Data analysis

The GRF obtained from the force plate was double integrated to calculate jump height and mean propulsive velocity, as detailed below:

a) Jump height: first, the acceleration curve was obtained by dividing the GRF values by the body mass (measured in the force plate) of each individual. Next, a trapezoidal integration of the acceleration curve was used to obtain the velocity curve, with the latter integrated again to obtain the distance at each time point of the movement. The greatest vertical distance was considered as the highest jump height (DAL PUPO et al., 2012).

b) Mean propulsive velocity: calculated as the average of the velocity values corresponding to the propulsive phase of the movement (concentric phase), that is, from the first positive value of velocity until the acceleration is lower than gravity (-9.81 m/s^2) (SANCHEZ-MEDINA et al., 2010).

The same variables obtained by the force plate were calculated by the *Ergonauta* encoder, as follows:

a) Jump height: calculated from the position called off-set, which corresponds to the point where the individual is standing, with the soles of their feet fully supported on the floor. From that point on, the entire elevation of the subject's center of mass is monitored and recorded by the equipment, and the point of greatest displacement of the center of mass during the jump is considered as the highest jump height.
b) Mean propulsive velocity: initially, the acceleration data is obtained from the first derivative of the velocity data as a function of time and the noise in the mathematically smoothed data (smoothing) by means of a Kalman filter. The MPV is calculated as the concentric average of all velocity values from the beginning of the concentric phase of the jump to the take-off, i.e. during the entire propulsive phase ($a < -9.81$m/s^2).

Statistical analysis

The Intraclass Correlation Coefficient (ICC) and Typical Error (TE expressed as coefficient of variation) were used as relative and absolute reliability indicators, respectively (HOPKINS, 2002; KOO; LI, 2016), considering the jump height and mean propulsive velocity obtained by both equipment (force plate and Ergonauta encoder). We used the ICC classification proposed by Koo and Li (2016) being: > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor. Finally, the Bland-Altman plot was used to verify the agreement between all metrics obtained by the Ergonauta encoder and force plate. All statistical analyses were conducted with JASP software (version 0.11.1, JASP team, University of Amsterdam, Netherlands), considering the level of significance set at $p<0.05$.

To test the criterion validity, the Pearson product correlation was used to verify the relationship of the metrics obtained by the *Ergonauta* encoder and force plate, with the following criteria to classify the magnitude: r: 0 to 0.1 (trivial), 0.1 to 0.3 (small), 0.3 to 0.5 (moderate), 0.5 to 0.7 (large), 0.7 to 0.9 (very large), and 0.9 to 1.0 (almost perfect) (HOPKINS, 2002).

Results

Table 1 presents the relative and absolute reliability analysis (ICC and TE, respectively) of CMJ metrics obtained by the force plate and *Ergonauta* encoder. Excellent relative reliability (ICC) was observed in all variables for both devices (ICC > 0.95). The absolute reliability (TE expressed as coefficient of variation – CV) was slightly lower for mean propulsive velocity and jump height in the *Ergonauta* encoder compared to the same variables obtained in the force plate.

Table 7. Test, retest and data reliability of CMJ metrics obtained by the force plate and *Ergonauta* encoder.

Metrics	**Test (M±SD)**	**Retest (M±SD)**	**ICC (95%CI)**	**TE (%CV)**
Force Plate				
Jump height (cm)	49.4 ± 6.5	48.0 ± 6.2	0.98 (0.96 – 0.99)	1.43 (1.10 – 2.20)
Mean propulsive velocity (m/s)	1.61 ± 0.1	1.57 ± 0.2	0.95 (0.89 – 0.98)	2.46 (1.90 – 3.80)
***Ergonauta* Encoder**				
Jump height (cm)	46.6 ± 6.4	45.3 ± 6.3	0.99 (0.99 – 1.00)	1.02 (0.80 – 1.60)
Mean propulsive velocity (m/s)	1.57 ± 0.1	1.55 ± 0.2	0.99 (0.98 – 1.00)	2.14 (1.22 – 9.88)

ICC = Intraclass Correlation Coefficient; TE= typical error of measurement 95% confidence interval; CV= coefficient of variation.

Considering the validity analysis, Figure 3 shows the correlation of jump height (A) and mean propulsive velocity (B) obtained in both devices (*Ergonauta* encoder and force plate). A very large correlation was found for mean propulsive velocity and an almost perfect correlation for jump height between the devices.

Figure 9: Correlation of CMJ metrics obtained by the Ergonauta device and force plate. Jump height (A) and mean propulsive velocity (B).

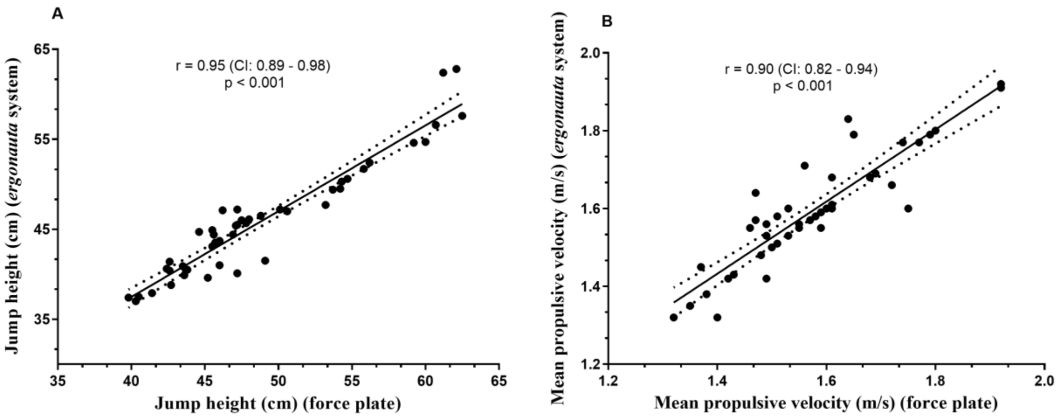
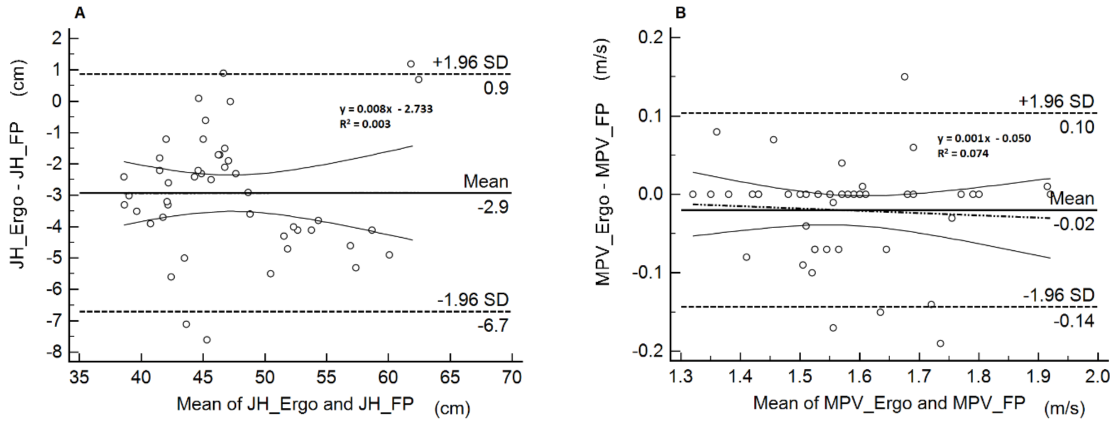


Figure 4 shows the Bland Altman plot analysis of metrics obtained from the Ergonauta encoder and force plate. The bias for jump height was -2.9, while for mean propulsive velocity the bias was close to zero (0.02), indicating agreement. For jump height, the upper limit was 0.9 and the lower limit -6.7, and for the mean propulsive velocity, the upper limit was 0.10 and the lower limit -0.14. The data did not present any significant correlations (R^2 = 0.003 and R^2 = 0.074 for vertical jump height and mean propulsive velocity, respectively), demonstrating an absence of systematic error.

Figure 10: Bland Altman plots of jump height and mean propulsive velocity obtained by the Ergonauta device and force plate. Note: VJH - jump height; MPV - mean propulsive velocity.



