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Faculdade de Educação Física e Desporto

Doutoramento em Educação Física e Desporto

ANÁLISE DA VELOCIDADE NA CORRIDA DE APROXIMACÃO NA DISCIPLINA DE SALTO COM VARA

Tese de Doutoramento defendida em provas públicas para a obtenção do Grau de Doutor em Educação Física e Desporto, orientada pelo Professor Doutor Jorge dos Santos Proença Martins.

Pedro Daniel Nunes da Silva Onofre Pinto / Nº 21108596

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“VERSÃO FINAL”

Tese defendida em provas públicas na Universidade Lusófona - Centro Universitário de Lisboa no dia 26/01/2024, perante o júri, nomeado pelo Despacho de Nomeação n.º: 335/2023, de 23 de agosto de 2023, com a seguinte composição:

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Resumo

A disciplina de Salto com Vara (ScV) é, geralmente, considerada a disciplina mais complexa e espetacular do Atletismo, sendo fundamental para o seu sucesso a relação que se estabelece entre o atleta e a vara. Entre os fatores determinantes para uma elevada performance desportiva, a velocidade parece desempenhar um papel decisivo.

Esta tese tem como objetivo central a compreensão do papel da velocidade no desempenho do ScV, sendo desenvolvido em três estudos complementares.

Revisão Sistemática - The velocity in the Pole Vault event: a sistematic review

O primeiro passo consistiu na realização de uma revisão sistemática da literatura, sobre o comportamento da velocidade do ScV na fase da corrida de aproximação (CA), com saltadores de elite masculina e feminina em ambiente de treino e competição. Através do protocolo PRISMA, foram utilizadas as bases de dados SPORTDiscus, PubMed e ISI Web of Science, realizando-se uma pesquisa de artigos publicados até janeiro de 2020. Selecionaram-se artigos, utilizando como critérios de inclusão, as palavras-chave: Pole Vault; Velocity; Speed.

Dos 62 estudos encontrados, apenas 21 foram considerados para revisão, tendo sido subdivididos em dois grupos: 12 artigos científicos (realizados em ambiente de treino e competição, de atletas de elite) e 9 relatórios científicos (realizados em grandes competições internacionais). Independentemente das metodologias aplicadas nos artigos selecionados, os valores de velocidade obtidos mostraram-se consistentes. Valores maiores de velocidade influenciaram outros parâmetros relacionados com o sucesso do salto, nomeadamente a escolha de varas maiores e mais rígidas, bem como a execução da chamada mais afastada do encaixe. Atletas medalhados obtiveram valores de velocidades médias superiores aos dos restantes atletas finalistas. Este estudo permitiu reforçar a ideia de que valores elevados de velocidade constituem um parâmetro fundamental para o sucesso do salto.

1º Estudo - The influence of the maximum velocity changes during a training season on full approach runs in the pole vault event

Este estudo longitodinal teve como objetivos (1) interpretar a velocidade máxima lançada e a velocidade na corrida de aproximação do atleta ao longo de duas épocas desportivas; (2) identificar a associação que se estabelece entre ambas e (3) estabelecer a relação entre estas e o desempenho desportivo, na prova de ScV. Durante 25 sessões de treino (três macrociclos) foram recolhidos dados referentes a 150 corridas de cada um dos dois atletas de elite que participaram neste estudo. Avaliou-se a velocidade máxima de uma CA sem o salto, denominada tarefa 1 (T1), e a velocidade máxima obtida num teste máximo de velocidade de 20m lançados sem vara - tarefa 2 (T2).

Concluiu-se existir uma correlação entre T1 e T2, com significância estatística (Atleta 1 = $R^2 = 0.801$, = < 0.001; Atleta 2 = $R^2 = 0.602$; = 0.001). Foi identificado um comportamento semelhante entre as tarefas T1 e T2 (com 97.53% para o Atleta 1 e 97.88% para o Atleta 2 da variância total). Verificou-se a existência de concordância entre as oscilações na velocidade máxima e as oscilações nas velocidades obtidas na CA.

Neste estudo longitudinal, existe relação entre T1 e T2 para estes dois atletas. Um aumento de velocidade máxima traduziu-se, sempre, numa maior velocidade na CA.

2º Estudo - Pole vault performance analysis using kinematic and technical parameters in training - a longitudinal study

O desempenho desportivo no evento de ScV resulta da combinação dos diferentes parâmetros físicos, técnicos e psicológicos. Assim, procurou-se nestes estudo determinar quais os parâmetros cinemáticos e técnicos que mais afetam o desempenho do ScV. Através de um estudo longitudinal com dois atletas de elite, foram avaliados 464 saltos (155 da atleta feminina e 309 do atleta masculino) em treino. Utilizando-se um sistema de Lidar a "laser", obtiveram-se os dados cinemáticos relativos a cada desempenho, aos quais se associaram os respetivos dados técnicos (altura da pega, flexibilidade da vara, número de passadas da CA).

Na observação das diferentes categorias de sucesso, o atleta M teve uma maior percentagem de saltos "Fail" nas corridas com 18 passos de CA (33.3%), tendo o atleta F realizado 55.5% de saltos "Fail" com 14 passos de CA. Verificou-se uma maior percentagem de saltos "Clear the bar" nas corridas de 8 passos de CA para o atleta M (38.9%) e nas corridas com 12 passos de CA para a atleta F (16.0%).

O estudo permitiu verificar que o comprimento da CA tem influência no sucesso do salto, com diferente impacto entre os atletas. Verificou-se a existência de outros parâmetros que influenciam o sucesso do salto, como a altura da pega e o comprimento da vara utilizados. Na categoria de "Clear the bar" verificou-se que, para saltos superiores a 90% do SB, os parâmetros com maior correlação com o sucesso foram: atleta M (Grip; size of the pole; v_max; $v_{med16-11m}$; $v_{med11-6m}$) e para atleta F (Grip; flex of the pole; dis_vmax).

3º Estudo - Non-linear and linear methods to analyze pole vault run-up in successful and unsuccessful jumps

Este estudo teve como objetivo analisar a corrida de aproximação do salto com vara utilizando métodos não-lineares e lineares, determinando a existência ou não de uma relação entre diferentes parâmetros identificados na corrida do salto com vara e o desempenho desportivo.

Foram analisados 215 saltos de um único atleta de elite do sexo masculino, com 28 anos de idade, que teve representação internacional pelo seu país. A análise fractal usando CoDim, entropia de amostragem (SampEn) e CV foi utilizada para medir variações na velocidade da fase de aproximação e relacioná-la com o desempenho desportivo do atleta durante o salto. A análise linear incluiu o parâmetro Δv_{male}, que mede a variação de velocidade nos últimos 10 metros da aproximação.

Nenhuma evidência significativa foi encontrada para SampEn, mas CoDim mostrou um efeito significativo em 8nStp e 18nStp para saltos bem-sucedidos, e CV mostrou evidência significativa em 12, 14, 16 e 18 passos. Embora os métodos usados neste estudo forneçam informações relevantes para treinadores, apenas pequenas diferenças em séries temporais foram identificadas usando métodos não-lineares. O parâmetro CV foi capaz de mostrar diferenças entre saltos com comprimentos de aproximação variados, e valores mais altos do parâmetro Δv_{male} indicaram um maior efeito no sucesso do salto.

Palavra chave: *Salto com vara, velocidade, corrida de aproximação, desempenho.*

Abstract

Pole Vaulting (ScV) is generally considered the most complex and spectacular discipline in Athletics, and the relationship established between the athlete and the pole is fundamental to its success. Among the determining factors of performance, velocity seems to play a decisive role.

The central objective of this thesis was to understand the role of velocity in ScV performance, which was developed through four complementary studies.

Sistematic Review - The velocity in the Pole Vault event: a sistematic review

A systematic literature review was carried out on the pole vault event from velocity behaviour in the approach running phase, with male and female elite jumpers in a training and competition environment. The SPORTDiscus, PubMed and ISI Web of Science databases were used through the PRISMA protocol, performing a search for articles published until January 2020. Articles were selected, using the keywords as inclusion criteria: Pole Vault; Velocity; Speed.

Of the 62 studies found, only 21 were considered for review, divided into 12 scientific articles (conducted in a training and competition environment of elite athletes) and nine scientific reports (conducted in major international competitions).

Regardless of the methodologies applied in the selected articles, the values of the velocities obtained were constant. Higher velocities values influenced other parameters related to the success of the jump, namely the choice of bigger and more rigid poles and performed take-offs further away from the box. The medal winners had higher average velocities values than the other finalist athletes. This study allowed us to reinforce the idea that high velocities are a fundamental parameter for the success of the jump.

1st Study - The influence of the maximum velocity changes during periodised training seasons on full approach runs in the pole vault event
1st Study The study aimed to (1) interpret the maximum flying velocity and the velocity in the athlete's approach run over two sporting seasons; (2) identify the association established between them, and (3) establish the relationship with sports performance in the pole vault event.

A longitudinal study was conducted with two elite athletes during two sporting seasons. During 25 training sessions, data were collected from 150 runs per athlete. The collected data measured the maximum velocity in the approach run without the jump, called task 1 (T1). The maximum velocity obtained by the athletes in the 20m fly test without a pole - task 2 (T2).

It was concluded that there is a statistically significant correlation between T1 and T2 (Athlete 1 = $R^2 = 0,801, = < 0,001$; Athlete 2 = $R^2 = 0,602$; = 0,001). Similar behaviour was identified (with 97.53% for Athlete 1 and 97.88% for Athlete 2 of the total variance) between tasks T1 and T2. It was verified the existence of an agreement between the oscillations in the maximum velocity and the oscillations in the velocity obtained in the approach run. In this longitudinal study, there is a relationship between T1 and

T2 for these two athletes. An increase in maximum velocity always translated into higher velocities in the approach run.

2nd Study - The influence of the speed in a pole vault the training season over a complete sport season

The performance in the pole vault event is due to the combination of different physical, technical and psychological parameters. We tried to determine which kinematic and technical parameters most affect the performance of the ScV. Through a longitudinal study with two elite athletes, 464 jumps (155 for the female athlete and 309 for the male athlete) in training were evaluated. Using a laser Lidar system, the kinematic data related to each performance were collected, to which the respective technical data were associated (grip, pole flexibility, run-up length).

In the observation of the different categories of success, athlete M had a higher percentage of "0 - Fail"jumps in runs with 18 steps of the approach run (33.3%), with athlete F performing 55.5% of "0 - Fail"jumps with 14 steps of approach run. There was a higher percentage of "3 - clear the bar"jumps in 8-step from the approach run for athlete M (38.9%) and in runs with 12 steps for athlete F (16.0%).

The study allowed us to verify that the approach run-length had an influence on the success of the jump, with different impacts among the athletes. It was confirmed the existence of other parameters that influenced the success of the jump, such as the grip height and the length of the pole used. In the category of "3 - clear the bar", it was found that for jumps greater than 90% of the SB, the parameters with the highest correlation with success were: Athlete M (Grip; size of the pole; v_max; $v_{med16-11m}$; $v_{med11-6m}$) and for Athlete F (Grip; flex of the pole; dis_vmax).

3rd Study - Non-linear and linear methods to analyze pole vault run-up in successful and unsuccessful jumps

This study aimed to analyze the running component of pole-vaulting using both nonlinear and linear methods and determine if there is a relationship between the running aspect of pole-vaulting and overall sport performance.

215 jumps were analyzed from a single elite male athlete, aged 28 years, who had international representation for their country. Fractal analysis using CoDim, sample entropy (SampEn), and CV was used to measure variations in the velocity of the run-up phase and compare it to the athlete's sports performance during the jump. Linear analysis included the parameter vmale, which analyzed the velocity variation in the last 10 meters of the run-up.

No significant evidence was found for SampEn, but CoDim showed a significant effect at 8nStp and 18nStp for successful jumps, and CV showed significant evidence at 12, 14, 16, and 18 steps. While the methods used in this study provide relevant information/data for coaches, only small differences in time series were identified using non-linear methods. The CV parameter was able to show differences between jumps with varying run lengths, and higher values of the Δv_{male} parameter indicated a greater effect on jump success.

Keywords: *Pole vault, velocity, run-up, high performance.*

Abreviaturas

AP - Altura da pega

CA - Corrida de aproximação

CoDim - Correlation dimension

CV - Coefficient of variation

CH- Chamada no Salto com Vara

CM - Centro de Massa

FPA- Federação Portuguesa de Atletismo

kg - Kilograma

nStp - number of steps na corrida de aproximação

m- Metros

m/s - Metros por segundo

T1 - Tarefa um

T2 - Tarefa dois

v_max - Velocidade máxima

dis_vmax - local de distância ao encaixe, onde é obtida a velocidade máxima

vmed16-11m - Velocidade média entre os 16 e 11 metros do encaixe

vmed15-10m- Velocidade média entre os 15 e 10 metros do encaixe

vmed11-6m- Velocidade média entre os 11 e 6 metros do encaixe

vmed10-5m - Velocidade média entre os 11 e 6 metros do encaixe

PB - Personal best

ScV - Salto com vara

SampEn - Sample entropy

SB - Season best

sd - Standard deviation

$\boldsymbol{\Delta v_{male}} = V_{med(11-6m)} - V_{med(16-11m)}$ - Variação de velocidade

20m lançados - Velocidade máxima em 20m lançados

WA - World Athletics

Glossário

Altura de pega - Corresponde à distância entre a extremidade inferior da vara e o topo da mão superior. Pode referir-se como altura da pega dos atletas.

Chamada - Corresponde à fase do salto que se caracteriza pelo último apoio da corrida de balanço. Tem como objetivo a realização de forças adicionais de forma a possibilitar a transição da corrida para a fase aérea.

Corrida de aproximação - Conjunto de movimentos que decorre desde o primeiro movimento até à chamada, contemplando a apresentação da vara.

Encaixe (da vara) - Refere-se ao o local onde a vara "encaixa" durante o salto. O encaixe tem dimensões pré-definidas pela World Athletics, apresentando uma profundidade de 20cm.

Fase de apresentação - Refere-se à fase final da corrida de balanço. Traduz-se na ação de elevação da extremidade superior da vara, de forma a preparar a seguinte fase: a chamada.

Jagodin - Corresponde a um exercício de salto com vara para o colchão mas sem a realização da inversão.

Push - Corresponde à diferença entre a altura da fasquia e a soma da altura de pega e dos 20cm da profundidade do encaixe.

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"A corrida, forma de motricidade mais comum na prática desportiva, quando realizada à velocidade máxima, desempenha um papel crucial na concretização das melhores performances..."