Discussion

The aim of this study was to test the data reliability and criterion validity of the *Ergonauta* encoder to assess the jump height and mean propulsive velocity in the CMJ. The *Ergonauta* encoder showed excellent relative reliability for the CMJ metrics (ICC = 0.99 for jump height and mean propulsive velocity) (Table 1). The TE was considered low (above 5%), showing good absolute reliability, with slightly lower values for jump height (FP = 1.43; LPT = 1.02) compared to the mean propulsive velocity (FP = 2.46; LPT = 2.14), in both measurement devices (*Ergonauta* encoder and force plate).

The reliability data are measured through repeated trials of the same measurements (HOPKINS, 2002). Good reliability implies better precision of a single measurement and better tracking of changes in measurements in research or practical settings. In the case of the metrics used in this study, both showed excellent reliability for the *Ergonauta* system. In similar studies that tested equipment validity of the CMJ using a linear position transducer, the reliability values for jump height were lower (ICC = 0.70; TE = 11.8% (O'DONNELL et al., 2017); ICC = 0.95) (WADHI et al., 2018) than our study. These differences may be explained in part by the different characteristics of the equipment tested, such as sampling rate, resolution and data filtering. For propulsive velocity, the results obtained by O'Donnell et al. (2017) showed excellent reliability (0.90 and 0.91 for peak velocity and mean velocity, respectively), but still lower than our study. These data suggest that the *Ergonauta* encoder can be used to monitor changes in CMJ performance, as it presents sufficient consistency (high ICC) and low typical error especially for jump height.

To test the criterion validity of the *Ergonauta* encoder, the data obtained by a force plate were used as a reference (gold standard). An almost perfect correlation was found for jump height (r = 0.95) between the *Ergonauta* encoder and force plate. Recently McMaster et al. (2021) and Hojka et al. (2022) found a similar magnitude of correlation in the jump height in CMJ measured by a linear position transducer (*Gymaware*) and force plate (r = 0.94 and r = 0.93, respectively), demonstrating high consistency between these devices for measuring jump height performance. Considering the mean propulsive velocity, the *Ergonauta* encoder showed a very large correlation (r = 0.90) between the same variable obtained by the force plate. Hojka et al. (2022) found lower magnitudes of correlation for peak velocity (r = 0.78) and mean velocity (r = 0.68) between the linear position transducer and force plate than those found in our study. Although the velocity variables used by Hojka et al. (2022) differ from the mean propulsive velocity tested in our study, all the measures are derived from the velocity curve, however, they are analyzed in different moments of the jump, which can result in different magnitudes of correlation.

In general, the Bland–Altman plots (Figure 2) showed a high level of agreement for the jump height and mean propulsive velocity measured by the *Ergonauta* encoder and force plate, especially considering that the majority of the values are within the limits of agreement. However, jump height provided by the *Ergonauta* underestimates the height obtained by the force plate by an average of 2.9 cm. Previous studies observed greater differences between the two methods (linear position transducer vs. force plate), reporting that the linear position transducer overestimates the values of jump height by averages of 7.0 (O'DONNELL et al., 2017), 8.0 (MCMASTER et al., 2021) and up to 9.8 cm (HOJKA et al., 2022). A possible explanation for these differences is that the aforementioned studies used the flight time (HOJKA et al., 2022; O'DONNELL et al., 2017) and velocity of the center of mass at the take-off (MCMASTER et al., 2021) to calculate jump height. The *Ergonauta* encoder uses the displacement of the center of mass during the jump (electromechanical sensor) to estimate the JH, which is a measure with low typical error. In addition, equipment sampling rates and the rapid transition between concentric and eccentric contraction phases may increase measurement errors and could explain the differences between studies (MORENO-VILLANUEVA et al., 2021).

When the jump height is calculated using the flight time (e.g., contact mats), in general, the result is underestimated by an average of 10.32 cm compared to the double integration of force method (ACHE-DIAS et al., 2011). Therefore, the use of these methods tends to underestimate the vertical jump height to a higher degree compared to the linear position transducer. The difference found in present study for the jump height between the methods (force plate vs. linear position transducer) is the lowest observed in the current literature. The mean propulsive velocity differed on average by -0.02 m/s between the two methods, showing excellent agreement. We analyzed this measure, particularly, because it is as an important alternative to determine the intensity of training with vertical jumps (GONZÁLEZ-BADILLO et al., 2015; LOTURCO et al., 2015; RODRÍGUEZ-ZAMORA et al., 2019). Additionally, it is an important indicator of athletic performance, as its calculation is independent of the athletes' body mass (LOTURCO et al., 2015). Thus, even if our results showed Ergonauta can estimate JH and MPV during the countermovement jump similarly to the force plate, we suggest both technologies are not are not completely interchangeable, taking into account the limits of agreement.

Finally, some limitations can be highlighted. First, only the CMJ was performed to test the validity of the *Ergonauta* encoder, so it is not possible to identify whether similar results would be found for the squat jump and the drop jump, for example. Despite this, some studies have shown great relevance of CMJ performance (LOTURCO et al., 2015; MARKOVIC et al., 2004). In addition, the use of the *Ergonauta* encoder can represent a practical tool particularly for use outside the laboratory environment, as it is portable and does not need to be connected to an electrical current. We recommend that future studies investigate the *Ergonauta* encoder in other jump tests (e.g. squat jump, drop jump) and considering other metrics (power output, force, peak velocity). Moreover, it is recommend analyzing upper limb exercises, for example, bench press performed on the Smith machine, using different protocols, with and without isometric pause between eccentric and concentric contractions, as well as testing other populations, such as elite athletes and female groups.

Conclusion

We concluded that the *Ergonauta* encoder is reliable and valid to measure CMJ performance variables (jump height and mean propulsive velocity). Thus, the *Ergonauta* encoder can be used to assess and monitor changes in CMJ performance over time; however, caution should be employed when comparing the metrics with other measuring devices.

References

The references of the paper are at “references section”.

5.3 Study 3

OPTIMUM POWER-LOAD PROFILE IN SQUAT AND COUNTERMOVEMENT JUMP AND ITS ASSOCIATION WITH FORCE-VELOCITY BALANCE

Article submitted to Sports Biomechanics

Abstract

This study aimed to test the optimal external load in vertical jump protocols (counter movement jump – CMJ and squat jump – SJ) on the jump height, power output, and mean propulsive velocity metrics, and to verify the association between force-velocity profile and optimal external load. Twenty-two recreationally active men participated in this study. The participants performed the CMJ and SJ considering different loads (0 to 50% of body mass) on two different days. Analysis of variance for repeated measures with Bonferroni post hoc was used to compare the CMJ and SJ metrics among different conditions. In addition, the Kappa test and Pearson's correlation were used to test the level of agreement between the categories and the relationship between vertical jump metrics and the force velocity profile, respectively, with the level of significance set at 5%. In general, there was a decrease in CMJ and SJ performance metrics (jump height, power output, and mean propulsive velocity) at higher loads ($p<0.05$). No significant agreements or correlations were found between the force-velocity profile (i.e. balance and non-balance) and CMJ and SJ metrics ($p>0.05$). We concluded that performance in the CMJ and SJ is higher in the condition of 0% external load, and the balanced force-velocity profile is not related with external load of CMJ and SJ.

Keywords: Power output, optimal load, force plate, muscle power.

Introduction

In a range of different sports, muscle power is essential for the execution of several motor actions involved in sport-specific technical and locomotor activities, such as jumps and sprints, with or without change of direction and accelerations (CRONIN; SLIVET, 2005). Since power is the product of force and velocity, both components need to be contemplated in a training program to develop muscle power. One of the most commonly discussed aspects in power training is the external workload used. The use of external load during the vertical jump is supported by the inverse association between force (external load) and velocity (HILL, 1938). In this perspective, the search for the ideal or optimal load for the development of muscle power has been widely studied in recent years, using different analysis methods and exercises to obtain maximal power output (MARKOVIC et al., 2011; LOTURCO et al., 2015; MORIN; SAMOZINO, 2016; MUNDY et al., 2016).

Identification of the optimal external load to be used in power training has shown contradictory results, as previous studies found values ranging from below body mass (i.e., negative external loads) during countermovement jump (CMJ) (MARKOVIC et al., 2011; VUK et al., 2012); to positive external loads of 60% of 1RM (one maximal repetition) (SMILIOS et al., 2013) and 100% of body mass (LOTURCO et al, 2015) in the jump squat exercise, and also situations in which peak power is obtained with only body mass (BEVAN et al., 2010; MOIR et al., 2012; MUNDY et al., 2016). Thus, the load capable of maximizing the power output seems to be dependent on the method used, considering, for example, the movement used and outcome variable analyzed.