Jorge Proença

Capítulo 1

Introdução

O salto com vara (ScV), disciplina integrante dos saltos, é composta, em primeiro lugar, por uma corrida de aproximação (CA), uma chamada (CH), uma fase aérea e, por fim, a queda no colchão, como ilustrado na fig 1.1. Sendo uma das disciplinas mais antigas do Atletismo, o ScV integra o programa Olímpico desde a sua primeira edição dos Jogos da Era Moderna (Jogos Olímpicos de Verão de 1896, Atenas). Tal como sucedido em muitas outras disciplinas, durante muitos anos, o ScV era apenas praticado por homens, tendo sido introduzido no programa Olímpico, no género feminino, nos Jogos Olímpicos de Sidney, 2000.

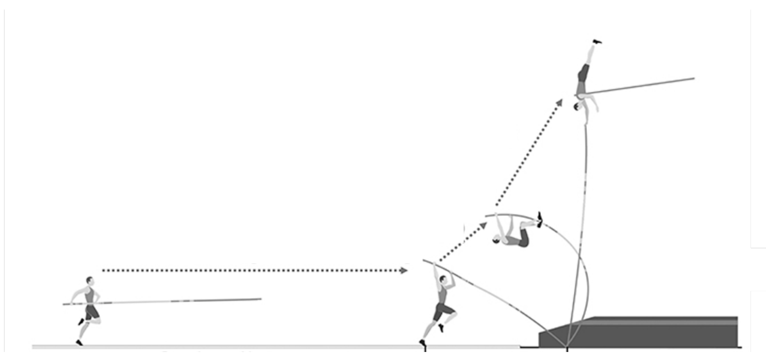

Figura 1.1: Imagem ilustrativa do salto com vara

Muitos consideram a disciplina mais complexa e espetacular do Atletismo (Frère et al., 2010), sendo fundamental para o sucesso do salto a relação que se estabelece entre o atleta e a vara (Arampatzis et al., 2004; McGinnis & Bergman, 1986; Schade et al., 2004). A introdução de fibra de vidro e fibra de carbono na fabricação de varas a partir do final dos anos 50 marcou uma notável evolução. Esses materiais tornaram as varas mais resistentes, proporcionando uma capacidade superior de conservar energia e, como resultado, contribuíram significativamente para a melhoria da técnica de salto (Angulo-Kinzler et al., 1994; Dillman & Nelson, 1968; Ekevad & Lundberg, 1997; Schade et al., 2000), como demonstrado na figura 1.2.

Entre os vários fatores que poderão determinar o desempenho no ScV, como por exemplo tamanho da vara, a altura da pega (AP), a flexibilidade da vara, as capacidades físicas e psicológicas do atleta, a velocidade destaca-se como um fator de máxima importância (Adamczewski & Perlt, 1997; Angulo-Kinzler et al.,

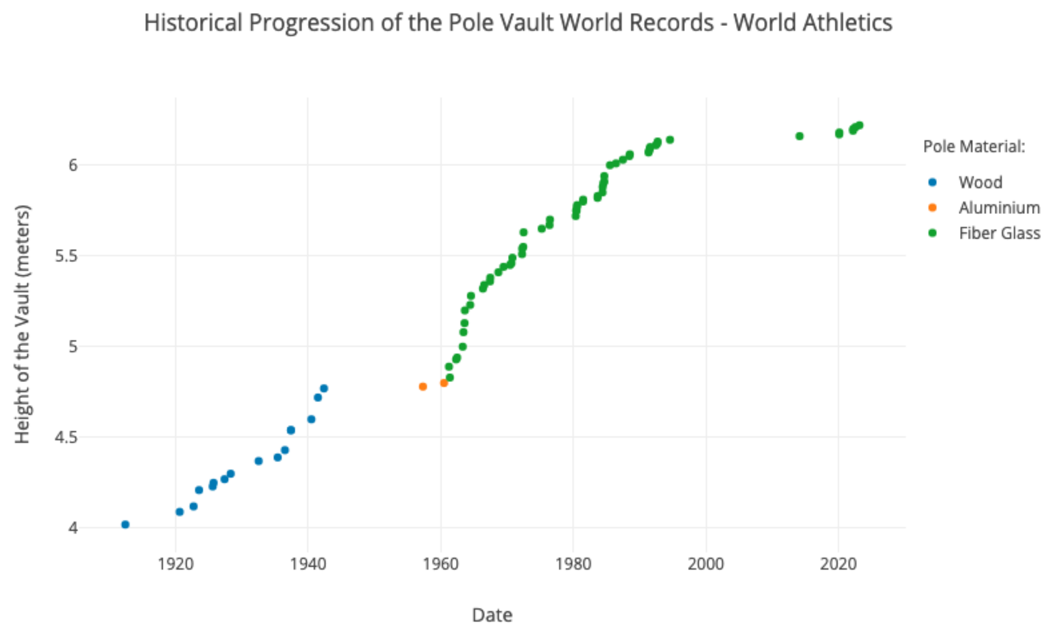

Figura 1.2: Progressão histórica do recorde mundial do salto com vara (homens) e respetivos materiais utilizados. Retirado de: plotly Chart Studio - Historical Progression of WA men Pole Vault World Records

1994; Christensen & Zebas, 2000; Frère et al., 2010; Hay, 1988; Linthorne & Weetman, 2012; Needham et al., 2017; Samozino et al., 2016). De acordo com (Linthorne & Weetman, 2012) existe uma correlação direta entre a velocidade máxima do atleta e o sucesso do salto. Fruto de vários anos de investigação, identificou-se uma correlação forte entre a velocidade alcançada na CA e a altura da fasquia transposta, estabelecendo-se uma relação com o sucesso do salto, em ambos os géneros: homens, r=0.69 (Adamczewski & Perlt, 1997) e mulheres, r=0.77 (McGinnis, 2008). Os seguintes autores, Krska et al. (2014), Linthorne (2000), Morlier e Cid (1996), Morlier e Mesnard (2007), Needham et al. (2017) e Plessa et al. (2010), frisaram a importância dos valores de velocidade máxima serem registados o mais próximo possível da chamada (CH).

Contudo, estudos mais recentes (Cassirame et al., 2019; Tamura et al., 2017), baseados em diferentes metodologias, consideraram a velocidade máxima isolada como um parâmetro insuficiente para definir o sucesso do ScV. Comparações realizadas numa série de saltos, de um mesmo atleta, demonstraram alterações mínimas na velocidade obtida na CA entre saltos válidos e saltos nulos. Como tal, colocou-se a possibilidade de existirem outros parâmetros que pudessem influenciar o sucesso do salto.

Além disso, estudos igualmente recentes focaram em descrever o comportamento dos atletas durante a CA. Em particular, investigaram como é que os atletas realizam ajustes subtis nos seus padrões de movimento em resposta a diferentes tipos de feedback - visual, físico e emocional - que são característicos de cada tentativa de salto. Autores como (Makaruk et al., 2017; Needham et al., 2018) destacaram a importância da consistência no local de realização da chamada e da manutenção de um padrão de corrida o mais constante possível para o êxito no salto. No entanto, ainda são limitados os estudos que identificam esses ajustes específicos e como eles afetam a corrida de aproximação e o desempenho geral no salto.

1.1 Pertinência e Objetivos da Investigação

No contexto do treino desportivo, uma das tarefas mais delicadas é a recolha e seleção de informação que fundamente o processo de treino (Proença, 1989). Assim, pretende-se nesta investigação identificar os fatores que determinam o desempenho no ScV, com ênfase na análise da velocidade, explorando o potencial desta informação em várias dimensões da análise do desempenho, quer no processo de treino quer na competição.

Desta forma estabelecem-se os seguintes objetivos específicos:

Objetivo específico 1 – Testar a relação entre a velocidade máxima do atleta (sem vara) e a sua velocidade na CA.

- **Estudo Experimental I -** ***The influence of the maximum velocity changes during a periodized training seasons on full approach runs in the pole vault event*** **-** O objetivo deste estudo foi analisar a variação da velocidade máxima de dois atletas de elite ao longo de três macrociclos. A intenção era entender como essa variação influencia a corrida de aproximação (CA) e o desempenho desportivo desses atletas.

Objetivo específico 2 – Testar o efeito combinado entre a velocidade e outras variáveis no desempenho desportivo dos atletas, ao longo do processo de treino.

- **Estudo Experimental II -** ***Pole vault performance analysis using kinematic and technical parameters in training*** **-**A velocidade e outras variáveis, como a altura da pega, a resistência e o tamanho das varas, e os diferentes comprimentos da corrida de aproximação (CA), têm sido apontadas como fatores com grande impacto no sucesso do salto com vara. Assim, este estudo procura esclarecer como a combinação dessas variáveis influencia o desempenho do salto ao longo de diferentes macrociclos.

Objetivo específico 3 – Utilização de métodos não lineares e lineares na análise da velocidade na CA.

- **Estudo Experimental III -** ***Non-linear and linear methods to analyze pole vault run-up in successful and unsuccessful jumps*** **-** Este estudo teve como objetivo analisar a corrida de aproximação (CA) utilizando medidas lineares e medidas não lineares, relacionando-as com o desempenho desportivo. A intenção é identificar, se existir, um perfil de velocidade característico ao longo da CA que diferencie os saltos bem-sucedidos dos que não têm sucesso.

1.2 Organização e Estrutura da Tese

O presente trabalho encontra-se organizado conforme as regras dispostas no regulamento de dissertações de Doutoramento da Universidade Lusófona - Centro Universitário de Lisboa. O capítulo I introduz a problemática que motivou a investigação, bem como as respetivas propostas, objetivos e estrutura da tese. O capítulo II apresenta a revisão sistemática de literatura (formato de artigo e redigido em inglês), abordando os fatores mais relevantes na perspetiva da velocidade no ScV, em contexto de atletas de elite.

O capítulo II descreve, detalhadamente todos os procedimentos metodológicos que serviram de base para os estudos experimentais apresentados nos capítulos seguintes. Os capítulo IV, V e VI apresentam três estudos desenvolvidos, procurando responder às questões, objetivos e hipóteses colocadas (formato de artigo e redigidos em inglês). O capítulo VII centra-se nas considerações finais, nomeadamente nas limitações encontradas no curso da investigação, direções futuras e conclusões finais.

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"A Natureza é exatamente simples, se conseguirmos encará-la de modo apropriado...Essa crença tem-me auxiliado, durante toda minha vida, a não perder as esperanças, quando surgem dificuldades na investigação."

Albert Einstein

Capítulo 2

Revisão Sistemática

The velocity in the Pole Vault event: A Sistematic Review

2.1 Abstract

This research aimed to conduct a systematic review of velocity data during the run-up phase among elite male and female pole vaulters in both training and competition environments. The PRISMA protocol was applied, and the SPORTDiscus, PubMed, and ISI Web of Science databases were consulted and screened up to January 2020. Studies that were relevant to the keywords 'pole vault,' 'velocity,' and 'speed' and met the inclusion criteria were selected. High-performance athletes' studies were included from scientific articles and scientific reports from major competitions. Out of the 62 titles found, only 21 studies were deemed suitable for review. The included studies were categorized into two groups: 12 scientific articles from either training or competition environments, and nine scientific reports from major competitions. Various data collection methods were employed, but the velocity data consistently exhibited stable values. This review identified velocity as a fundamental determinant of jump success. Higher velocities also influenced other parameters critical to the success of the jump, including the likelihood of using larger and stiffer poles, maximum pole bend, and a greater distance from the take-off point to the box. Medalists achieved higher average velocity values compared to other finalist athletes.

Keywords: athletics, elite athletes, high-performance, kinematics

2.2 Introduction

The pole vault is one of Athletics' most impressive and complex events (Cassirame, Sanchez, Exell et al., 2019; Pavlović et al., 2019). This event's success comes from the blend of physical, technical, and psychological abilities (Cassirame, Sanchez & Morin, 2017; Gross et al., 2019). Physically this event necessitates speed, jumping capacity and gymnastic capability to transfer kinetic energy in potential energy (Arampatzis et al., 2004; Frère et al., 2010; Linthorne & Weetman, 2012).

Four successive phases broadly describe pole vault: (1) run-up, (2) pole planting and take-off, (3) pole bending, and (4) pole straightening and bar clearance (Frère et al., 2010).

The run-up phase has a crucial role in the event's success. The athletes can maximise the kinetic energy through the higher horizontal velocity attained in the run-up (Frère et al., 2010; Linthorne, 2000; Linthorne & Weetman, 2012). The horizontal velocity is the most determinant parameter for the effectiveness of the jump with a moderate to a strong linear correlation (R-values of 0.69–0.86) (Adamczewski & Perlt, 1997; Frère et al., 2010; Linthorne, 2000; McGinnis, 1997; Mcginnis, 2004). Other authors went further and realised that the take-off velocity explains, even more, the variability in the vault heights for men (74%) and women (58%). Some authors give more focus to the maximum velocity in the run-up (Angulo-Kinzler et al., 1994; Linthorne, 2000; McGinnis, 1997); others refer to the energy attained during the run (Adamczewski & Perlt, 1997; Arampatzis et al., 2004; Schade et al., 2006) as more relevant, others refer to the velocity achieved at the end of the run-up (near to the take-off) as the most pertinent to success to the jump (Cassirame, Sanchez, Homo et al., 2017; Frère et al., 2010; Mcginnis, 2004).

A critical issue concerns the methods employed to collect data. Different biomechanical research groups have adopted various approaches, (Gros & Kunkel, 1990) use photocells to quantify the approach velocities, (Gravestock et al., 2017a; Hanley et al., 2019a; Kim et al., 2011) uses video with high-speed cameras, (Mendoza et al., 2009; Schade et al., 2007) use radar gun technology, and (Cassirame, Sanchez & Morin, 2017; Gross et al., 2019; Makaruk et al., 2016) used Optojump systems to obtain velocity information from the run-ups.

It is challenging to fully grasp the substantial relevance of velocity as a kinematic parameter for jump success, but its significance is undeniable. To organize the data for coaches and researchers, several questions were presented: (1) How many scientific studies and reports were identified based on the defined inclusion criteria in the pole vault event?; (2) What types of methods were presented in both groups?; (3) What methods (instruments and procedures) were employed to collect the data?. The questions outlined above help us to identify some of the primary objectives of this systematic review, which focuses on velocity data during the run-up phase of elite athletes in training or competition environments. To address these objectives, several hypotheses were formulated: (H1) velocity data may differ based on the instruments and procedures used; (H2) differences in velocity data obtained during major competitions over time may influence performance; (H3) The velocity parameter of the top three athletes may exceed the velocity values of other athletes.

2.3 Methods

2.3.1 Protocol

This systematic review was undertaken after performing an exploratory search, following the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Liberati et al., 2009; Moher et al., 2009). The final search on databases was conducted in January of 2020.

2.3.2 Methodological Quality Assessment

Two independent reviewers quantified the methodological quality of the articles. Methodological quality was measured using the methodological quality assessment scale (Downs & Black, 1998), which defines the items in the following subcategories: report, external validity, internal validity and power. The original version has 27 items for a total of 31 points. However, the sucessive adaptations were designed to fit the investigation objective best: (i) item 5, item 14, item 15, item 17, item 21, item 22, item 23, item 24, item 25 (Moens et al., 2019) and the item 27 (Feitosa et al., 2019) was not used; (ii) the word patient was replaced by the participant (Feitosa et al., 2019). Previous studies carried out similar adaptations (Costa et al., 2015; Feitosa et al., 2019). Higher rated studies were considered to be of higher quality (Feitosa et al., 2019), and the following scoring levels were assessed, low quality, $< 10/17$ and high quality $> 10/17$ (Moens et al., 2019).

2.3.3 Inclusion Criteria

Scientific articles: The inclusion criteria were: (1) be considered a scientific article; (2) be performed with high-performance athletes (Nationals and Internationals Athletes), (3) the articles written in English, French and Portuguese. The exclusion criteria were: (1) papers with no relation with velocity and speed data; (2) no run-up phase study; and (3) publications in languages other than those used in the inclusion criteria.

Scientific reports: The inclusion criteria were: (1) report of a major world competition (*Olympic Games; World Championship; World Indoor Championship and World Athletics Final*); (2) report has been published; and (3) the articles written in English. The exclusion criteria were: (1) unofficial report's; (2) no run-up phases description; and (3) publications in languages other than those used in the inclusion criteria.

The "All Fields"search query was utilised to provide the best opportunity to capture all relevant articles for our review. The article search was completed on January 15, 2020, and a publication year cut-off was not instituted. Additionally, the references from the articles found through the database searches were screened to filter out further articles that matched the inclusion criteria.

2.3.4 Search

A systematic search was conducted using the electronic databases EBSCO-SportDiscus, PubMed, and ISI Web of Science. Using the keywords "pole vault"and "velocity", and "speed". The Boolean operator "AND"was used for the search (pole vault) AND (velocity) and (pole vault) AND (speed).

2.3.5 Studies Selection

The studies were selected utilizing the search electronic databases EBSCO-SportDiscus, Pub-Med, and ISI Web of Science. Figure 3.1 showed a flow chart with the different search phases and determining the studies included in the review. The initial search identified 450 titles with the keyword "pole vault". When added the keyword "velocity"and "speed", 86 were identified. After duplicate removal, 62 titles and abstracts were screened for relevance, out of which 41 were excluded based on eligibility criteria, and 21 were retrieved for in-depth full-text review.

After reference list hand search and full-text review, 12 articles met the inclusion criteria for and were considered eligible for review in the group of scientific articles: (Cassirame, Sanchez, Garnier et al., 2019; Cassirame, Sanchez & Morin, 2017; Frère et al., 2017; Garcia et al., 2012; Gross et al., 2019; Gudelj et al., 2013; Krska et al., 2014; Linthorne & Weetman, 2012; Makaruk et al., 2016; McGinnis, 1987). Furthermore, nine articles met the inclusion criteria for and were considered eligible for review in the group of scientific reports: (Angulo-Kinzler et al., 1994; Bruggemann et al., 1999; Gravestock et al., 2017a; Gros & Kunkel, 1990; Hanley et al., 2019a; Kim et al., 2011; Mendoza et al., 2009; Schade et al., 2007).

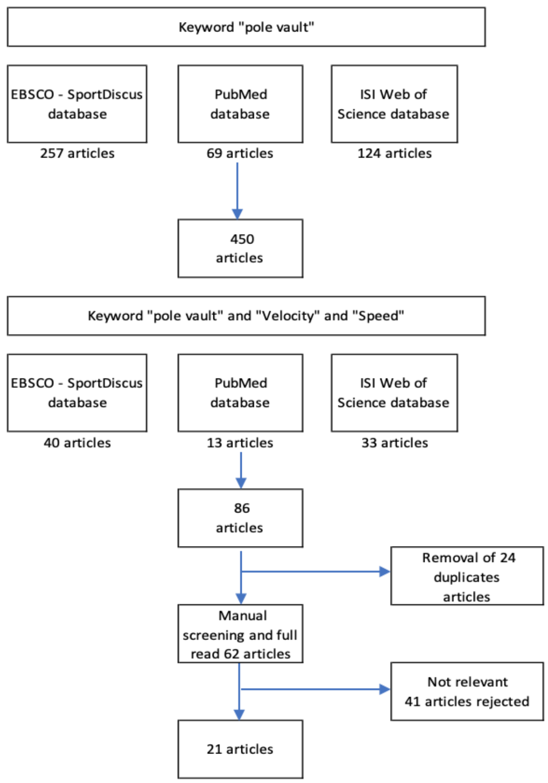

Figura 2.1: Flow chart of metodology used for the article search.

2.4 Results

2.4.1 Methodological Quality Assessment

The methodological quality score of the twelve scientific studies reviewed had an interval of 9 and 14, with an average of 11,9 results of 17, indicating a high methodological quality for the reviewed studies (table 2.1).

For the nine scientific reports reviewed, the methodological quality score had an interval of 9 and 10, with an average of 9,6 results of 17, indicating a less methodological quality for the reviewed reports (table 2.2).

Tabela 2.1: Characterization of the scientific studies reviewed and the quality score (n=12)

Study	Population (n)	Environment	System	Score of Quality Assessment
(McGinnis, 1987)	n=30, male pole vaulters	Competition	Video	12
(Linthorne & Weetman, 2012)	n=1, male pole vaulter	Training	Video	12
(Garcia et al., 2012)	n=10, 7 men and 3 women pole vaulters	Training	Photocells, video and radar	11
(Gudelj et al., 2013)	n=27, female pole vaulters	Competition	Video	12
(Krska et al., 2014)	n=19, female pole vaulter	Competition	Video	9
(Makaruk et al., 2016)	n=12, male pole vaulters	Competition	Optojump and video	13
(Cassirame, Sanchez, Homo et al., 2017)	n=62, 31 men and 31 women pole vaulters	Competitions	Optojump, radar and video	13
(Cassirame, Sanchez & Morin, 2017)	n=20, male pole vaulters	Competition	Optojump and radar	12
(Frère et al., 2017)	n=17, 10 women and 7 men pole vaulters	Training	Radar	11
(Cassirame, Sanchez, Exell et al., 2019)	n=132, 65 women and 67 male pole vaulters	Competition	Optojump and radar	13
(Cassirame, Sanchez, Garnier et al., 2019)	n=83, 40 womens and 43 men pole vaulters	Competition	Optojump and radar	11
(Gross et al., 2019)	n=20, womens	Competition	Optojump	14

2.4.2 Characteristics of the reviewed studies

The studies reviewed in the context of the (12) scientific articles with 433 elite pole vaulter athletes (219 male and 215 female). In the (9) scientific reports, there were a total of 135 elite athletes in the pole vault to be evaluated (81 male and 54 female). In all studies (21), the kinematic parameters were analysed using various instruments, namely photoelectric cells (Gros & Kunkel, 1990), high speed cameras (Angulo-Kinzler et al., 1994; Bruggemann et al., 1999; Cassirame, Sanchez, Homo et al., 2017; Garcia et al., 2012; Gravestock et al., 2017a; Gros & Kunkel, 1990; Gudelj et al., 2013; Hanley et al., 2019b; Kim et al., 2011; Krska et al., 2014; Linthorne & Weetman, 2012; McGinnis, 1987), optoelectronic systems (Cassirame, Sanchez, Homo et al., 2017; Cassirame, Sanchez, Exell et al., 2019; Cassirame, Sanchez, Garnier et al., 2019; Cassirame, Sanchez & Morin, 2017; Gross et al., 2019; Makaruk et al., 2016) and radar laser systems (Cassirame, Sanchez, Homo et al., 2017; Cassirame, Sanchez, Exell et al., 2019; Cassirame, Sanchez, Garnier et al., 2019; Cassirame, Sanchez & Morin, 2017; Frère et al., 2017; Garcia et al., 2012; Mendoza et al., 2009; Schade et al., 2007).

Tabela 2.2: Characterization of the scientific reports reviewed and the quality score (n=9)

Study	Population (n)	Environment	System	Score of Quality Assessment
(Gros & Kunkel, 1990)	n=8, finalist men	Competition	Photocells and video	10
(Angulo-Kinzler et al., 1994)	n=8, finalist men	Competition	Video	10
(Bruggemann et al., 1999)	n=11, finalist men	Competition	Video	10
(Schade et al., 2007)	n=8, finalist men and n=8 finalist women	Competition	Radar	9
(Mendoza et al., 2009)	n=8, finalist men and n=7 finalist women	Competition	Radar	9
(Mendoza et al., 2009)	n=8, finalist men and n=7 finalist women	Competition	Radar	9
(Kim et al., 2011)	n=8, finalist men and n=8 finalist women	Competitions	Video	10
(Gravestock et al., 2017a)	n=9, finalist men and n=12 finalist women	Competition	Video	10
(Hanley et al., 2019b)	n=15, finalist men and n=11 finalist women	Competition	Video	10

2.4.3 Applied methods for determining the velocity

In all studies, the kinematic parameters were analysed using various instruments. Of the twelve scientific articles, the instrument applied to obtain the velocity values by the respective studies were as follows: **Video** - four articles (Gudelj et al., 2013; Krska et al., 2014; Linthorne & Weetman, 2012; McGinnis, 1987); **Radar** - one article (Frère et al., 2017); **Optojump System** - one article (Gross et al., 2019); **Optojump + Radar** - three articles (Cassirame, Sanchez, Homo et al., 2017; Cassirame, Sanchez, Exell et al., 2019; Cassirame, Sanchez, Garnier et al., 2019); **Optojump + Video** - one article (Makaruk et al., 2016); **Optojump + Radar + Video** - one article (Cassirame, Sanchez, Homo et al., 2017); **Photocells + Video + Radar** - one article (Garcia et al., 2012). Regarding the nine scientific reports, the methodology applied were as follows: **Video** - five articles (Angulo-Kinzler et al., 1994; Bruggemann et al., 1999; Gravestock et al., 2017a; Hanley et al., 2019b; Kim et al., 2011); **Radar** - three articles (Mendoza et al., 2009; Schade et al., 2007); with **Photocells and Video** - one article (Gros & Kunkel, 1990).

It is essential to identify the protocol used to obtain the velocity data. Of the twelve scientific articles, nine are carried out in a competition environment and three in a training environment. Seven articles attempt to establish a relationship between the speed obtained in the approach run and the success of the jump (Cassirame, Sanchez, Homo et al., 2017; Cassirame, Sanchez, Exell et al., 2019; Cassirame, Sanchez, Garnier et al., 2019; Gross et al., 2019; Gudelj et al., 2013; Krska et al., 2014; Makaruk et al., 2016). Two identified the velocity parameter (Linthorne & Weetman, 2012; McGinnis, 1987), but it also determined the grip and take-off place as factors for successful jumps. The other three articles mention the differences between running with and without a pole and run on the elevated track (Cassirame, Sanchez, Homo et al., 2017; Frère et al., 2017; Garcia et al., 2012).

Beyond the instruments applied, it was essential to identify the protocol used to obtain the velocity data. For the group of the scientific reports, three of the nine performed a different protocol to obtain the velocity in competition. (Gros & Kunkel, 1990) used (10m-5m) used (10m-5m) distance from the box to calculate the average velocity of the athletes instead of the (11m-6m), and (Angulo-Kinzler et al., 1994; Bruggemann et al., 1999) calculated the mean horizontal velocity for the last stride (MHV) and the horizontal velocity of the centre of mass at touch down (VHTD). The speed range obtained from (10m-5m) for men was (9.77-9.16m/s), the MHV range was (8.95-9.74m/s) and the VHTD range was (8.83-10.10m/s).

The rest of the scientific reports (six), most recently published, present a standard protocol in which they analysed the average speed of athletes between 11-6m for men and 10-5m for women distance to the box (Gravestock et al., 2017a; Hanley et al., 2019b; Kim et al., 2011; Mendoza et al., 2009; Schade et al., 2007). In this case, the speed range obtained was (8.71-9.63m/s) for men and (7.52-8.68m/s) for women.

2.4.4 Data velocity from the reviewed studies

Since many of the authors adopt different methodologies, and the data collection was realised in different environments, two groups were created. This way, it is feasible to analyse the velocities obtained in the group of scientific studies and the group of scientific reports and rapidly compare the data.

Data velocity from the scientific studies

Not all scientific studies included by the inclusion criteria had final velocity values as the main findings. Despite using velocity as a parameter of research, the purpose of some studies was not aimed to identify the value of the velocity achieved in the approach run. In the next (table 2.3), it summarised the main findings, and there are significant differences.

Tabela 2.3: Characterization of the scientific studies reviewed (n=12)

Study	Main Findings	Velocity Data
(McGinnis, 1987)	Performance in pole vaulting is largely determined by 1 - pole stiffness, 2 - grip heigh, 3 - distance between the takeoff foot and vault box, and 4 - horizontal velocity at takeoff	no data
(Linthorne & Weetman, 2012)	The athlete's peak height, grip height, and push height increased with increasing run-up velocity; The peak height increased linearly at a rate of 0.54 m per 1 m/s increase in run-up velocity; Although a faster run-up velocity resulted in a greater loss of energy during the take-off the athlete always had a net gain of energy during the vault because of the muscular work performed during the pole support phase	wide range of run-up velocities (4.5–8.5 m/s) was obtained by setting the length of the athlete's run-up (2–16 steps)
(Garcia et al., 2012)	Speed, step frequency, and step Iength were higher in running situations withou the pole and when situations were more specific. Speed was more controlled when pole-vaulters had fo plant and take-off	S1 (max veocity) - without pole - 8.8m/s - with pole - 7.3m/s; S2 - (full run with takeoff without box) without pole - 8.3m/s - with pole - 7.1m/s; S3 - (full run with takeoff with box) without pole - 6.3m/s - with pole - 6.4m/s
(Gudelj et al., 2013)	The greatest influences on the prediction of pole vault success, regarding all the analyzed kinematic parameters, were the following variables: maximum pole bend, last stride speed and time of pole bend	Penultimate stride speed - Min. - 6.90 (m/s); Max. - 8.70 (m/s); Ultimate stride speed - Min. - 6.30 (m/s); Max. - 8.70 (m/s)