Due to their feasibility, the squat jump (SJ) and CMJ exercises are widely used by strength and conditioning coaches in power training and assessment programs. The specificity of the mechanical characteristics of these tasks (e.g., the presence of a negative phase and elastic energy in the CMJ) may lead to different strategies for maximizing jump performance, resulting in different power load profiles in SJ and CMJ. Another important aspect is the outcome variable. Mean power (MPO) and peak power output (PPO) collected during the upward portion of the movement are widely used to assess sport performance and to optimize training strategies. PPO obtained during the vertical jump corresponds to a specific moment close to the take-off, while MPO represents the entire push-off phase; therefore, these measures seem to represent different mechanical principles and may have different sensitivity to detect neuromuscular adaptations from training (DAL PUPO et al., 2020). In addition, the use of a fixed velocity value obtained at the optimum power load is another variable outcome proposed in the literature (LOTURCO et al., 2015), justified by the use of linear encoders and/or accelerometers to determine the optimum loads, at a low cost and reduced the time spent assessing power. Loturco et al. (2015) point out that despite their extensive use as reference values of muscle power, the varied spectrum of loads used to assess these variables produces large dissimilarity in the outputs obtained.

It has been suggested that one of the possible explanations for the variety in the optimum power load zone is the force-velocity (F-v) profile of athletes. Samozino et al. (2010) proposed that athletes with differing F-v characteristics would likely optimize power under different external loading conditions. According to Morin et al. (2020) an athlete who has an optimal F-v profile will have their own body mass as optimal load and, thus, will produce maximum power during a vertical jump without additional load; however, this does not always occur and may be associated with an imbalance in the force-velocity curve. On the other hand, Jaric and Markovic (2013) suggest that the ideal load depends on the individual's muscle strength capacity, that is, the power peak occurs at a higher percentage of body mass or load for relatively stronger individuals instead of their own body mass, while the opposite occurs for weaker individuals.

Therefore, the current study aimed to analyze the optimal power load (0, 10, 20, 30, 40, and 50% of body mass) in the squat jump and countermovement jump, considering the outcome variables of peak power and mean output and mean propulsive velocity, as well as to analyze the association between the force-velocity profile (balanced or unbalanced individuals) and the optimal external load condition (loaded or unloaded). The first hypothesis was that the participants would perform better in the condition of 0% load (i.e., body mass), based on previous studies (MOIR et al., 2012; MUNDY et al., 2016). Secondly, we hypothesized that there would be an influence of the force-velocity profile on the optimal power production.

Methods

Study Design

The study had a cross-sectional descriptive design, in which participants performed two visits to the laboratory. On both visits, the subjects were familiarized with the CMJ and SJ protocols and their preferred squat depth during the jump was determined. On the first visit, the CMJ test was performed under the conditions: unloaded jump (0% BM) and with loads corresponding to 10, 20, 30, 40, and 50% of body mass (loaded jumps). After an interval of from 48 to 72 hours, the SJ test was applied with the same loads performed in the CMJ. The optimal power load was analyzed taking peak and mean power output, mean propulsive velocity, and jump height as outcome variables. In addition, the force-velocity profile was verified.

Participants

Twenty-two recreationally active men participated in this study, with the following characteristics: age 22.7 ± 4.07 years, height 179 ± 7.0 cm, and weight 77.2 ± 12.2 kg. All participants were undergraduate students and were not engaged in any club, collegiate, or professional sport. Participants were: a) physically active (i.e., practice strength training, running, and/or sports involving jumps such as volleyball, basketball, judo, and soccer) three to five times a week for at least one year; and b) had no injuries or pathologies that would preclude maximum effort in the tests. Participants read and signed the informed consent. The university's Institutional Review Board approved this project (CAEE: 57615022.7.0000.0121) according to the declaration of Helsinki. During the procedures, individuals were required to wear athletic clothing and shoes.

Procedures

Determination of power load profile in vertical jump

Before the vertical jump assessment, the subjects participated in a familiarization/warm-up, involving 30 seconds of jumping on a trampoline, 3 series of 10 jumps on the ground, and 5 submaximal CMJs. For the CMJ, participants started from a static standing position and were instructed to perform a counter movement (descent phase) followed by rapid and vigorous extension of the lower limb joints (ascent phase). During the jump, the participants were asked to keep their trunk as vertical as possible, and the hands holding an iron bar on the shoulders with the previously determined loads. In the condition without external load (i.e. 0% of body mass), the individual supported a rigid plastic pipe weighing close to 200 grams and measuring 2 meters, with the objective of adopting the same position as with the iron bar. The athletes were then instructed to jump as high as possible. In the SJ, the subjects started the jump from a static position, with the knees at an angle of approximately 90°, and the jump was performed without any countermovement. The vertical jumps were performed on a piezoelectric force platform (9290AD, 500 Hz, Kistler, Quattro Jump, Winterthur, Switzerland). In addition, a linear encoder (*Ergonauta*) was attached using a waist belt to measure the mean propulsive velocity during the jumps.

The load power profile was tested using six different external loads (0%, 10%, 20%, 30%, 40%, and 50% of body mass). Each participant completed two attempts at each load, and in cases where there was a coefficient of variation greater than 5%, a third attempt was performed. The highest jump height was used for the analyses. A 1-minute rest was provided between each jump, with a 3-minute rest between each load.

Determination of Force-Velocity Profile

To determine the individual force-velocity (F-V) profile, mechanical parameters were calculated for each load condition for the SJ and CMJ, following the method proposed by Samozino et al. (2008) and Jiménez-Reyes et al., (2017). This method proposes that force (F), velocity (v), and power (P) can be calculated during a vertical jump from the measurement of the jump height and squat jump positions. To calculate the F-v profile, the flight time recorded on the force platform was used to obtain the height of the jumps. Force, velocity, and power were calculated using three equations that consider the following variables: body mass (m), jump height (h), and push-off distance (h_{PO}) (distance covered by the center of mass during push-off) (SAMOZINO et al., 2008). The value of h_{PO} was measured as the difference between the extended lower limb length (iliac crest to toes with plantar flexed ankle) and the length in the individual standardized starting position (iliac crest to ground vertical distance). F, v, and P were calculated using the following equations:

$$F = mg\left(\frac{h}{h_{PO}} + 1\right)$$

$$v = \sqrt{\frac{gh}{2}}$$

Where m is the body mass in an unloaded condition and the body mass of the system (subject + additional load) in loaded conditions, g is the gravitational acceleration, h is the jump height, and h_{PO} is the vertical push-off distance. From F and v values, individual linear F-v relationships were determined by least-squares linear regressions (SAMOZINO et al., 2012) to obtain the F-v profile normalized to body mass (S_{Fv}, slope of the F-v curve) and P max (W.kg^{-1}) was determined as:

$$P_{max} = \frac{F_0 \, . \, v_0}{4}$$

From Pmax and push-off distance values, an individual theoretical optimal F-v profile (normalized to body mass), maximizing vertical jumping performance, was computed using the equations proposed by Samozino et al (2012). The F-v imbalance (Fv_{imb}, in %), was then individually calculated with the equation proposed by Samozino et al (2014):

$$Fv_{imb} = 100. \left| 1 - \frac{S_{Fv}}{S_{Fv}opt} \right|$$

An Fv_{imb} value near 100% represents the optimal profile (perfect balance between force and velocity qualities), whereas an F-v profile value higher or lower than 100% indicates a profile oriented for force or velocity capabilities, respectively.

Data analysis

The ground reaction force (GRF) obtained from the force plate was double integrated to calculate jump height, as detailed below:

a) Jump height: first, the acceleration curve was obtained by dividing the GRF values by the body mass (measured by the force plate) of each individual. Next, a trapezoidal integration of the acceleration curve was used to obtain the velocity curve, with the latter integrated again to obtain the distance at each time point of the movement. The greatest vertical distance was considered as the highest jump height.

b) Power output: calculated by multiplying GRF by velocity at the concentric phase of the jump. The peak and mean value of the curve was used for analysis.

c) Mean propulsive velocity: calculated as the average of the velocity values corresponding to the propulsive phase of the movement (concentric phase), that is, from the first positive value of velocity until the acceleration is lower than gravity (−9.81

m/s^2). The MPV was calculated using an *Ergonata* encoder, previously validated (GHELLER et al., 2023).