(Krska et al., 2014)	Speed parameters enable us to evaluate effectiveness of movement activity of female pole-vaulters during phases of approach and work on pole	Average horizontal CGv speed of female pole-vaulters at the beginning of last step reached 7.27 m/s. At the first touchdown moment of take-off the velocity even slightly increases on average value 7.46 m/s. The fastest (8.48 m/s) is always the one with the best sport performance result, S.D. (483 cm). During take-off reached pole-vaulters average lost of velocity 1.02 m/s.
(Makaruk et al., 2016)	Findings revealed that each of the track and field jumping events required a distinctive approach run. Therefore, training workouts need to be designed specifically to train the unique gait pattern of the long jump, triple jump, and pole vault	no data
(Cassirame, Sanchez, Homo et al., 2017)	Results showed that speed is more important for men than women (74.4 vs. 36.9%). Women performance is also largely affected by ability to transform speed into pole flexion to convert energy. Confirmed the specificity of women pole vault technique with major importance of energy stored at maximal pole bending. This study also suggests that women could improve massively their performance with adapted strength program to obtain more benefits from their run or working on different technical strategy to improve pole flexion	no data
(Cassirame, Sanchez & Morin, 2017)	Our study identifies that elevated tracks can increase final approach speed in pole vault and positively influencing performance	no data
(Frère et al., 2017)	Pole carriage during sprinting induces a large decrease in power output due to simultaneous impairment in force and velocity capabilities	Mean velocity: Without pole (9.29 ± 0.67 m/s); with pole (8.70 ± 0.57 m/s)
(Cassirame, Sanchez, Exell et al., 2019)	Small differences were found between successful and unsuccessful jumps. The speed at last touchdown showed a significant small difference between successful and unsuccessful jumps, as the greater speed at take-off (+0,15 m/s) was observed at successful jumps compared to unsuccessful jumps. Results suggest that pole vaulters should produce a fast run-up and avoid a decrease in speed before take-off	Mean velocity from 10-5m: in successful jumps - Elite Women (EW; n =26) - 7.82 ± 0.41 m/s; Elite men (EM, n=22) - 9.23 ±0.21 m/s; Mean velocity from 10-5m: in failed jumps - Elite Women (EW; n =26) - 7.80 $\pm 0.25 m/s; Elitemen(EM, n = 22) - 9.17\pm$ 0.28 m/s
(Cassirame, Sanchez, Garnier et al., 2019)	world class athletes have significant different results than other groups. For national and inter-regional levels, all athletes are French and practise in France whereas for international level, only 4 athletes are French (3 men 1 women). This comment suggests a national specificity regarding technical approach leading to higher relationship between speed, pole bending and use of energy provided by pole	All Men (n=43) = 0.82**** International (n=16) = 0.15* National (n=12) = 0.38** Inter-regional (n=15) = 0.87**** All Women (n=40) = 0.85**** International (n=15) = 0.30* National (n=15) = 0.43** Inter-regional (n=10) = 0.53*** *small, **moderate, ***large, ****very large
(Gross et al., 2019)	The correlations between approach speed and vault height, between sprint speed and approach speed, and between explosive strength indicators and sprint speed were large or very large. Correlation between reactive strength and sprint speed was small. Differences in speed during the vault approach compared with the flying sprint are mainly due to reduced step length rather than lower step frequency	Group 1 (elite) - pb - 4.46 ± 0.1 - Mean Approach speed (m/s) - 7.9 ± 0.3; Mean Sprint-speed potential (m/s) - 8.5 ± 0.4; Mean Speed utilization (vapproach/vsprint) (%) - 93 ± 3%

Data velocity from scientific reports

The following table 2.4 summarise the velocities obtained in competition in official competition reports. They are the average velocity reached by athletes between (11m-6m) from the box for men and (10m-5m) from the box for women. Some reports used different methodologies, as we can see from the reports marked by asterisks. The referred data was collected in 1987 with the World Champs in Rome. Not all major competitions had biomechanical reports providing data from kinematic analysis achieved by athletes.

We can see in the (tables 2.5) and (2.6) the values of the average velocities obtained from both men and women who performed in major competitions with the averages of the performance marks. What system was used to get the data values were also taken into consideration. In a temporal view, three groups were created, one for each decade, enabling a better observation of the data carried out between groups, giving a broader perspective of the evolution of the athletes' performance marks and velocities.

The results show us very stable values concerning the averages of the performance marks achieved, with values between (5.70m-5.75m) in thirty-one years of major competitions. Regarding the velocities, we found that the values presented in the first decade are higher than in the following two decades, with values between 9.53m/s from the first decade and values of 9.17m/s and 9.24m/s in the following decades, respectively. Regarding the systems used to obtain the data, only one study was carried out with photocells, five used video

Tabela 2.4: Velocity data from the scientific reports reviewed (n=9)

	Male velocity data (11m-6m) [m/s]				Female velocity data (10m-5m) [m/s]			
Scientific Reports	Max. Vel.	Min. Vel.	Mean	SD	Max. Vel.	Min. Vel.	Mean	SD
(Gros & Kunkel, 1990)*	9.70	9.16	9.41	0.20	-	-	-	-
(Angulo-Kinzler et al., 1994)**	9.74	8.95	9.36	0.32	-	-	-	-
(Bruggemann et al., 1999)***	10.10	9.61	9.81	0.25	-	-	-	-
(Schade et al., 2007)	9.43	8.94	9.15	0.16	8.53	7.52	7.98	0.33
(Mendoza et al., 2009)	9.36	8.87	9.17	0.16	8.28	7.69	7.98	0.22
(Mendoza et al., 2009)	9.54	8.73	9.18	0.23	8.68	7.68	8.23	0.30
(Kim et al., 2011)	9.63	9.05	9.26	0.22	8.30	8.13	8.23	0.06
(Gravestock et al., 2017a)	9.49	9.23	9.33	0.08	8.33	7.52	7.87	0.22
(Hanley et al., 2019b)	9.59	8.71	9.12	0.22	8.33	7.67	7.97	0.23

Max. Vel.= maximum velocity; Min. Vel.= minimum velocity;
(*) - report that used 10-5m for men; (**) - report that used the mean horizontal velocity from last stride;
(***) - report that used horizontal velocity of CM at touch down;

and three used radar.

Tabela 2.5: Velocity data and performance from the finalist in men event

Study	**Competition**	$\bar{X}$ **Velocity (m/s)**	$\bar{X}$ **Finalist mark (m)**	**System**
(Gros & Kunkel, 1990)	WC Rome 1987	9.41	5.73	Photocells
(Angulo-Kinzler et al., 1994)	OG Barcelona 1992	9.36	5.66	Video
(Bruggemann et al., 1999)	WC Athens 1997	9.81	5.81	Video
Mean Group I	**(1987-1997)**	**9.53**	**5.73**	-
(Schade et al., 2007)	WC Helsinki 2005	9.15	5.61	Radar
(Mendoza et al., 2009)	IAAF WF Stuttgart 2007	9.17	5.75	Radar
(Mendoza et al., 2009)	WC Berlin 2009	9.18	5.74	Radar
Mean Group II	**(2005-2009)**	**9.17**	**5.70**	-
(Kim et al., 2011)	WC Daegu 2011	9.26	5.81	Video
(Gravestock et al., 2017a)	WC London 2017	9.33	5.75	Video
(Hanley et al., 2019b)	WIC Birmingham 2018	9.12	5.7	Video
Mean Group III	**(2011-2018)**	**9.24**	**5.75**	-

$\bar{X}$=mean; WC - World Championship; OG - Olympic Games; IAAF WF - World Athletics Final;
WIC - World Indoor Championship.

In (table 2.6), we can observe that there are fewer data with women's event. The female pole vault discipline officially only started in major competitions at the 2000 Olympic Games in Sidney. The first competition with official data providing the velocities achieved was in 2005 at the World Championships in Helsinki. There is a small change in the velocity data over the thirteen years in the women's event with values between 8.06m/s and 8.02m/s. However, observed the average mark performance of the pole vault finalist event, a significant increase from 4.56m to 4.67m, can be seen, (table 2.6).

It is essential to try understanding if there are differences in the velocities between medal and non-medal athletes. We can see in the summary (table 7.1),the average velocities values between male and female medallists and non-medallists athletes performed in major competitions.

Tabela 2.6: Velocity data and performance from the finalist in women event

Study	**Competition**	$\bar{X}$ **Velocity (m/s)**	$\bar{X}$ **Finalist mark (m)**	**System**
(Schade et al., 2007)	WC Helsinki 2005	7.98	4.52	Radar
(Mendoza et al., 2009)	IAAF WF Stuttgart 2007	7.98	4.59	Radar
(Mendoza et al., 2009)	WC Berlin 2009	8.23	4.58	Radar
Mean Group I	**(2005-2009)**	**8.06**	**4.56**	-
(Kim et al., 2011)	WC Daegu 2011	8.23	4.72	Video
(Gravestock et al., 2017b)	WC London 2017	7.87	4.62	Video
(Hanley et al., 2019a)	WIC Birmingham 2018	7.97	4.69	Video
Mean Group II	**(2011-2018)**	**8.02**	**4.67**	-

$\bar{X}$=mean; WC - World Championship; OG - Olympic Games; IAAF WF - World Athletics Final;
WIC - World Indoor Championship.

Tabela 2.7: Resume table of the values of velocity from medalists and not medalists

Athletes	$\bar{X}$ Max.Velocity
All medalists men (n=24)	9.29m/s
Non-medalists men (n=49)	9.20m/s
differences	*(-0.09m/s)*
All medalists female (n=18)	8.14m/s
Non-medalists female (n=44)	7.97m/s
differences	*(-0.17m/s)*

$\bar{X}$=mean; Max. Velocity= maximum velocity;

2.5 Discussion and implications

This research carried out a systematic review of studies that examined the velocity data on the run-up phase, using only elite athletes in training or competition environment.

2.5.1 Characteristics of the reviewed studies

Searching for studies that include the words ”pole vault”, ”velocity”, and ”speed”, twenty-one studies were identified. From the twenty-one, twelve scientific studies and nine scientific reports, all have elite athletes as a study population. The studies were carried out in training and competition environments.

When comparisons are made between the two groups, we must differentiate what we intend to observe. In the groups of scientific studies, not all studies aimed to find the velocities obtained in run-ups. Only four studies allow a comparison between the two groups because they were studies carried out in a competitive environment.

Although the velocity values observed in the reports are from finalists of major competitions reporting special moments of peak performance, with values for men in a range of **(9.12m/s - 9.81m/s)** and in women **(7.87m/s - 8.23m/s)** the velocities values obtained in scientific studies show values within the previously mentioned ranges; Men - (9.23±0.21m/s) (Cassirame, Sanchez, Exell et al., 2019); Womens - (6.90m/s - 8.70m/s) (Gudelj et al., 2013); (7.46m/s - 8.48m/s) (Krska et al., 2014) and (7.9±0.21m/s) (Gross et al., 2019). Even with some possible differentiation of the groups, the values obtained in non-major competitions were within the velocity's ranges of major competitions for both men and women.

2.5.2 Methods utilised to measure velocity

In all studies, the kinematic parameters were analysed using various instruments, namely photoelectric cells, high-speed cameras, optoelectronic systems and Lidar laser systems, as reported in the results. With the use of multiple instruments, there is a risk of having inconsistent data over the years. As we can see between the average values obtained from the rates between studies like (Gros & Kunkel, 1990) performed with photocells (9.41m/s), the value obtained (9.81m/s) in the report of (Bruggemann et al., 1999) video and the average speed value of (9.15m/s) in (Schade et al., 2007). It was also found values in the range of (9.18m/s) with the use of Lidar as an instrument. In scientific studies there is the use of combined systems between Optojump Next system and Lidar Laser, obtaining values in the order of the elite women of (7.82±0.41m/s) e elite men (9.23±0.21m/s). Not only different instruments allow different values, but also different protocols result in different velocity values. Some studies obtain the average velocities from the last step, and other studies evaluate the average speeds between a space (11m-6m) from the box for men and (10m-5m) from the box for women. Other authors consider the velocities at the time of touch down (TD) and take off (TO) in the jump.

It is essential to have consistency in the data, with the need to standardise the instruments and protocols applied or validate them if new instruments are used. Coaches tend to look for consistency in getting the velocities as a way to compare results between competitions.

2.5.3 Velocity data in the reviewed studies

In this systematic review, extensive research involving pole vault and the velocity parameter was necessary. If we look at just the numbers, the studies' result was high, but the number was reduced to 21 studies through the inclusion and exclusion criteria. There are two types of studies with different specificities. The group of studies reports from major competitions in which the objective is to obtain data from the finalist athletes. Another group of studies independent of the environment, being carried out in a training or competition environment. In this group of scientific studies, we can see different objectives and not just the velocity achieved in a world competition. Various answers were given, adding velocity with other parameters linked to the jump's success.

Velocity findings from scientific studies

This section shows that several studies have tried to correlate the velocity with other parameters to the jump's success. The performance in pole vaulting is largely determined by the horizontal velocity at TO, facilitating a higher grip and pole stiffness (McGinnis, 1987). Other authors agree that with the increase of the approach run, there will be an increase in speed that will make possible grip higher and have a bigger pole and push in the jump (Linthorne & Weetman, 2012). The authors (Gudelj et al., 2013) refer that the last step's velocity correlates with the success in pole vaulting and maximum pole bend and time of pole bend. In this study, the data obtained for the ultimate stride velocity - Min. - 6.30 (m/s); Max. - 8.70 (m/s).

Cassirame, Sanchez, Homo et al. (2017) identify the mechanical performance determinants in women's vs men's pole-vault. The results showed that speed is more important for men than women (74.4% vs 36.9%). Women performance is also largely affected by the ability to transform speed into pole flexion to convert energy. This study suggests that women could improve their performance massively with adapted strength programs to obtain more benefits from their run or work on a different technical strategy to improve pole flexion.

Cassirame, Sanchez, Garnier et al. (2019) the relationships between running speed, pole bending, and pole vaulting performance are critical questions. The results of the study showed that for all men (n=43), R=0.82 and all women (n=40), R=0.85, which means a substantial relationship between. It is important to report the main findings from (Krska et al., 2014), which mentions that during the take-off, the pole vaulters lost an average of 1.02 m/s of the velocity reach during the run-up.

Another parameter study by two other authors is the athlete's ability to run fast with a pole and the relationship of loss of speed with and without a pole planting (Frère et al., 2017; Garcia et al., 2012). Speed, step frequency, and step length were higher in running situations without the pole. Speed was more controlled when pole-vaulters had to plant and do the take-off. Max velocity- without pole - 8.8m/s - with pole - 7.3m/s; full run with take-off without box - without pole - 8.3m/s - with pole - 7.1m/s. Pole carriage during sprinting induces a large decrease in power output due to simultaneous impairment in force and velocity capabilities. Mean velocity: without pole - 9.29±0.67m/s; with pole - 8.70±0.57m/s (Frère et al., 2017).

It was also identified small differences between successful and unsuccessful jumps (Cassirame, Sanchez, Exell et al., 2019). Results suggested that pole vaulters should produce a fast run-up and avoid a decrease in speed before take-off. The mean velocity in the elite women was 7.82±0.41m/s in successful jumps and 7.80±0.25 m/s in failed jumps. For the men, the elite group, the mean velocity was 9.23±0.21 m/s for the successful jumps and 9.17±0.28 m/s for failed jumps.