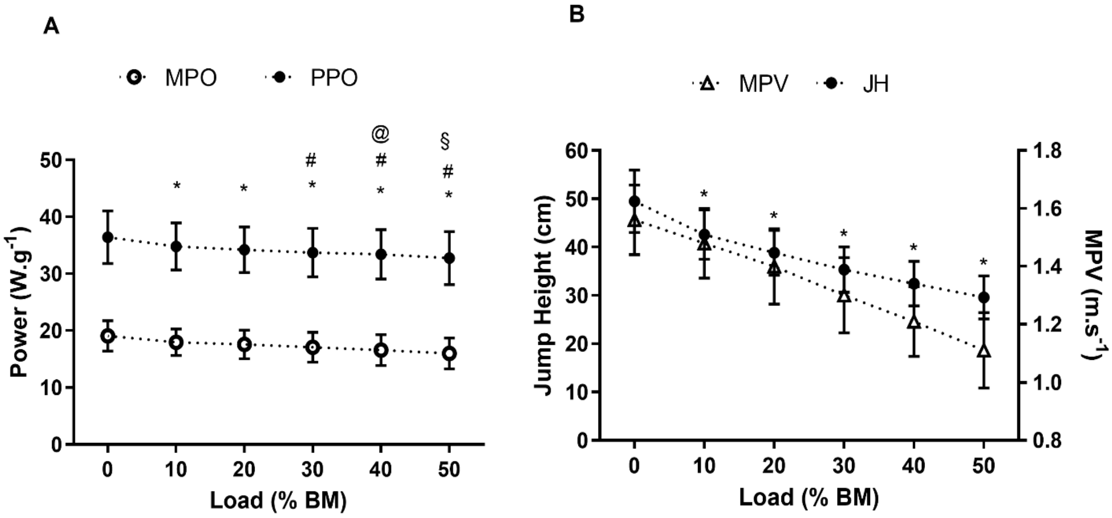
Statistical analysis

Data are reported as means and standard deviations. The Shapiro–Wilk test was used to verify the normality of the residual data. Analysis of variance with repeated measures (within-subject ANOVA) and Bonferroni post hoc tests were used to compare the vertical jump metrics (power output, jump height mean propulsive velocity) among different conditions of external load (0-50% of body mass) for both CMJ and SJ. The effect sizes (ES) for ANOVA were calculated using partial eta squared (η_p^2), with <0.01 (small), 0.01-0.06 (medium), and 0.06-0.14 (large), respectively (COHEN, 1988). The Kappa test was used to test the level of agreement between the categories generated by the optimum power load zone (optimum power load in loaded or unloaded jumps) and the F-v profile groups (balanced = Fv_{imb} between 90 and 110%; non-balanced = Fv_{imb} <90 or >110%). The following Kappa classification was adopted: 0 indicates no agreement, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1 almost perfect agreement (LANDIS; KOCH, 1977). For all analyses, the significance level was set at 0.05 and JASP software was used.

Results

Figure 11 shows the variables peak and mean power output (Panel A), jump height, and mean propulsive velocity (Panel B) for different external loads (0, 10, 20, 30, 40, and 50% of body mass) in the CMJ. Significant differences were found for peak power ($F_{5,105} = 38.61$; $p < 0.001$; η p2 = 0.637 [large]), mean power (F5,105 = 47.80; $p < 0.001$; η p2 = 0.685 [large]), jump height (F5,105 = 31.52; $p < 0.001$; η p2 = 0.935 [large]), and mean propulsive velocity (F5,105 = 34.12; $p < 0.001$; η p2 = 0.859 [large]). The post hoc analysis showed high values in the 0% load compared to the other loads (10, 20, 30, 40, and 50%) for peak and mean power. Considering the 10% load, differences were found compared to 30, 40, and 50%. The 20% load was higher compared to 40% (only for mean power) and 50% and 30% was higher compared to 50%. The post hoc detected a progressive decrease in jump height and mean propulsive velocity throughout the load conditions.

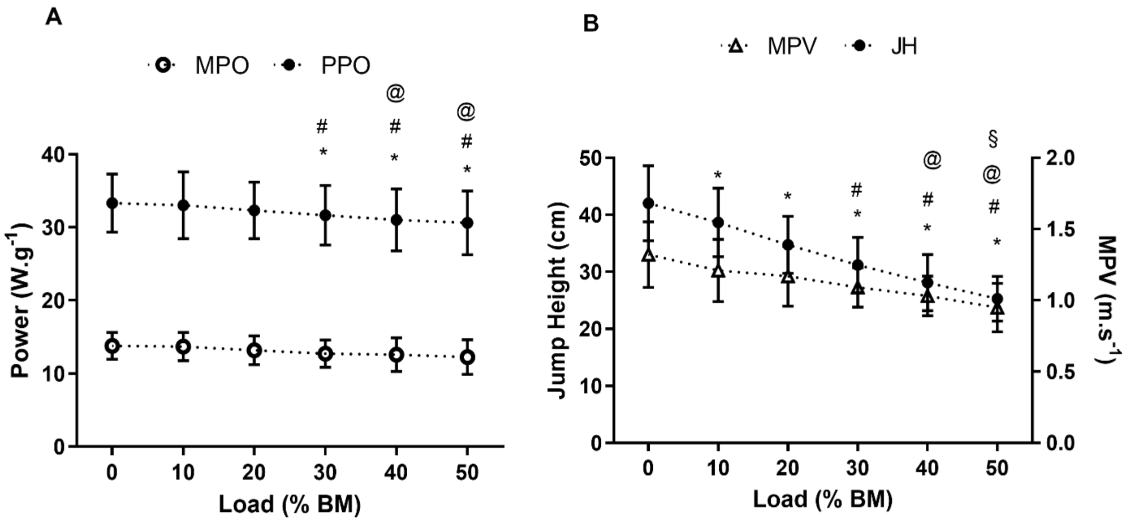
Figure 11. Comparison of vertical jump metrics among different external loads (0, 10, 20, 30, 40, and 50% of body mass) in the Countermovement Jump.



Note: MPO = mean power output; PPO= peak power output; MPV = mean propulsive velocity; JH = jump height; * different from 0%, # different from 10%, @ different from 20%; § different from 30%.

Figure 12 shows the variables peak and mean power output (Panel A), jump height, and mean propulsive velocity (Panel B) for different external loads (0, 10, 20, 30, 40, and 50% of body mass) in the SJ. Significant differences were found for peak power ($F_{5,105}$ = 43.22; $p < 0.001$; η p2 = 0.954 [large]), mean power (F5,105 = 40.07; $p < 0.001$; η p2 = 0.323 [large]), jump height (F5,105 = 25.67; $p < 0.001$; η p2 = 0.925 [large]), and mean propulsive velocity (F5,105 = 30.86; $p < 0.001$; η p2 = 0.595[large]). The Bonferroni post hoc analysis demonstrated higher values of peak and mean power in the 0% load compared to 30%, 40%, and 50%. High values were found for 10% compared to 30%, 40%, and 50%. Finally, high values were detected at 20% compared to 40% (only for peak power and 50%). For jump height, the post hoc detected progressive decreases throughout the loaded conditions. For mean propulsive velocity, high values were found in the 0% load compared to 10, 20, 30, 40, and 50%, and high values were found for the 10% load compared to 30, 40, and 50%. In addition, the 20% load was higher compared to 40 and 50%.

Figure 12. Comparison of vertical jump metrics among different external loads (0, 10, 20, 30, 40, and 50% of body mass) in the Squat Jump (SJ) protocols.



Note: MPO = mean power output; PPO= peak power output; MPV = mean propulsive velocity; JH = jump height; * different from 0%, # different from 10%, @ different from 20%; § different from 30%.

Tables 8 and 9 present the analysis of agreement between the F-v profile (balanced and non-balanced individuals) and the load where optimum maximum power was obtained (loaded or unloaded jumps) for peak and mean power in the SJ and CMJ, respectively. No significant agreement was detected between the F-v profile (balanced or unbalanced) and the optimum power load condition (loaded and unloaded) in the SJ for peak (*k*= -0.085, p=0.531) and mean power (*k*= -0.086, p=0.484), or in the CMJ, considering peak (*k*=-0.078, p=0.629) and mean power (*k*=-0.082, p=0.579).

Table 8. Agreement between force-velocity (F-v) profile and load condition (loaded and unloaded jumps) for PPO and MPO in the SJ.