Velocity findings in scientific reports

In competition, particularly in major competitions, athletes' velocities values are always among the main points mentioned in the reports.

The velocities obtained in the studies (Angulo-Kinzler et al., 1994; Bruggemann et al., 1999; Gros & Kunkel, 1990) report higher values than in the rest of the other reports, with maximum values between 10.10m/s to 9.70m/s. It is possible to see in (table 2.4), there is a significant difference between the velocities values obtained in these first three reports. The remaining reports show similar values for the velocities achieved regardless of the instruments or protocols used.

Interestingly, if the medallist male and female athletes of all the competitions analysed in these reports obtained higher values than the other finalists of these great competitions, as we can see from the summary presented in (table 7.1) for both men and women, the medallists obtained a higher average. The value is more significant in women with a difference of (+ 0.17m/s) for medal athletes; for men, the value is only

(+ 0.09m/s) higher. This conclusion is in line with (Cassirame, Sanchez, Homo et al., 2017) suggesting that women could improve their performance massively with adapted strength programs to obtain more benefits from their run or work on a different technical strategy to improve pole flexion.

We can see from the data that the women technical index increased through the data in table 3.6. Although the velocity values have remained very similar, the average value of the performance mark from the finalist has increased substantially, rising 11 cm the average between Group I and Group II.

2.6 Practical implications

This study allows us to identify the importance of the velocity applied to the pole vault event, allowing coaches and athletes to identify relevant points to produce better performances. These findings refer to the extent of reaching high velocities during the approach run to obtain better performance. Using the same instruments and protocols, other coaches and other athletes can replicate the process both in training and competition to get more data that can serve as a basis for comparison.

It is possible to question whether, with more knowledge from the best athletes' velocities, some athletes may consider changing their jump style. They can choose a more traditional form of jumping with the Russian technique or a less traditional technique for a type of jump that increases the pole's accumulated energy, bending more the pole, benefiting more from the accumulated energy and the transfer to the athlete.

2.7 Future perspectives

The PRISMA protocol was designed for a scientific community more connected to the medical sciences. It could be asked if these systematic reviews protocols can include all the work carried out with relevance to the specific sports activities like pole vaulting? Using these protocols to carry out a systematic review in the field of sport can make it challenging to include specific articles from world specialists. Their articles cannot be considered readable studies with this PRISMA protocol, but they are quality work from expert coaches with decades of experience. We believe that in the future, there should be a mix of systematic reviews and included bibliographic references from specialists in the field who have carried out works with relevance quality even if they are not considered scientific papers.

It is possible to suggest an evolution of the instruments, mainly in obtaining the data in real-time and preferably adaptable in any competitive and training environment. Development studies and validation of new instruments are suggested in the analysis of the velocities such as the Inertial measurement unit (IMU) because they allow capturing instantaneous values in real-time that can benefit a lot in the data capture process.

2.8 Conclusions

With this study, it was possible to identify the significance of the velocity in the pole vault event. Of the twenty-one reviewed studies that met the criteria, twelve were scientific studies, and nine were scientific reports from major competitions. Different methodologies were identified in the cohort of scientific studies. Some of the assessments were carried out in a competition and training environment, with different aims depending on the studies. The studies have been relating the velocity parameter to the jump's success; however, other parameters have been added, such as the grip high, stiffer poles, the distance of the take-off and maximum pole bend, to the performance. To respond to this methodologies, different data collection instruments and procedures were used.

In the scientific studies, there was only one investigation that adopt photocells. Most of the studies have used video image digitisation, laser Lidar systems, and the Optojump system or the mixture of the two systems.

In the scientific reports from major competitions, the instruments adopted were very similar, with only one report utilizing the photocells system (World Champs in Rome 1987). Between 1992 and 1997 (Barcelona Summer Olympic Games 1992; World Champs in Athens 1997), high-speed cameras were implemented to obtain images and subsequent digitisation. Between 2005 and 2009 (World Champs in Helsinki 2005; IAAF World Final in Stuttgart 2007 Men - 2008 Women; World Champs in Berlin 2009), the gun system was the Radar gun - LAVEG1 technology. During the championships (World Champs in Daegu 2011; World Champs in London 2017; World Indoor Champs in Birmingham 2018), the velocity collection system was once again the video with high-speed cameras.

Despite the application of different instruments, the velocity data had very stable values except in the first years of the collection (WC Rome 1987; OG Barcelona 1992; WC Athens 1997). when the values presented are higher, with an average of 9.53m/s group I in contrast to the average 9.17m/s group II and 9.24m/s for group III see table 3.5. We cannot say that these higher values were due to another system because the video was also used.

Considering the three groups as a good organisation over time, the average values of velocity and performance have remained surprisingly stable, in more than 30 years of collections in major competitions, the average of the finalists' mark was between 5.70m and 5.75m and the velocities between 9.53m/s and 9.24m/s. In women, there was an increment in technique. However, the velocities values remained similar between 8.06m/s and 8.02m/s for group I and group II. The average value of the finalists in the pole vault rises significantly from 4.56m to an average of 4.67m.

When evaluating the medallist's velocities, a direct correlation can be observed. The medals were, on average, the athletes who run the fastest. The difference is considerably more visible in women, where the difference is between 7.97m/s for non-medallist's and 8.14m/s for medalled athletes. In men, the difference is smaller, 9.20m/s for non-medals and 9.29m/s for medals.

2.9 Appendix

Tabela 2.8: Characterization of the scientific studies reviewed (n=12)

Study	Metodology	Environment	Capture Instruments	System	Population (n)	Study purpose	Main findings	Values of velocity
(McGinnis, 1987)	High speed 16mm camaras were used to record competitive vaults by 30 athletes vaulting at crossbar heights of 5,19 to 5,81	Competitio	no data	Digitilize video	n=30 male pole vaulters	Identify the mechanical parameters wich limit performance in the pole vault. A theoretical model of the pole vault was developed to identify variables related to sucess in the event	Performance in pole vaulting is largely determined by 1 - pole stiffness, 2 - grip heigh, 3 - distance between the takeoff foot and vault box, and 4 - horizontal velocity at takeoff	no data
(Linthorne & Weetman, 2012)	Experienced male pole vaulter were video recorded in the sagittal plane and a wide range of run-up velocities (4,5–8,5 m/s) was obtained by setting the length of the athlete's run-up (2–16 steps). A selection of performance variables, kinematic variables, energy variables, and pole variables were calculated from the digitized video data	Training	Panasonic NV-D560 video camera operating at 50 Hz	Video - Ariel Performance Analysis System (Ariel Dynamics, Trabuco Canyon, CA, USA) was used to manually digitize the motion of the athlete in the video images	n=1, an experienced male pole vaulter with a personal best performance of 4,90	1 - to determine the mathematical form and sensitivity of the relationship between run-up velocity and vault height. 2- to determine the changes in the athlete's kinematics and the changes in the pole characteristics that are necessary to make effective use of a faster run-up velocity, and 3 - to determine the resulting changes in the patterns of energy exchange that occur during the vault	The athlete's peak height, grip height, and push height increased with increasing run-up velocity; The peak height increased linearly at a rate of 0,54 m per 1 m/s increase in run-up velocity; Although a faster run-up velocity resulted in a greater loss of energy during the take-off the athlete always had a net gain of energy during the vault because of the muscular work performed during the pole support phase	wide range of run-up velocities (4,5–8,5 m/s) was obtained by setting the length of the athlete's run-up (2–16 steps)
(Garcia et al., 2012)	10 pole vaulter (7 men and 3 women) were analyzed from Radar, video and photocells after performing warm up to do 2 runs from wich situations S1 (max velocity); S2 (full run with takeoff without box); S3 (full run with takeoff with box)	Training	Radar system (Stalker ATS Pro) / Photocells (Ergo-jump System) / Camara digital Samsung VP03 de 25 Hz	Photocells* / Video** / Radar***	n=10, 7 men and 3 women. 18 years $\pm 2,14$ years, height of 1,76 $\pm 0,09$ m, weight of 69,23 $\pm 1,09$ Kg, pole length of 4,20$\pm$ 0,48 m	The purpose ot the present study was to establish tests and reference values for fhe approach run	Speed, step frequency, and step Iength were higher in running situations withou the pole and when situations were more specific. Speed was more controlled when pole-vaulters had fo plant and take-off	S1 (max veocity) - without pole - 8,8m/s - with pole - 7,3m/s; S2 - (full run with takeoff without box) without pole - 8,3m/s - with pole - 7,1m/s; S3 - (full run with takeoff with box) without pole - 6,3m/s - with pole - 6,4m/s
(Gudelj et al., 2013)	11 kinematic parameters has been applied, according to the McGinnis model, representing a predictor assemblage of variables. The maximum height vaulted presented a criterion variable	Competition	Two Panasonic S-VHS, W-M95 cameras. The speed of the camera shutter was set at 1/500, with an opened focus	Digitilize video	n=27, female pole vaulters at the European Junior Championship in 2009	Correlation between some kinematic parameters and the result success in the pole vault	The greatest influences on the prediction of pole vault success, regarding all the analyzed kinematic parameters, were the following variables: maximum pole bend, last stride speed and time of pole bend	Penultimate stride speed - Min. - 6,90 (m/s); Max. - 8,70 (m/s); Ultimate stride speed - Min. - 6,30 (m/s); Max. - 8,70 (m/s)
(Krska et al., 2014)	Data collect in 2004 - 2006 on the meetings Golden spiked shoes in Ostrava, Czech Republic. Kinetic parameters were gained by two-dimension analyser Consport Motion Analysis System (CMAS)	Competitio	Consport Motion Analysis System (CMAS)	Video	n=19, There are involved 19 female pole-vaulters with the sport performance 380 – 483 cm	CAnalyse the spedd parameter in the female pole vault event	Speed parameters enable us to evaluate effectiveness of movement activity of female pole-vaulters during phases of approach and work on pole	Average horizontal CGv speed of female pole-vaulters at the beginning of last step reached 7,27 m/s. At the first touchdown moment of take-off the velocity even slightly increases on average value 7,46 m/s. The fastest (8,48 m/s) is always the one with the best sport performance result, S.D. (483 cm). During take-off reached pole-vaulters average lost of velocity 1,02 m/s.

(Makaruk et al., 2016)	Twenty-five Optojump Next transmitter and receiver bars, which were 1 m in length each, were placed parallel to each other on the approach runway for Kinematics collect during indoor track and field competitions (2 Polish championships and 1 international meeting)	Competition	Optojump Next system and A webcam (Logitech C920) with a sampling rate of 30 Hz was used to count the number of steps during the approach run in each subject	Optojump Next system / video (webcam)	n=12, pole vaulters with 5,30 $\pm 0,37$m with the best competition results and at least 5 full jumps were selected for analysis	Examine the changes in selected kinematics in the long jump, triple jump, and pole vault to highlight the unique movement pattern characteristics in the approach runs utilised in these events	Findings revealed that each of the track and field jumping events required a distinctive approach run. Therefore, training workouts need to be designed specifically to train the unique gait pattern of the long jump, triple jump, and pole vault	no data
(Cassirame, Sanchez, Homo et al., 2017)	All data were collected during the All Star Perche 2017 meeting with 20-m Optojump Next system (Microgate, Bolzano, Italy) was placed along the runway, starting at 2.2 m from zero position (planting box). Athlete speed were mesure during the run-up with a Radar gun Stalker Pro II (Stalker ltd, Plano, United states) was placed behind the landing mat in the run-up direction at a 1.4 m height	Competition	Optojump Next system (Microgate, Bolzano, Italy); Radar gun Stalker Pro II (Stalker ltd, Plano, United states); high frequency camera (100 Hz) captured the take-off position in the sagittal plane	Optojump Next system / Radar Laser / Video	n= 62; Best vault of 31 men (73,9 ± 9,2 kg; 180,2 ± 6,2 cm) and 31 women (59,6 ± 6,3 kg; 169,1 ±4,7 cm) were analyzed	Identify the mechanical performance determinants in womens vs mens pole-vault	Results showed that speed is more important for men than women (74,4 vs. 36,9%). Women performance is also largely affected by ability to transform speed into pole flexion to convert energy. Confirmed the specificity of women pole vault technique with major importance of energy stored at maximal pole bending. This study also suggests that women could improve massively their performance with adapted strength program to obtain more benefits from their run or working on different technical strategy to improve pole flexion	no data
(Cassirame, Sanchez & Morin, 2017)	Performance and run-up criteria (speed, stride rate, contact and aerial time) were measured from 20 high level male pole-vaulters during official competitions either on a regular or on an elevated track. Parameters comparisons were proceed between both conditions and run-up parameters were confronted to speed modification on elevated track	Competition	Optojump Next system (Microgate, Bolzano, Italy); Radar gun Stalker Pro II (Stalker ltd, Plano, United states)	Optojump Next system / Radar	n=20; Twenty highly trained male pole-vaulters. Eleven elite athletes with personal best jumps from 5,45 to 6,16 m and nine young high level athletes with personal bests ranging from 4,60 to 5,15m	The aim of this study is to investigate the potential advantage of using an elevated track during elite pole-vault competitions on run-up speed parameters	Our study identifies that elevated tracks can increase final approach speed in pole vault and positively influencing performance	no data
(Frère et al., 2017)	After warm-up, athletes performed 2 maximal accelerations without pole and 2 with pole carriage	Training	Radar gun Stalker Pro II (Stalker ltd, Plano, United states)	Radar Laser	n=17; 10 women with personal best: 4,03 ± 0,22 m; 7 men with personal best: 5,08 ± 0,16 m	The Influence of pole carriage on sprint mechanical properties during pole vault run-up	Pole carriage during sprinting induces a large decrease in power output due to simultaneous impairment in force and velocity capabilities	Mean velocity: Without pole (9,29 ± 0,67 m/s); with pole (8,70 ± 0,57 m/s)

(Cassirame, Sanchez, Exell et al., 2019)	Two hundred and seven pairs of successful and unsuccessful jumps at the same height were analysed. Participants included male and female athletes of three different age groups with bar height clearances ranging from 2,81 to 5,91m. Run-up parameters were collected using an Optojump Next system and a Stalker Pro II radar gun. A 2D kinematical analysis was conducted to obtain selected parameters of the take-off	Competition	Optojump Next system (Microgate, Bolzano, Italy); Radar gun Stalker Pro II (Stalker ltd, Plano, United states)	Optojump Next system / Radar Laser	n=132; pole vaulters from six different categories: cadet women (CW; n =19), cadet men (CM; n =25), junior women (JW; n =20), junior men (JM; n =20), elite women (EW; n =26) and elitemen (EM; n =22)	The biomechanical differences between successful and unsuccessful jumps during a pole vault competition	Small differences were found between successful and unsuccessful jumps. The speed at last touchdown showed a significant small difference between successful and unsuccessful jumps, as the greater speed at take-off (+0,15 m/s) was observed at successful jumps compared to unsuccessful jumps. Results suggest that pole vaulters should produce a fast run-up and avoid a decrease in speed before take-off	Mean velocity from 10-5m: in successful jumps - Elite Women (EW; n =26) - 7,82 ± 0,41 m/s; Elite men (EM, n=22) - 9,23 ±0,21 m/s; Mean velocity from 10-5m: in failed jumps - Elite Women (EW; n =26) - 7,80 $\pm 0,25 m/s; Elitemen (EM, n = 22) - 9,17 \pm$ 0,28 m/s
(Cassirame, Sanchez, Garnier et al., 2019)	During two editions of All-star perche elite from 2017 and 2018 which include athletes from international, national and inter-regional levels were collected take-off speed as last 0,2 second before last contact time on the floor (TkS, in m/s)	Competition	Optojump Next system (Microgate, Bolzano, Italy); Radar gun Stalker Pro II (Stalker ltd, Plano, United states)	Optojump Next system / Radar Laser	n=83; 40 women with personal best from 3,40 to 4,910m; 43 men with personal best from 4,40 to 6,16 m	The aim of this study was to investigate the relationships between running speed, pole bending and performance in pole vaulting	world class athletes have significant different results than other groups. For national and inter-regional levels, all athletes are French and practise in France whereas for international level, only 4 athletes are French (3 men 1 women). This comment suggests a national specificity regarding technical approach leading to higher relationship between speed, pole bending and use of energy provided by pole	All Men (n=43) = 0,82**** International (n=16) = 0,15* National (n=12) = 0,38** Inter-regional (n=15) = 0,87**** All Women (n=40) = 0,85**** International (n=15) = 0,30* National (n=15) = 0,43** Inter-regional (n=10) = 0,53*** *small, **moderate, ***large, ****very large
(Gross et al., 2019)	A cross-sectional study design was implemented to investigate the relationships between adjacent levels in a cascade of contributing factors to pole vault performance. Physical and kinematical parameters were analyse	Competition	Optojump Next system (Microgate, Bolzano, Italy)	Optojump Next system	n=20; 20 women with age from 16–31, representing 8 nations participated in the study	This study investigated the relationships between pole vault height, approach speed, sprint-speed potential, and indicators of both explosive and reactive strength in 20 international female pole vaulters	The correlations between approach speed and vault height, between sprint speed and approach speed, and between explosive strength indicators and sprint speed were large or very large. Correlation between reactive strength and sprint speed was small. Differences in speed during the vault approach compared with the flying sprint are mainly due to reduced step length rather than lower step frequency	Group 1 (elite) - pb - 4,46 ± 0,1 - Mean Approach speed (m/s) - 7,9 ± 0,3; Mean Sprint-speed potential (m/s) - 8,5 ± 0,4; Mean Speed utilization (vapproach/vsprint) (%) - 93 ± 3%

Tabela 2.9: Characterization of the scientific reports reviewed (n=9)

Study	Competition	Metodology	Capture instruments	System	Population (n)	Result of the top 8 Men	Steps run-up Men	Result of the top 8 Women	Steps run-up Women	Take-off distance Men (m)	Take-off distance Women (m)	Values of Velocity: 16-11m (m/s)	11-6m (m/s)	15-10m (m/s)	10-5m (m/s)	MHV	VHTD	V (TO) M	V (TO) W
(Gros & Kunkel, 1990)	World Champs in Rome 1987	Three LOCAM highspeed cameras. C1- Optical axis intersected all the plane of motion at 4m from box. C2-Optical axis intersectd the plane on motion of the second phase of the jump. C3-Mounted in the stands directly in line with the runway	Approach velocities (m/s) were measured with photocells	Photocells* and Video**	n=8, The best vault of the eight top ranked athletes was chosen for analysis from the 2nd World Champinships in Rome	5,85 5,80 5,80 5,80 5,70 5,70 5,60 5,60								9,47* 9,42* 9,40* 9,16* 9,26* 9,12* 9,12* 9,29*	9,77* 9,43* 9,6* 9,26* 9,31* 9,51* 9,16* 9,29*			8,6** 8,3** 8,3** 8,0** 8,2** 8,3** 8,6** 8,4**	
(Angulo-Kinzler et al., 1994)	Barcelona Summer Olympic Games 1992	Two time code synchronized S-VHS video cameras operating at 50 Hz were used. 22 body landmarks were manually digitized in each frame for both cameras	Two time code synchronized S-VHS video cameras operating at 50 Hz	Video	n=8, best finalist pole vaulters of Barcelona Olympic Games	5,80 5,80 5,75 5,75 5,65 5,60 5,55 5,40										9,74 9,64 9,68 9,42 9,44 9,00 9,70 8,95	9,65 9,80 9,68 9,23 9,34 8,83 9,57 8,83		
(Bruggemann et al., 1999)	World Champs in Athens 1997	The data was record using two synchronized stationary video cameras operating at 50 Hz. Video data was digitized using the Peak-Motus system. The calculation of the parameters use was made developed by the Department of Track and Field and Gymnastics from the German Sport University of Cologne, Germany	Two synchronized stationary video cameras operating at 50 Hz	Video	n=8, finalist	6,01 5,96 5,91 5,80 5,70 5,70 5,70 5,70											10,10 9,61 9,73		
(Schade et al., 2007)	World Champs in Helsinki 2005	Data calculated from laser distance measurement, the distances refer to the zero-line	Radar gun	Laser	n=8, finalist men and women	5,80 5,75 5,65 5,65 5,50 5,50 5,50 5,50		5,01 4,60 4,50 4,50 4,50 4,35 4,35 4,35				9,01 9,16 8,77 8,90 9,11 8,99 9,09 9,38	9,04 9,26 8,96 8,94 9,23 9,16 9,21 9,43	8,10 7,80 7,60 7,39 7,75 7,49 8,33 7,99	8,31 8,01 7,72 7,52 8,00 7,70 8,53 8,05				
(Mendoza et al., 2009)	IAAF World Final in Stuttgart 2007 (Men) - 2008 (Women´s)	The run-up velocities have been measured with the LAVEG1 technology. The measurements and video clips were analysed. The results of our analyses on average speed for defined run-up sections, take-off position and lengths of the two last steps are presented	Radar gun - LAVEG1 technology	Laser	n=8, finalist men; n=7 finalist women	5,91 5,86 5,81 5,81 5,70 5,70 5,60 5,60	18 18 18 18 20 18 18 18	4,70 4,70 4,70 4,50 4,50 4,50 4,50	16 17 16 18 17 18 16	4,15 3,65 3,85 3,60 4,45 4,05 3,80 4,35	3,85 3,90 3,70 3,60 3,85 3,55 3,75		9,36 9,28 9,14 9,21 9,36 9,16 8,87 9,03		8,05 8,28 7,76 8,20 7,69 7,87 8,06				
(Mendoza et al., 2009)	World Champs in Berlin 2009	The run-up velocities have been measured with the LAVEG1 technology. The measurements and video clips were analysed. The results of our analyses on average speed for defined run-up sections, take-off position and lengths of the two last steps are presented	Radar gun - LAVEG1 technology)	Laser	n=9, finalist men; n=8 finalist women	5,90 5,85 5,80 5,75 5,75 5,65 5,65 5,65 5,65	18 18 20 18 16 20 18 18 18	4,75 4,65 4,65 4,65 4,55 4,55 4,40 4,40	16 16 16 16 16 14 17 16	4,35 4,15 4,65 4,30 4,25 3,60 4,25 4,20 4,25	3,45 3,35 3,75 3,80 3,85 3,40 3,80 3,55		9,24 8,99 9,54 9,12 8,73 9,35 9,07 9,35 9,24		8,68 8,32 7,92 8,33 8,26 8,24 7,68 8,43				
							5,90	16	4,85	18	4,50	4,04		9,05		8,27			
(Kim et al., 2011)	World Champs in Daegu 2011	DLT set were used for two-dimensional analysis to analytical variables included total approach distance, number of steps, mean step length, approach position, and average velocity from 6-11 meters away from the pole box	High speed camera (Casio, EX-F1, Japan)	DLT image set	n=8, finalist men and women	5,90 5,85 5,85 5,85 5,75 5,75 5,65	20 18 18 16 18 16 18	4,80 4,75 4,70 4,70 4,65 4,65 4,65	16 16 18 14 16 16 16	4,55 4,79 4,51 4,47 3,80 4,48 4,45	4,10 3,40 3,54 3,69 3,46 3,39 3,35		9,48 9,63 9,09 9,05 9,34 9,09 9,31		8,23 8,30 8,30 8,15 8,27 8,20 8,13				
(Gravestock et al., 2017a)	World Champs in London 2017	Three locations housed a Sony PXW-FS5 and a Canon EOS 700D. The final position was occupied by an additional Canon EOS 700D. All cameras were deployed to record each attempt during the men's and women pole vault final. The Sony PXW- FS5 cameras operating at 200 Hz (shutter speed: 1/1250; ISO: 2000; FHD: 1920x1080 px) recorded the last section of the runway to bar clearance. The Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1250; ISO: 3200; SHD: 1280x720 px) recorded the entire trial from the start of the runway to landing. Two separate calibration procedures were conducted after the competition. First, a rigid cuboid calibration frame was positioned on the runway over the plant box. This frame was then moved to a second position, away from the plant box to ensure an accurately defined volume that athletes would take off from and clear the crossbar	High speed camera. Sony PXW-FS5 and a Canon EOS 700D	The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) for full body manual digitising	n=9, finalist men; n=12 finalist women	5,95 5,89 5,89 5,82 5,75 5,65 5,65 5,65 5,60	20 16 20 18 16 24 18 20 18	4,91 4,75 4,65 4,65 4,65 4,65 4,65 4,55 4,55 4,55 4,45 4,45	16 15 16 16 14 17 16 16 13 17 14 15	4,02 4,09 4,45 4,21 3,97 3,56 4,37 4,31 3,60	3,29 3,29 3,34 3,36 3,48 3,59 3,45 3,39 3,41 3,49 3,66 3,07		9,23 9,33 9,49 9,33 9,23 9,44 9,13 9,49 9,53		8,13 8,33 7,63 7,87 7,69 7,94 7,75 8,00 7,52 7,87 7,94 7,81				
(Hanley et al., 2019b)	World Indoor Champs in Birmingham 2018	Three locations were situated on the home straight, one at the first bend, and a final position was located about two- thirds of the way along the back straight. Four locations housed a Sony PXW-FS5; the final position was occupied by a Canon EOS 700D. All cameras were deployed to record each attempt during the men's final. The Sony PXW-FS5 cameras operating at 200 Hz (shutter speed: 1/1250; ISO: 2000-4000; FHD: 1920x1080 px) recorded the last section of the runway to take-off. The Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1250; ISO: 1600-3600; SHD: 1280x720 px) recorded the entire trial from the start of the runway to take-off and was used to count the number of steps each athlete took during the run-up	High speed camera. Sony PXW-FS5 and a Canon EOS 700D	The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) for full body manual digitising	n=15, finalist men; n=11 finalist women	5,90 5,85 5,85 5,80 5,80 5,80 5,70 5,70 5,70 5,60 5,60 5,60 5,60 5,60 5,45	21 18 16 18 18 20 18 20 18 24 18 18 18 20	4,95 4,90 4,80 4,75 4,70 4,70 4,60 4,60 4,60 4,50 4,50	14 16 16 12 16 16 14 16 16 16 14	4,54 4,01 4,05 4,40 4,19 4,19 3,97 3,81 3,83 3,87 4,35 4,47 4,35 4,12 4,19	3,61 3,95 3,28 3,68 3,18 3,64 3,46 3,71 3,47 3,24 3,36		9,23 8,99 8,71 9,05 9,59 9,05 9,33 9,35 9,00 8,81 9,25 9,22 9,18 9,00 8,98		8,30 8,21 8,10 7,70 8,33 7,80 7,81 7,94 7,82 7,99 7,67			9,01 8,32 8,23 8,50 8,40 8,23 8,10 7,89 8,31 8,43 8,63 8,49 7,60 7,81 7,64	7,75 8,02 7,36 7,13 7,49 6,85 7,18 6,73 7,19 7,21 7,03

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"Toda arte e toda investigação, assim como toda ação e toda escolha, tem em mira um bem qualquer; e por isso foi dito, com muito acerto que o bem é aquilo a que todas as coisas tendem."

Aristóteles

Capítulo 3

Metodologias Gerais Utilizadas

Este capítulo apresenta uma descrição geral da abordagem metodológica utilizada nos três estudos apresentados nesta investigação. Os estudos seguem uma linha de pensamento evolutiva, baseada numa lógica de resposta científica aos objetivos propostos.

3.1 Participantes

Participaram neste estudo dois atletas de elite portugueses de ScV. Os atletas foram devidamente informados sobre o objetivo dos estudos nos quais estavam envolvidos, assim como sobre as etapas de recolha de dados, tratamento e apresentação dos resultados. Todos os procedimentos foram aprovados pela Comissão de Ética da Universidade Lusófona. As recolhas realizadas foram incorporadas no processo de treino, não interferindo no mesmo, nem modificando o planeamento estabelecido pelo treinador. Durante todas as recolhas os atletas não apresentaram qualquer problema físico.

3.2 Protocolo de aquecimento

Foi adotado um protocolo de aquecimento específico conhecido pelos atletas, já realizado regularmente durante o processo de treino. Cada atleta realizou o seu aquecimento com o objetivo de estar o mais preparado possível para iniciar as recolhas à máxima intensidade, mantendo sempre uma postura de teste. Os atletas realizaram várias passagens pelas células fotoélectricas até estarem realmente quentes e preparados para a recolha efetiva (velocidade máxima) (Estudo I).

Os atletas realizaram um protocolo de aquecimento igual ao realizado durante as competições (Estudo II). Este protocolo previa tanto um aquecimento físico como técnico, realizando saltos técnicos para o colchão com diferentes varas e comprimentos de CA até estarem realmente preparados para o início das recolhas (Estudo II).

3.3 Avaliação da velocidade

3.3.1 Intrumentos e protocolos

No estudo experimental I foi avaliada a velocidade máxima em diferentes tarefas (T1: CA com vara e T2: corrida máxima de 20 metros lançados sem vara), em situação de treino sem salto.

As tarefas foram realizadas num corredor da pista com uma zona de aceleração de 30 metros e uma zona de obtenção da velocidade máxima de 20 metros. Foi colocado um par de células fotoelétricas, de duplo corte da Microgate, modelo Rei 2 de fabricação Italiana, no final da zona de aceleração e a cada 10 metros na zona de velocidade máxima (total 3 pares) (Buchheit et al., 2012; Rabita et al., 2015; Romero-Franco et al., 2017; Young et al., 2008).