		PPO in loaded SJ	**PPO in unloaded SJ**
F-v profile	Balanced	0 (0%)	1 (100%) *
	Non-balanced	6 (28.6%)	15 (71.4%)
		MPO in loaded SJ	**MPO in unloaded SJ**
F-v profile	Balanced	0 (0%)	1 (100%) #
	Non-balanced	7 (33.3%)	14 (66.7%)

MPO = mean power output; PPO = peak power output

Table 9. Agreement between force-velocity (F-v) profile and peak power output (PPO) and mean power output (MPO) in loaded and unloaded conditions in the CMJ.

		PPO in loaded CMJ	**PPO in unloaded CMJ**
F-v profile	Balanced	0 (0%)	1 (100%) *
	Non-balanced	4 (19%)	17 (81%)
		MPO in loaded CMJ	**MPO in unloaded CMJ**
F-v profile	Balanced	0 (0%)	1 (100%) #
	Non-balanced	5 (23.8%)	16 (76.2%)

MPO = mean power output; PPO = peak power output

Discussion and Implications

The aim of this study was to analyze the optimal power load profile (0 – 50% of body mass) in the CMJ and SJ protocols and to verify the relations of the force-velocity profile of the individuals. Considering the first goal, the first hypothesis was accepted, since the participants presented the optimum power at 0% BM (unloaded condition) for both CMJ and SJ. Considering the second aim, our hypothesis was refuted.

The results of the present study were similar to those observed in previous studies, in which the optimum load to generate maximum power output was found in the unloaded condition (i.e., only with body mass), for CMJ (SHEPPARD et al., 2008; MUNDY et al., 2016; KANG, 2018), and SJ (BEVAN et al., 2010). Furthermore, Markovic and Jaric (2007b) found that the peak power output was higher when the participants performed the CMJ without external load or with a negative load (-30% of body mass), while there was a decrease in peak power with positive external loads (~15 and 30% of body mass). Moir et al. (2012), when analyzing 0% and up to 85% of 1RM and verified that the peak power output occurred at the 0% load accompanied by a progressive reduction in this variable with increased load during the jump squat. This aspect is possibly linked to the fact that the increase in inertia caused by the external load (i.e. higher than body mass) significantly decreases the velocity of the vertical jump movement and, consequently, can lead to a reduction in power output (CORMIE et al., 2008).

Other studies have found contrary results, i.e., peak power was identified in external loads higher than body mass, but using the Smith machine to perform the performance protocols (NUZO et al., 2010; JIMENEZ-REYES et al., 2016; LOTURCO et al., 2015) instead of vertical jumps (i.e. free form), as in our investigation. In this sense, it is possible to identify different results when different exercises or methodologies are used in studies with jump protocols.

Analyzing the jump height and MPV, the optimal external load was identified at the 0% load with significant decreases in these variables with load increases in both CMJ and SJ protocols**.** Several studies found similar results when performing vertical jumps with external load (e.g. decrease in performance with higher loads) (JIMENEZ-REYES et al., 2016; MUNDY et al., 2017; KANG, 2018, PÉREZ-CASTILLA et al., 2021; LOTURCO et al., 2021). The decrease in jump height in the vertical jump protocols is expected, because during the jumping movement, the neuromuscular system is overloaded by the inertia of the body mass and body segments (LINTHORNE et al., 2011). However, when the vertical jump is performed with external load there is additional inertia, with an increase in total inertia, decreasing the ability to perform the jump and the velocity of the movement (LEONTIJEVIC et al., 2012). In addition, the height obtained in the CMJ and SJ has a strong correlation with peak velocity ($r > 0.95$), so these metrics have a similar response during the vertical jump (DAL PUPO et al., 2012).

Another interesting aspect is the identification of MPV at the optimal external load, as proposed by Loturco et al. (2015). According to the authors, the optimum power load is found when the MPV is close to 1 $m.s^{-1}$ during the jump squat in the Smith machine. However, in the present study the MPV corresponding to the optimum power load was higher for both CMJ (1.61$m.s^{-1}$) and SJ (1.30$m.s^{-1}$). These differences may be related to the different methodologies adopted, such as the type of vertical jump performed, the use of equipment (Smith) to perform the jumps, and the training level of the subjects. As pointed out by Loturco et al (2015), the usage of a fixed and known velocity related to the optimum power zone may help sport scientists who use linear encoders and/or accelerometers to determine the optimum loads for their athletes, which may significantly reduce the time spent assessing power.

The second goal was to test the influence of the force-velocity profile (balance and non-balance individuals) on the optimal zone of power production. The second hypothesis was rejected, as no significant agreement was found between the F-v profile (balanced and non-balanced) and power output in loaded and unloaded conditions in the CMJ and SJ. This result can be explained by the fact that the participants of the present study are from different sports, presenting different training characteristics and muscle adaptations. Previous studies have shown that volleyball players (PLEŠA et al., 2021), track and field athletes (sprinters and jumpers) (JIMÉNEZ-REYES et al., 2014), and soccer players (MARCOTE-PEQUEÑO et al., 2019) have an F-v profile oriented on velocity (force deficit), while rugby players have an F-v profile oriented on force (velocity deficit) (JIMÉNEZ-REYES et al., 2017). Thus, the orientation of the F-v profile is different between sports, in addition to presenting high variability between individuals within each sport (HAUGEN et al., 2019).

Finally, as the main limitation of the study, we can point out the low and diverse level of sports experience for the participants (e.g. volleyball, basketball, judo, and soccer players), which may lead to greater variability in the metrics associated with the CMJ and SJ performances.

Conclusion

We concluded that the optimum power load for CMJ and SJ were at 0% BM (i.e., unloaded condition) taking peak power output and mean power output as outcome variables The MPV related to the optimum power load zone was, on average, 1.61 m/s and differed between CMJ and SJ. The F-v profile (balanced or unbalanced individual) seems not to influence the optimal zone of power production in the CMJ and SJ. For the practical applications, we recommend that coaches using vertical jump training to improve muscle power, specifically the CMJ and SJ, should prescribe training without external load (i.e., only with body mass). In addition, the MPV of 1.61 m/s would be a reference for training at the optimum power zone.

References

The references of the paper are at “references section”.

5.4 Study 4

BRIEF NOTE

METHODS TO CALCULATE LOWER-BODY STRETCH-SHORTENING CYCLE UTILIZATION IN THE VERTICAL JUMP: WHICH IS THE BEST FOR ATHLETES OF DIFFERENT SPORTS?

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Abstract

Purpose: This study aimed to verify if different stretch-shortening cycle (SSC) methods, obtained by the vertical jump test, present the same characteristics through consistency and agreement analysis, and to compare the SSC methods between athletes of different sports.

Summary of facts and results: 341 male athletes of three sports groups (combat sports, team sports, and runners) participated of this study. Athletes performed the countermovement jump and squat jump tests to identify the SSC using three methods: reactive strength index (RSI), pre-stretch augmentation percentage (PSA), and eccentric utilization ratio (EUR). The results demonstrated very large correlations between the methods for jump height (r=0.96-0.98) and power output (r=0.95-0.98), almost perfect agreement for jump height (k=0.86-0.91) and substantial to almost perfect agreement for power output (k=0.77-0.92). The RSI, PSA, and EUR were higher in team sports than combat sports for jump height (p=0.006, p=0.008, p=0.007, respectively), EUR was higher for team sports than combat sports for power output (p=0.041).

Conclusion: The methods of SSC are strongly correlated and present excellent agreement. Team sports athletes presented greater use of SSC compared to combat sports regardless of the method.

Keywords: Jump height, elastic index, power output, jump performance.

Introduction

The stretch-shortening cycle (SSC) is a phenomenon of muscle function that occurs naturally when a muscle is stretched (eccentric contraction), followed immediately by a shortening (concentric contraction) of the same muscle (KOMI, 2000). Several methods have been utilized to assess the ability to use the SSC, most of which involve calculations using jump height and power output measures of countermovement jump (CMJ) and squat jump (SJ) performances (SUCHOMEL, SOLE; STONE, 2016), such as the reactive strength index (RSI) (YOUNG, 1995), pre-stretch augmentation percentage (PSA) (WALSHE, 1996), and eccentric utilization ratio (EUR) (MCGUIGAN et al., 2006). These SSC methods present different calculations based on the differences between CMJ and SJ using jump height and power output measures (SUCHOMEL, SOLE; STONE, 2016); however, there is no consensus in the literature on which method is more effective to determine the ability to use the SSC. Athletes of different sports can showed differences in the use of SSC. Suchomel, Sole and Stone (2016) compared different SSC methods between team and individual sports (e.g. baseball, soccer, tennis, and volleyball), and found that regardless of the method female tennis players and male soccer players use the SSC more effectively compared to other sports.

In the current study, we intend to identify whether the SSC methods respond in a similar way, and to compare the SSC methods in large groups of sports (i.e. combat sports, team sports, and individual sports), which involve SSC mechanisms in sport-specific tasks (DAL PUPO et al., 2021). Thus, the objectives of the current study were: (a) to verify, through consistency and agreement analysis, if different SSC methods obtained from jump height and power output present the same characteristics; b) to compare the SSC methods between athletes of different sports.

Methods

Participants

Three-hundred and forty-one male athletes (age: 24.8±5.5 years; height: 177±12 cm; body mass: 72.8±12.0 kg) participated in this study. The participants were divided into three sports groups: 61 athletes from combat sports (judo and Brazilian jiu-jitsu), 267 from team sports (soccer, futsal, and volleyball), and 13 from individual sports (sprint runners). Participants attended training sessions on at least 3 days a week and had a minimum of 6 years of experience in their sport. All participants signed a written informed consent form agreeing to participate. The study was approved by the University Ethics Committee, in accordance with the Declaration of Helsinki.

Countermovement Jump (CMJ) and Squat Jump (SJ) Assessments and SSC Calculations

Initially the athletes were familiarized and warmed-up through 3 series of 10 jumps, and 5 submaximal CMJs. For the CMJ, they started from a static standing position with their hands on their waist and were instructed to perform a countermovement (descent phase) followed by rapid and vigorous extension of the lower limb joints (ascent phase). In the SJ, the subjects started the jump from a static position, with the knees at an angle of about 90°, and the hands on the waist. The jump was performed without any countermovement. The vertical jumps were performed on a force platform (Kistler, Quattro Jump). Each participant completed 5 jumps with a rest interval of 1 minute between attempts; the 3 best attempts were retained for analysis. Double integration of the ground reaction force from the analysis of the force platform data were used to calculate jump height and mean power output (W/kg).

Three different methods were used to determine the use of the SSC. The reactive strength index (RSI) was calculated using the equation CMJ variable – SJ variable (YOUNG, 1995). The pre-stretch augmentation percentage (PSA) was calculated using the equation [CMJ variable – SJ variable] / [SJ variable] * 100 (WALSHE, 1996). The eccentric utilization ratio (EUR) was calculated using the equation CMJ variable / SJ variable (MCGUIGAN et al., 2006).

Statistical Analysis

To identify the consistency between SSC methods for jump height and power output, Pearson's linear correlation was used, and the Kappa test was used to test the level of agreement between the categories (tertiles) generated by the three different SSC methods. ANOVA one way with Tukey post hoc test was used to compare the SSC methods between the three sports groups (combat sports, team sports, and individual sports). The significance level for all analysis was set at 0.05, JASP software was used for analysis.

Results

Very large correlations were found between the SSC methods. For jump height, the EUR ratio was correlated with the PSA ($r=0.98$, $p<0.01$) and RSI ($r=0.97$, $p<0.01$), and the PSA was correlated with the RSI ($r=0.98$, $p<0.01$). For power output, the EUR was correlated with the PSA ($r=0.98$, $p<0.01$) and RSI ($r=0.96$, $p<0.01$), and the PSA was correlated with the RSI ($r=0.95$, $p<0.01$).

Table 1 shows the Kappa results (agreement) among the methods for jump height and power output. There was a significant agreement of the EUR with the PSA ($k=0.86$; $p<0.01$, almost perfect agreement) and RSI ($k=0.87$, $p<0.01$, almost perfect agreement), as well as between the PSA and RSI ($k=0.91$, $p<0.01$, almost perfect agreement). For the power output, there was a significant agreement of the EUR with the PSA ($k=0.92$; $p<0.01$, almost perfect agreement) and RSI ($k=0.77$, $p<0.01$, substantial agreement), as well as between the PSA and RSI ($k=0.81$, $p<0.01$, almost perfect agreement).

Table 10. Relative and absolute agreement generated by eccentric utilization ratio, pre-stretch augmentation percentage and reactive strength index (for jump height and power output), into the three tertiles.

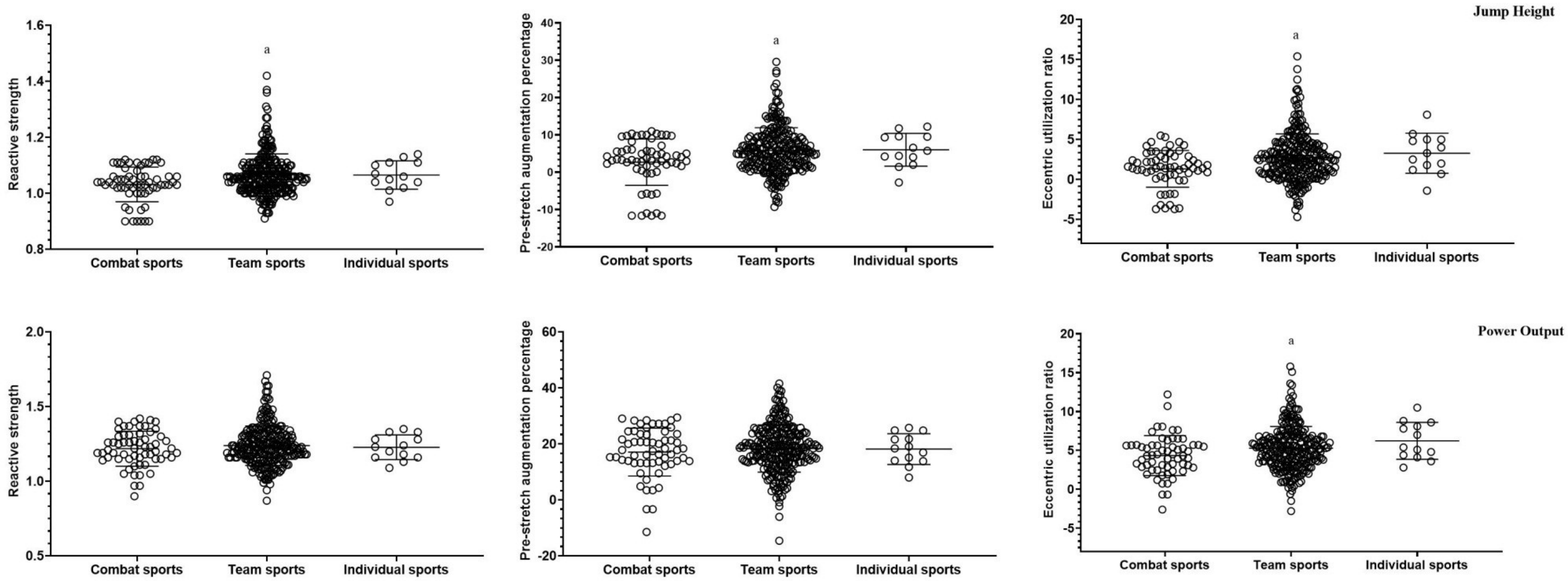
Jump Height		**Eccentric utilization ratio (JH)**		
		Inferior	Intermediate	Superior
Pre-stretch augmentation percentage (JH)	Inferior	**85.7% (114)**	14.3% (19)	0% (0)
	Intermediate	0% (0)	**88% (95)**	12% (13)
	Superior	0% (0)	0% (0)	**100% (0)**
Reactive strength index (JH)	Inferior	**86.5% (115)**	13.5% (18)	0% (0)
	Intermediate	0% (0)	**91.7% (99)**	8.3% (9)
	Superior	0% (0)	3.0% (3)	**97.0% (97)**
		Pre-stretch augmentation percentage (JH)		
Reactive strength index (JH)	Inferior	**98.2% (112)**	1.8% (2)	0% (0)
	Intermediate	2.6% (3)	**93.9% (107)**	3.5% (4)
	Superior	0% (0)	9.7% (11)	**90.3% (102)**
Power output		**Eccentric utilization ratio (PO)**		
		Inferior	Intermediate	Superior
Pre-stretch augmentation percentage (PO)	Inferior	**89.0% (113)**	11% (14)	0% (0)
	Intermediate	1% (1)	**96.2% (100)**	2.9% (3)

	Superior	0% (0)	0% (0)	**100% (0)**
Reactive strength index (PO)	Inferior	**83.5% (106)**	16.5% (21)	0% (0)
	Intermediate	7.7% (8)	**80.8% (84)**	11.5% (12)
	Superior	0% (0)	10.9% (12)	**89.1% (98)**
		Pre-stretch augmentation percentage (JH)		
Reactive strength index (PO)	Inferior	**90.4% (103)**	9.6% (11)	0% (0)
	Intermediate	9.6% (11)	**82.5% (94)**	7.9% (9)
	Superior	0% (0)	10.6% (12)	**89.4% (101)**

JH = Jump Height; PO = Power output

Figure 1 shows the use of the SSC for jump height and power output for the sports groups. For jump height, a difference was detected considering the RSI ($p = 0.008$, small effects), PSA ($p= 0.010$, small effects), and EUR ($p= 0.007$, small effects). The Tukey post hoc detected a higher RSI, PSA, and EUR for team sports compared to combat sports ($p=0.006$, $p=0.008$, $p=0.007$) respectively. For power output, a difference was found only for the EUR ($p= 0.019$, small effects), being higher for team sports compared to combat sports ($p=0.041$). No difference was found for the RSI ($p= 0.52$, small effects) and PSA ($p= 0.55$, small effects).