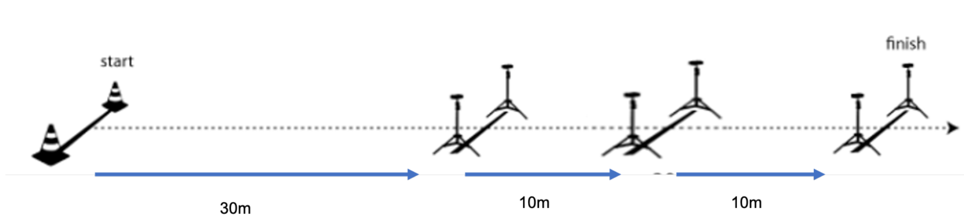

Figura 3.1: Esquema do teste de velocidade

Foi utilizado um sistema de cronometragem profissional da Microgate, modelo Rei 2, com feixe de duplo corte, que permite a recolha fidedigna da velocidade do atleta através da sincronização e sobreposição, do sinal de ambas as células. Este sistema garante que as fotocélulas são interrompidas pelo tronco do atleta e não pelo movimento dos braços ou da vara.

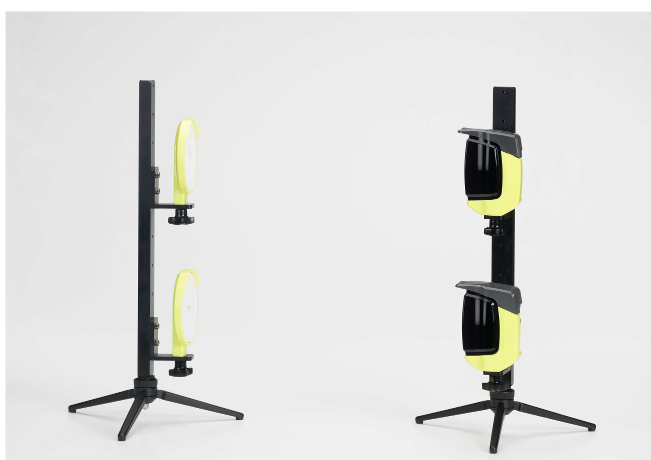

Figura 3.2: Células fotoelétricas de duplo corte

Cada atleta realizou três repetições de cada tarefa, tendo sido considerado para análise a melhor prestação em cada tarefa.

Para o estudo experimental II e III, foi avaliada a velocidade da CA com salto, bem como outros parâmetros técnicos, nomeadamente, tamanho da vara, altura da pega, flexibilidade da vara, altura da fasquia e sucesso no salto. Estes parâmetros foram avaliados em CA com diferentes comprimentos (entre 8 a 18 passadas).

Os dados do posicionamento do atleta ao longo da CA foram registadas através do Lidar Jenoptik LDM301, Germany (Dickwach et al., 1994), colocado no início da CA (figura 3.3), a partir dos quais se obteve o perfil de velocidade da corrida do atleta (figura 3.4).

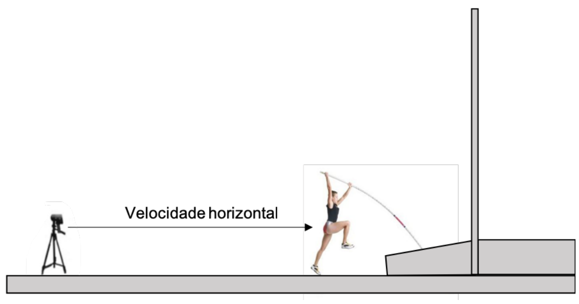

Figura 3.3: Representação gráfica do protocolo realizado para o estudo experimental II e III

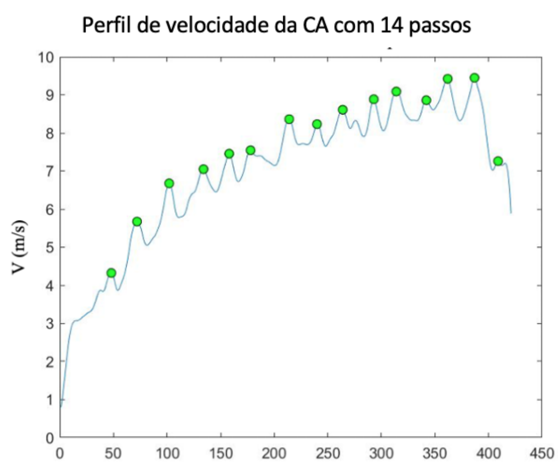

Figura 3.4: Perfil da CA em corrida de 14 passos

3.3.2 Processamento e análise

Os dados recolhidos através das células fotoelétricas não requerem processamento, uma vez que os valores da velocidade máxima são diretamente extraídos pelo sistema. Ao contrário, os dados recolhido através do Lidar, requerem processamento uma vez que os valores da velocidade são cálculado através da derivada das posições captadas ao longo da CA. Para tal foi criada uma rotina em Pyton para realizar esses cálculos. A análise gráfica e estatística dos dados foi feita em Rstudio Version 1.2.1335, © 2009-2019 RStudio, Inc.

Foram eliminados todos os saltos em que o atleta se desviou do corredor central, tendo sido perdido o contato com o feixe de luz emitido pelo Lidar e consequente erro na leitura do seu posicionamento (Cassirame et al., 2017).

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"Não existem métodos fáceis para resolver problemas difíceis."

René Descartes

Capítulo 4

Estudo Experimental I

4.1 The influence of the maximum velocity changes during a training season on full approach runs in the pole vault event

4.1.1 Abstract

This study had three primary objectives: (1) Analyze the maximum velocity of athletes and the full approach run velocity throughout a two sports season; (2) Determine the correlation between these two velocities; (3) Assess how these velocities are related to an athlete's performance in the pole vault event. To achieve these objectives, a longitudinal investigation was conducted over two seasons, involving two elite pole vaulters. Data collection included measuring the maximum velocity during a simulated full approach run with a pole on the track, referred to as "Task 1"(T1), and the maximum velocity attained by the athletes in a 20-meter fly test without a pole, referred to as "Task 2"(T2). The study established a strong relationship between T1 and T2, which was supported by statistically significant findings for both athletes (Athlete one: $R^2 = 0.801$, $p < 0.001$; Athlete two: $R^2 = 0.602$, $p = 0.001$). Despite T1 and T2 being distinct tasks, they exhibited significant synergies, explaining 97.53% of the total variance for athlete one and 97.88% for athlete two. Notably, changes in maximum velocity (whether increasing or decreasing) corresponded to changes in velocities during the full approach run with a pole, indicating a consistent behavioral pattern.

Keywords: pole vault, maximal velocity, full approach run.

4.1.2 Introduction

Pole vault is widely acknowledged as the most complex and unique event in athletics (Frère et al., 2010; Simona & Cristian, 2015). The success of a pole vault jump hinges on the intricate relationship between the athlete and the pole (Garcia et al., 2012; McGinnis & Bergman, 1986; Schade et al., 2004). From a technical standpoint, it's a demanding jump that involves carrying a relatively large object (the pole) at high speeds, placing significant physical and mental demands on athletes. A skilled pole vaulter must possess strong physical attributes, including speed, jumping ability, and gymnastic skills (Linthorne, 2000). Furthermore, they aspire to excel in handling the pole at maximum velocity (Frère et al., 2017; Morlier & Mesnard, 2007). Crucial aspects such as the time of pole planting, take-off performance (Ruf, 1992), and gymnastic technique are considered paramount for an athlete's successs (Linthorne, 2000). Several authors suggest that achieving horizontal velocity during the approach phase is the most decisive kinematic parameter for jump success (Adamczewski & Perlt, 1997; Armbrust, 1993; Boiko & Nikonov, 1990; Christensen & Zebas, 2000; Gros et al., 1994; Liu & Zhou, 2000; McGinnis, 1997; Sullivan et al., 1994). Some authors go a step further, proposing that attaining the highest possible velocity as close to take-off as possible is of utmost importance (Frère et al., 2010; Linthorne, 2000). Additionally, Garcia et al. (2012) argue that running with a pole at maximum velocity is critical for optimizing an athlete's performance. Athletes also need to sprint swiftly while carrying the pole and execute a successful planting action into the box.

The primary objective of the approach run is to increase horizontal velocity, thereby generating a significant amount of kinetic energy (Frère et al., 2010; Linthorne, 2000; Schade et al., 2007). Additionally, it aims to ensure the smooth planting of the pole into the box without any loss of velocity (Angulo-Kinzler et al., 1994). Lundin e Berg (1993) emphasized that the approach run should facilitate the athlete in achieving optimal take-off conditions. Gross et al. (2019) have suggested that increasing the athlete's maximum flying sprint velocity is necessary to potentially translate into higher pole-vaulting approach velocity. However, it's essential to note that improving maximum velocity levels in a velocity test (e.g., the 20m fly) indicates that athletes are generally faster, but it doesn't necessarily guarantee increased speed during the actual jump.

In high-level sports performance, the specificity of parameters becomes increasingly crucial. For coaches who closely monitor daily training, it's essential to identify which parameter is most directly related to success. In the context of the pole vault event, simply recognizing an athlete's speed is not enough. What truly matters is ascertaining whether the athlete's daily training routines consistently contribute to the speed of their approach run, consequently leading to improved jump performance. Therefore, a coach's role is to design an approach run that enables the athlete to unleash their full potential, facilitating exceptional performance. Running with a pole introduces asymmetry and physical challenges to the body, which directly affect the run (Theodorou et al., 2017). To adapt to these demands, pole vaulters incorporate approach drills, such as pole-assisted sprints, into their training regimen, even without actual vaulting. An athlete who struggles with handling the pole or has an incorrect approach run structure may develop doubts about their jump. Hence, it becomes unnecessary to focus solely on making the athlete faster; instead, the focus should be on addressing these specific technical and structural aspects of their performance.

There is a notable absence of longitudinal analyses investigating the athlete's maximum velocity and its transfer to the full run approach. Conducting longitudinal studies with elite athletes is a complex undertaking. In this longitudinal investigation, we opted for a case study approach to delve into the impact of speed on highly trained pole vaulters. The principal objectives of this study were as follows: (1) To analyze the athlete's maximum flying velocity and their velocity during the entire approach run throughout an entire sports season. (2) To establish the relationships between these velocities. (3) To evaluate the correlations between these velocities and the athlete's performance in the pole vault event.

4.1.3 Methods

Participants and design

Two elite pole vaulters, one female and one male, both representing their respective countries at the international level, willingly gave their informed consent to participate. This followed approval from the Lusófona University ethics committee, ensuring the study's adherence to ethical standards. It's worth noting that both participants maintained their physical well-being and health during the data collection period. The study was structured as a longitudinal investigation.

Procedures

In order to make a valid comparison of velocities between the two tasks, it was crucial to eliminate the influence of the jumping element, allowing us to discern if any changes in velocities were indeed genuine. Task 1 (T1) involved achieving the maximum velocity during a full approach run with pole, including the pole planting and take-off, but without the actual jump, conducted on the track. In contrast, task 2 (T2) represented one of the most reliable tests for determining an athlete's maximum velocity, the 20-meter fly test with a 30-meter acceleration.

Our data collection process comprised 25 sessions on an indoor sprint track, spanning two consecutive seasons. The first data collection session was held in May 2017, marking the onset of the outdoor competition season. We then resumed data collection in the subsequent season, commencing in late November 2017 and wrapping up in late August 2018. The data collection extended into the following season, with the next phase commencing in late November 2018 and concluding during the indoor training season of 2018.

In total, we collected 300 runs (with 150 runs from each athlete). For statistical analysis, we selected the best run from each session in both the T1 and T2 tasks. Athletes participated in these sessions as per their individualized competition and training schedules, which are detailed in Table 4.1.

The data were gathered during regular training sessions, specifically during sessions focused on improving velocity. The coach played a vital role in this process, providing immediate feedback after each run to motivate the athletes and encourage them to perform at their highest level.

Tabela 4.1: Distribution of the data-colection

Season	**Summer 2017**	**Winter 2017/18**	**Summer 2018**	**Winter 2018/2019**	**Total of session**
A1	2	6	10	7	25
A2	4	5	11	5	25

Data processing

We utilized a professional timing system, the Microgate Rei 2 from Bolzano, Italy, equipped with a double-photocell beam for each sprint trial. The double-photocell system in athletics consists of two synchronized photocells positioned one above the other. It's important to note that a signal is generated only when both photocells are simultaneously interrupted, ensuring that the interruption is caused by the athlete's torso rather than by their arm movements. The velocity-time data were meticulously recorded in an Excel spreadsheet, offering a comprehensive overview of both the coach's and the athlete's speed behaviors throughout the T1 and T2 sports seasons.

Statistical analysis

The statistical tests were conducted using Excel from Microsoft Corporation Inc., based in NM, USA, and RStudio, Version 1.2.1335, 2009-2019 by RStudio, Inc., utilizing the R programming language. To visually represent the distribution of each task (T1 and T2), we plotted the correlation between the maximum velocity achieved in the last 10 meters of the full run approach without jumping and the maximum velocity (20-meter fly).

Furthermore, we calculated the Variance Accounted For (VAF) between two signals using RStudio. The VAF quantifies the proportion of variance explained between two signals. Specifically, the VAF between y and $yhat$ for the ith component is defined as

$$\mathrm{VAF}_i = \left(1 - \frac{\mathrm{var}(y_i - \hat{y}_i)}{\mathrm{var}(y_i)}\right) \times 100\%$$

The VAF of two signals that are the same is 100% . If they differ, the VAF will be lower.

4.1.4 Results

Variations in Maximum Velocities between T1 and T2

Figure 4.1 illustrates the changes in maximum velocities over the course of 25 weeks. The maximum velocities achieved without a pole (T2) ranged from 9.80 m/s to 10.53 m/s. As for the velocities obtained during the run-up without jumping (T1), they varied between 8.26 m/s and 9.09 m/s for the A1 athlete.

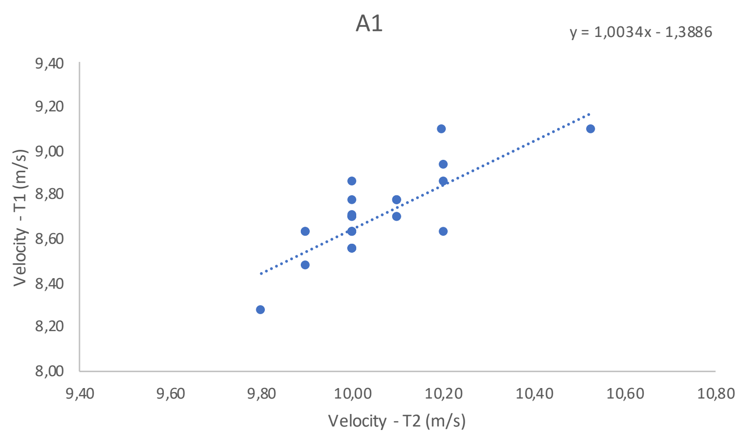

Figura 4.1: Trend line for athlete A1

In the case of athlete A2, we can observe that the variations in T2 velocities ranged from 8.40 m/s to 8.85 m/s, while in the T1 task, the variations ranged from 7.35 m/s to 7.75 m/s over the 25-week period (as shown in Figure 4.2).