Figure 13. Comparison of reactive strength index, pre-stretch augmentation percentage, and eccentric utilization ratio for jump height and power output according to sports groups. Note: a = different from combat sports group.



Discussion

The goal of this study was to verify if different SSC methods obtained from jump height and power output present the same characteristics through consistency and agreement analysis, and to compare the SSC methods between athletes of different sports. The SSC methods presented strong correlations (consistency) and agreement, probably because they are derived from the same metrics. The team sports athletes showed higher use of SSC compared to combat sports athletes.

The methods of SSC calculation analyzed in this study are derived from the differences between CMJ and SJ performances using jump height and power output as metrics (SUCHOMEL, SOLE; STONE, 2016). Identifying these parameters provides important information on muscle function in different motor tasks in which SSC is present (e.g. running, jumping, hoping). We can state that all methods analyzed in this study may be used to identify the SSC use in different sports, as they showed similar consistency and agreement. In a previous study, Suchomel, Sole and stone (2016) also found excellent magnitudes of correlation between the SSC methods, considering 86 male and female athletes of different sports (e.g., soccer, tennis, and volleyball). Although jump height and power output do not represent the same thing (KONS et al., 2018), it seems that there is a similar agreement in the SSC methods using both variables, indicating that SSC indices can be calculated from the jump height or power output with similar results.

It was found that team sports athletes showed higher use of SSC compared to combat sports athletes regardless of the method. This difference could be explained by the fact that athletes of team sports usually perform movements that involve high use of the SSC during sport-specific training, such as sprinting, change of direction in soccer, futsal, and especially, jumps in volleyball (DAL PUPO et al., 2021). Combat sports athletes require the use of the SSC to maximize sport-specific performance, especially during the execution of certain throwing techniques and submissions. In combat sports the fighters are often required to quickly produce a substantial amount of force, thus, the time they spend from initiating to completing a movement is often minimal, which reduces the preparatory movement phase in the lower limbs, reducing the use of the SSC (VIEIRA; TUFANO, 2021). An interesting result was that only the eccentric utilization ratio differed between sports groups when using the power output metric (higher for team sports). Therefore, when performing comparisons between sports groups, jump height may be used instead of power output in all SSC methods analyzed in this study.

Conclusion

We conclude that the different methods of SSC calculations (based on the differences between CMJ and SJ performances) are strongly correlated and present excellent agreement between them considering jump height and power output. Athletes of team sports showed higher values of SSC compared to combat sports regardless of the method, particularly when jump height is used as a metric.

References

The references of the paper are at “references section”.

7. FINAL CONSIDERATIONS

The current thesis was composed of four studies, in which three emphasized aspects related to power training or variables used in the training prescription, and one study focused on methods of SSC calculation obtained by vertical jumps protocols. The first study (systematic review) investigated the ability to transfer effects of vertical jump and sprint training on speed-velocity parameters. The second study tested the reliability and validity of the *Ergonauta* encoder (linear position transducer) to assess jump height and mean propulsive velocity. The third study identified the optimal power load in the vertical jump protocols (CMJ and SJ) on jump height, power output and mean propulsive velocity and verify its association with force-velocity profile. Finally, the forth study analyzed the use of the SSC in athletes from different sports in addition to showed the consistency and agreement of different SSC methods.

In general, the study 1 showed that both vertical jump and sprint training models presented training transfer to the trained and untrained skill, but the vertical jump training induced greater transfer effects than sprint training even for the untrained skill (i.e. sprint). From a practical view, this evidence demonstrates that vertical jump training can be used to replace sprint training, especially in situations where it cannot be applied, for example, in small spaces to perform sprints or when the athletes need to improve performance in both vertical jump and sprint, but there is no time available for the isolated training of each specific action.

The study 2 was carried out to test whether the *Ergonauta* encoder can be used to identify vertical jump variables and then use it as a parameter to monitor or prescribe training loads, particularly considering the mean propulsive velocity, which is a practical and useful variable for strength and conditioning coaches and physical trainers. We verified that the *Ergonauta* encoder showed excellent reliability and validity to measure CMJ performance variables (jump height and mean propulsive velocity). Thus, it can be used to assess and monitor changes in CMJ performance over time, offering several advantages, as it is portable device, does not need electrical current and the results are obtained through a cell phone app.

The study 3 evidenced that the 0% of external load (i.e. only the subject's body mass) generated the higher peak power, jump height and mean propulsive velocity in the CMJ and SJ. These results are important for sports professionals who use vertical jump training, as optimizing power is essential to improve performance, in this case with only body mass as an external load. Contrary to our hypothesis, the F-v profile (balanced or unbalanced individual) seems does not influence the optimal zone of power production in vertical jump protocols; however, this topic needs further investigation with other samples.

The last study (study 4) showed the three SSC calculation methods (reactive force index, pre-stretching increase and eccentric utilization rate) can be used to assess SSC use in athletes from different sports. Coaches and sports professionals can use any of the methods mentioned above in order to monitor changes in the ability to use the SSC in athletes from different sports. It is recommended to use the jump height metric (instead of power) in the calculation of SSC utilization regardless of the chosen method.

The studies developed in this thesis have great practical applicability, since they bring important results and, until then, not available in the literature, such as: a) the beneficial effects and greater transfer of training from vertical jumps (compared to sprint training) on speed-power parameters; b) the use of the external load corresponding to the individual's body mass as a greater inducer of power, mean propulsive velocity and jump height in the CMJ and SJ; c) use of the *Ergonauta* encoder to measure jump height and mean propulsive velocity during the CMJ; d) the applicability of different methods of SSC calculation in athletes from different sports.

Finally, it is recommended that future studies investigate the transfer of training in females groups, and with subgroups analysis, for example, considering the training experience, the training volume and the type of exercise performed (e.g. sprint resisted and non-resisted). Future research should also investigate the association between the optimal power load and the F-v profile in athletes of specific sports in addition to considering different types of exercise for power assessment. It is also recommended that future studies test the reliability, validity and sensitivity of other jump tests (e.g. squat jump, drop jump) using the *Ergonauta* encoder and considering other metrics (power output, force, peak velocity). Moreover, to analyze upper limb exercises (e.g. bench presses performed on the Smith Machine), considering different protocols, with and without isometric pause between eccentric and concentric contractions. Finally, future studies should evaluate the use of the SSC in other sports, especially those with different eccentric loads, and should also take into account the investigation of female athletes, as specific responses by sex is an important research perspective.

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7. APPENDIX

Appendix A

UNIVERSIDADE FEDERAL DE SANTA CATARINA - UFSC

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Efeitos da especificidade do modo de exercício no treinamento de potência: análise da transferência, controle de carga e respostas de treino.

Pesquisador: Daniele Detanico

Área Temática:

Versão: 3

CAAE: 57615022.7.0000.0121

Instituição Proponente: Universidade Federal de Santa Catarina

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 5.499.019

Apresentação do Projeto:

Trata-se de projeto de tese de doutorado de Rodrigo Ghedini Gheller, sob orientação da professora Dra. Daniele Detanico, do Programa de Pós-graduação em Educação Física, da Universidade Federal de Santa Catarina.

As informações que seguem e as elencadas nos campos “Objetivo da pesquisa” e “Avaliação dos riscos e benefícios” foram retiradas do arquivo PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1904538.pdf, de 22/06/2022, preenchido pelos pesquisadores.

Segundo os pesquisadores:

Os objetivos do estudo serão analisar as respostas neuromusculares agudas e subagudas após a realização de uma sessão de treino com saltos verticais com ciclo alongamento-encurtamento curto (drop jump - DJ) vs. longo (countermovement jump - CMJ) e verificar a efetividade da utilização do CMJ no monitoramento e controle da carga para treinamento de sprint. Para isso o estudo será dividido em duas etapas: a) estudo transversal; b) estudo longitudinal. No estudo transversal cruzado (cross over), os participantes deverão realizar 7 visitas ao laboratório de Biomecânica. Para avaliar a recuperação neuromuscular e dor muscular serão aplicados testes (salto vertical, dinamômetro isocinético e percepção de dor muscular) imediatamente após (IA), 24h e 48h horas após o protocolo de treinamento. No estudo longitudinal com objetivo de verificar

Conclusões ou Pendências e Lista de Inadequações:

Os pesquisadores resolveram as pendências listadas no parecer no. 5.452.448 e o projeto está aprovado.

Informamos aos pesquisadores a necessidade de enviar relatório final por meio de notificação. Qualquer alteração nos documentos apresentados deve ser encaminhada para avaliação do CEPSH. Eventuais modificações ou emendas ao protocolo devem ser apresentadas de forma clara e sucinta, identificando a parte do protocolo a ser modificada e as suas justificativas.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1904538.pdf	22/06/2022 08:59:55		Aceito
Folha de Rosto	folhaDeRosto.pdf	22/06/2022 08:59:33	Rodrigo Ghedini Gheller	Aceito
Outros	CARTA_RESPOSTA.docx	24/05/2022 10:22:25	Rodrigo Ghedini Gheller	Aceito
Declaração de Instituição e Infraestrutura	Carta_de_Anuencia.pdf	24/05/2022 10:22:00	Rodrigo Ghedini Gheller	Aceito
Projeto Detalhado / Brochura Investigador	Projeto.docx	24/05/2022 10:20:23	Rodrigo Ghedini Gheller	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.docx	24/05/2022 10:20:05	Rodrigo Ghedini Gheller	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

FLORIANOPOLIS, 29 de Junho de 2022

Assinado por:
Nelson Canzian da Silva
(Coordenador(a))

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Human Kinetics
ARTICLE

Effect of Vertical Jump and Sprint Training on Power and Speed Performance Transfer

Rodrigo Ghedini Gheller,[1] Rafael Lima Kons,[2] Juliano Dal Pupo,[1] and Daniele Detanico[1]

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The aim of this systematic review was to investigate the effect of specific sprint and vertical jump training interventions on transfer of speed–power parameters. The data search was carried out in three electronic databases (PubMed, SCOPUS, and SPORTDiscus), and 28 articles were selected (13 on vertical jump training and 15 on sprint training). We followed the PRISMA criteria for the construction of this systematic review and used the Physiotherapy Evidence Database (PEDro) scale to assess the quality of all studies. It included studies with a male population (athletes and nonathletes, $n = 512$) from 18 to 30 years old who performed a vertical jump or sprint training intervention. The effect size was calculated from the values of means and *SD*s pre- and posttraining intervention. The percentage changes and transfer of training effect were calculated for vertical jump training and sprint training through measures of vertical jump and sprint performance. The results indicated that both training interventions (vertical jump training and sprint training) induced improvements in vertical jump and linear sprint performance as well as transfer of training to speed–power performance. However, vertical jump training produced greater specific and training transfer effects on linear sprint than sprint training (untrained skill). It was concluded that vertical jump training and sprint training were effective in increasing specific actions of vertical jump and linear sprint performance, respectively; however, vertical jump training was shown to be a superior alternative due to the higher transfer rate.

Keywords: muscle power, stretch-shortening cycle, sports performance, running

Sprint and vertical jumps are widely used training methods to develop speed–power abilities (Markovic et al., 2007), which are important for successful performance in a range of team sports, martial arts, and track and field (Dal Pupo et al., 2021; Kons et al., 2018; Loturco, Nakamura et al., 2015; Moran et al.,

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Original Article

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Validity and reliability of *ergonauta* encoder to assess countermovement jump performance

Rodrigo G Gheller[1], Rafael L Kons[2], Wladymir Külkamp[3], Juliano Dal Pupo[1] and Daniele Detanico[1]

Abstract

This study aimed to test the reliability and criterion validity of the *Ergonauta* encoder to assess countermovement jump (CMJ) performance, considering jump height and mean propulsive velocity metrics. Twenty-three recreationally active men participated in this study. The participants were positioned on a force plate with the *Ergonauta* individually connected through a belt. Two CMJs were performed, and the jump height and mean propulsive velocity metrics were analyzed. The intraclass correlation coefficient (ICC) and typical error (TE) were used as relative and absolute reliability indicators, respectively. The Pearson correlation was used to verify the relationship between the *Ergonauta* and force plate derived-metrics, and the Bland-Altman plot was used to verify the agreement between the metrics (*Ergonauta* encoder and force plate), with the level of significance set at $p < 0.05$. The results show excellent relative reliability for both metrics, considering the two evaluation devices (ICC = 0.95–0.99, TE = 1.02–2.46). The jump height and mean propulsive velocity obtained by the *Ergonauta* encoder and the force plate were strongly correlated ($r = 0.95$; $r = 0.90$, respectively, $p < 0.01$). The Bland-Altman plot showed good agreement for both metrics (jump height and mean propulsive power) and equipment (close to 0). We concluded that the *Ergonauta* encoder is reliable and valid for assessing CMJ performance, particularly the jump height and mean propulsive velocity metrics.

Keywords

Velocity, linear position transducer, vertical jump, lower limb, devices, encoder, mean propulsive velocity, muscle power, exercise performance

Date received: 8 November 2022; accepted: 5 April 2023

Introduction

The vertical jump (VJ) test is one of the main methods used to assess lower limb performance of athletes.[1] For example, the VJ is used to monitor the neuromuscular status over a season, to discriminate groups of athletes, to identify inter-limb asymmetries, to detect muscular fatigue, etc. The VJ is considered an important and practical tool for coaches and strength and conditioning professionals.[2,3] VJ tests are often used to evaluate athletes' lower limb muscle power in sports such as sprinting, kicking in soccer, jumping in volleyball/basketball, or specific attack techniques in combat sports.[4] Conventionally, the countermovement jump (CMJ) has been the most used VJ test over the years,[5] showing high reliability and factorial validity.[6] Due to its practicality, the height reached in the VJ is the most commonly used metric to assess lower limb performance.[5] Vertical jump height (VJH) has been associated with sport-specific tasks in different modalities,[4,7,8] such as judo-specific performance tests, sprint performance, repeated shuttle sprint ability for futsal players,[4] and attack effectiveness for volleyball players.[7] Moreover, VJH was sensitive to detect long-term changes in sport-specific performance in basketball players.[8]

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Thank you for your submission.

Submission ID	**230929770**
Manuscript Title	**Optimum Power-Load Profile in Squat and Countermovement Jump and its Association With Force-Velocity Balance**
Journal	**Sports Biomechanics**

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SHORT COMMUNICATION

Methods to calculate lower-body stretch—shortening cycle utilization in the vertical jump: Which is the best for athletes of different sports?

Détermination de la meilleure méthode de calcul du cycle d'étirement—raccourcissement du bas du corps dans le saut vertical pour les athlètes de différents sports

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KEYWORDS
Jump height;
Elastic index;
Power output;
Jump performance

Summary
Purpose. — This study aimed to verify if different stretch—shortening cycle (SSC) methods, obtained by the vertical jump test, present the same characteristics through consistency and agreement analysis, and to compare the SSC methods between athletes of different sports.
Summary of facts and results. — Three hundred and forty-one male athletes of three sports groups (combat sports, team sports, and runners) participated in this study. Athletes performed the countermovement jump and squat jump tests to identify the SSC using three methods: reactive strength index (RSI), pre-stretch augmentation percentage (PSA), and eccentric utilization ratio (EUR). The results demonstrated very large correlations between the methods for jump height (r = 0.96—0.98) and power output (r = 0.95—0.98), almost perfect agreement for jump height (k = 0.86—0.91) and substantial to almost perfect agreement for power output (k = 0.77—0.92). The RSI, PSA, and EUR were higher in team sports than combat sports for jump height (P = 0.006, P = 0.008, P = 0.007, respectively), EUR was higher for team sports than combat sports for power output (P = 0.041).

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