Correlation between T1 and T2

For both athletes reveals a strong relationship. For athlete A1, the correlation coefficient is $R^2 = 0.801$, p=< .001, and for athlete A2, it is $R^2 = 0.602$, p=0.001. Additionally, there is a noticeable increasing trend in both cases, as depicted in Figures 4.3 and Figure 4.4.

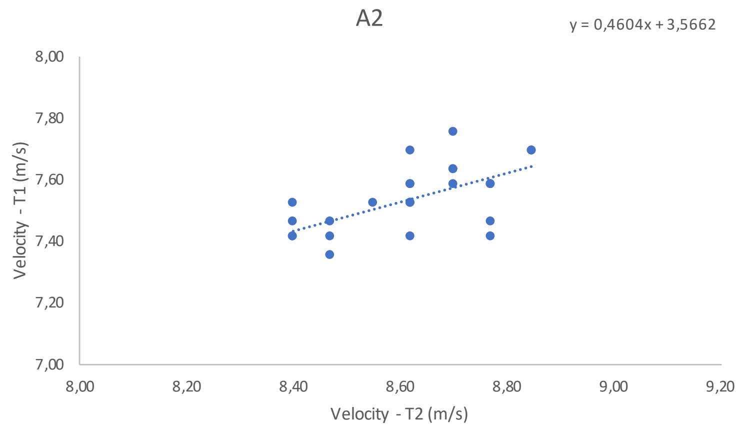

Figura 4.2: Trend line for athlete A2

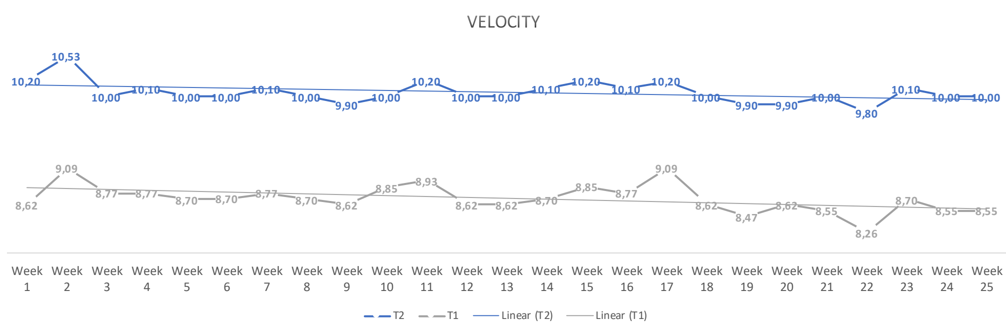

Figura 4.3: Velocity variation from athlete A1 for T1 and T2 (m/s)

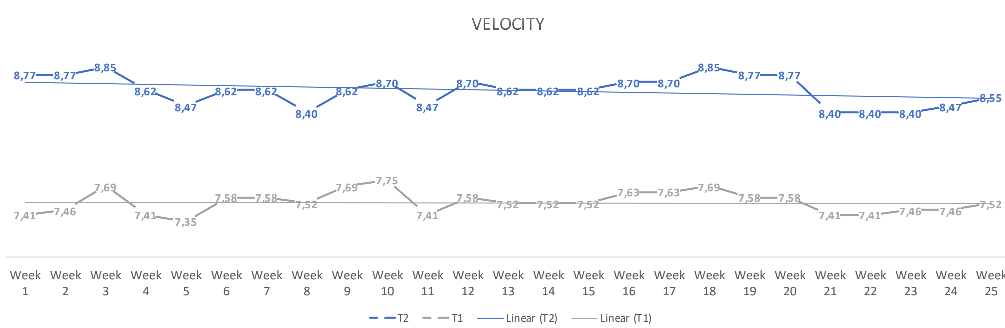

Figura 4.4: Velocity variation from athlete A2 for T1 and T2 (m/s)

By applying the criteria previously outlined, the signal synergies between the two tasks were analyzed. These synergies accounted for 97.53% of the total Variance Accounted For (VAF) for athlete A1 and 97.88% of the total VAF for athlete A2. This high degree of similarity in the behavior of the two signals indicates the presence of inter-individual variability in the velocity of pole vaulters between task one (T1) and task two (T2).

Relationship between velocities and performance

Figure 4.5 and Figure 4.6 clearly illustrate that when athletes achieve higher speeds in both task one and two, it is typically associated with better competition performance.

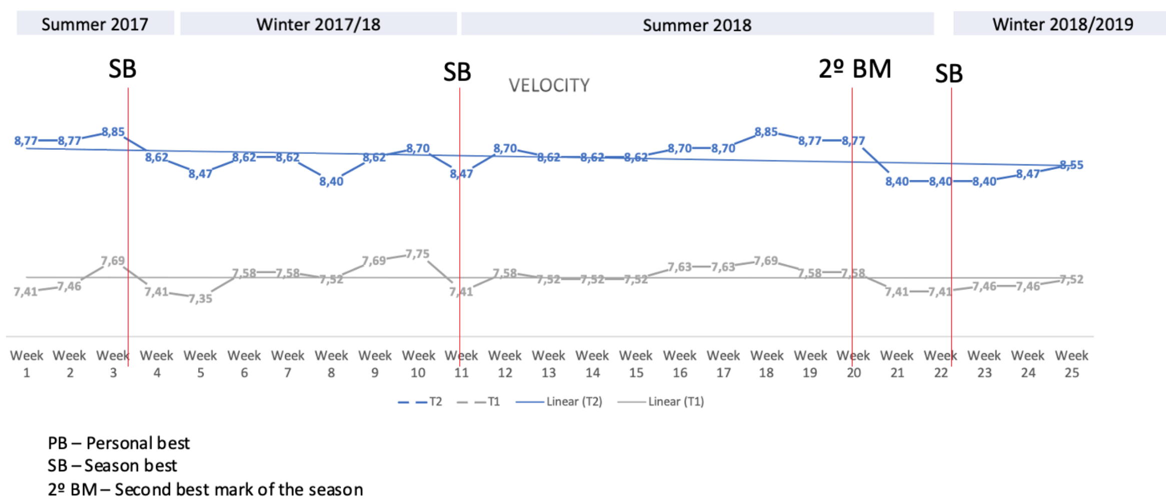

Figura 4.5: Velocity variation from athlete A1 (m/s) and peak performance

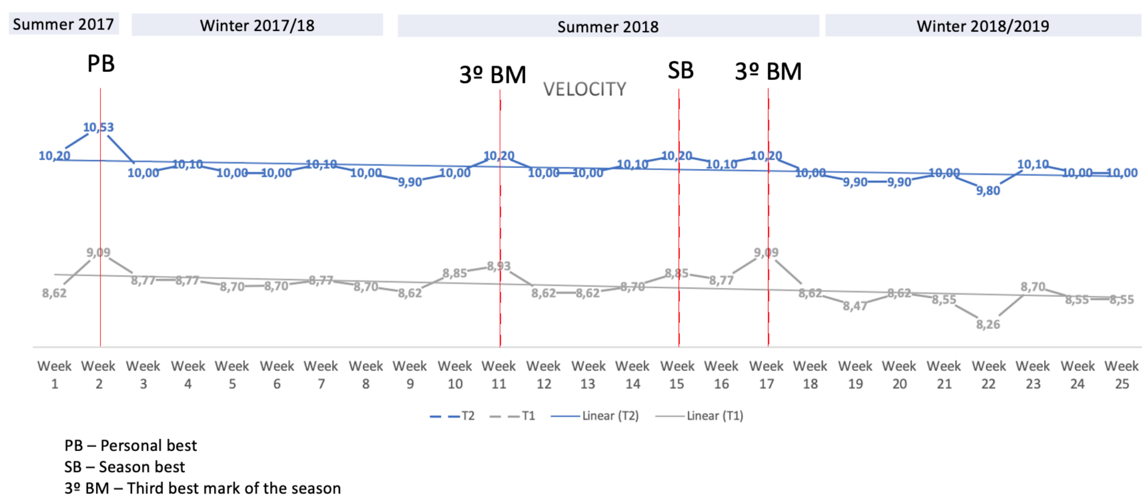

Figura 4.6: Velocity variation from athlete A2 (m/s) and peak performance

4.1.5 Discussion and implications

While it is unquestionable that velocity is a crucial parameter for the success of a pole vault jump, as emphasized by other authors (Adamczewski & Perlt, 1997; Frère et al., 2017; Mcginnis, 2004), our objective was to gain a deeper understanding of how maximum velocity is intricately linked to the pole vault event. Therefore, this study aimed to achieve the following objectives: (1) Analyze the athlete's maximum flying velocity and the velocity during the full approach run throughout an entire sports season. (2) Establish the associations between these velocities. (3) Explore how these velocities are related to an athlete's performance in the pole vault event.

Maximum velocities variations from T1 and T2

Gross et al. (2019) proposed that enhancing an athlete's maximum flying sprint velocity is crucial for the potential transfer to pole vaulting approach velocity. To investigate this, we collected data on two different types of velocities for comparison. This allowed us to determine the athlete's maximum flying velocity without a pole, denoted as T2, and to gain insights into how the athletes' maximum velocity changed over the course of a sports season. Subsequently, we made the deliberate decision to exclude the jumping component from the data collected on the athletes' maximum velocity during the full approach run (T1). This was done to minimize any potential influence on the variations in velocity values, as depicted in Figures 1 and 2. Our goal was to gain a comprehensive understanding of the athlete's maximum velocity behavior by isolating the physical component from the psychological constraints of velocity training. We wanted to focus on the technical aspects of training, particularly the maximum velocity achieved during the run-up with the pole. To accomplish this, we needed to eliminate the constraint of the jump in the run-up. Our aim was to determine whether there was a transfer of the physical component to the full approach run. The results indicate that, for these athletes, such a transfer did indeed occur. The variations in velocity values throughout the season reflect the athletes' peak performance.

Correlation between T1 and T2

The study's second objective aimed to establish the connection between an athlete's maximum flying velocity and the velocity achieved during a full approach run. Figures 1 and 2 clearly illustrate a similar trend in behavior between these two tasks. Whenever the athletes' maximum flying velocity increased or decreased, the maximum velocity during the run-up with the pole displayed a corresponding increase or decrease.

Through the application of the VAF statistical test, we confirm that this behavior is not simply a visual impression but a statistically significant finding. Consequently, we can assert that there is a consistent relationship between variations in an athlete's maximum velocity without a pole (T2) and their velocity with a pole during a complete approach run (T1). In essence, the faster an athlete can run without the pole on the track, the faster they will run during the full run-up approach.

If this correlation does not hold, it may indicate that the athlete is encountering technical challenges with pole transport (Frère et al., 2017), pole planting (Schade & Arampatzis, 2012), or difficulties in smoothly transitioning between different phases of the run at maximum velocity (Arampatzis et al., 2002; Linthorne & Weetman, 2012).

Relationship between velocities and performance

The study's third objective aimed to investigate the relationship between velocity and performance. Lycholat (2000) and Gross et al. (2019) suggest that velocity is influenced by a combination of factors, including maximum strength, force development, explosive strength, and running technique. Running at maximum velocity is essentially an embodiment of peak performance. Attaining high running velocities necessitates the proper development of various physical components.

In the context of this study, when athletes demonstrated high values in both the maximum velocity run tests, both without the pole on the track and with the pole in the run-up, it indicated a moment of physical peak performance. This suggests that athletes can leverage this peak performance to enhance their competitive performance. If an athlete excels in both maximum velocity tests (without the pole and with the pole in the run-up approach), it is expected that this peak performance will translate into successful jumps. As illustrated in Figure 4.5 and Figure 4.6, athletes who achieved outstanding results in both velocity measures generally performed better in competition. Despite the inherent challenges of pole vaulting, athletes consistently achieved positive competitive outcomes when their velocities were at their peak. Conversely, when athletes experienced a decline in their running speed, their performances suffered.

When athletes display strong performance in both velocity tests but still encounter challenges in their jumps, it suggests that other factors or constraints may be influencing their overall performance. Evaluating athletes based on their performance in these two velocity tests provides coaches with valuable insights. It enables coaches to offer more informed feedback and develop individualized strategies for each athlete. This data-driven approach, rooted in scientific and credible information, enhances the coach's capacity to effectively support their athletes. It allows for a more targeted and holistic approach to coaching and helps in addressing the complexities of each athlete's performance in pole vaulting.

4.1.6 Conclusion

For both elite pole vaulters, variations in maximum velocity were observed over the course of the season and during training progress. These variations corresponded with fluctuations in performance, indicating a strong correlation between the two tasks. When Task 2 (T2) experienced an increase, the results of Task 1 (T1) also displayed an upward trend, and when T2 values decreased, T1 values followed suit. Notably, the peaks in velocity for both T1 and T2 tended to align. It's worth highlighting that the highest velocity values for both tasks were attained during the same weeks in which athletes achieved favorable results in competitions. The methods employed in this study offer a straightforward means to monitor both physical and technical characteristics, with a specific focus on their impact on the success of the pole vault jump. This approach provides valuable insights for coaches and athletes in optimizing their training regimens and improving their competitive performance.

Acknowledgments

This investigation "The influence of the maximum velocity changes during periodised training seasons on full approach runs in the pole vault event" has an implication of high-level athletes, the Portuguese Federation of Athletics' and IPDJ support.

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"A ciência é uma forma de sabedoria. Ela é uma busca da verdade, embora saibamos que nunca possamos ter a verdade completa."

Carl Sagan

Capítulo 5

Estudo Experimental II

5.1 Pole vault performance analysis using kinematic parameters and technical constraints in training - longitudinal study among athletes

5.1.1 Abstract

Performance in the pole vault event is influenced by a complex interplay of various factors, including kinematic, physical, technical, and mental parameters. This study aimed to identify specific kinematic and technical parameters that can impact pole vault performance in a long-term training context. The analysis involved two elite-level athletes participating in technical training sessions employing a Lidar laser system. Various statistical analyses were applied to explore relationships within the dataset. When categorizing jumps as either "Fail- (0) or "Clear the bar- (3), intriguing patterns emerged. For Athlete M, the "Fail"category had a failure rate of 42.9% with a 12-step run-up and 21.4% with a 14-step run-up. Meanwhile, Athlete F experienced a 44.2% failure rate with a 10-step run-up, 20.9% with a 12-step run-up, and 23.3% with a 14-step run-up. In the "Clear the bar"category, Athlete M achieved success rates of 6.7% and 2.2% with 16 and 18 steps, respectively. On the other hand, Athlete F did not produce any valid jumps with 14 and 16 steps in the run-up. This study unveiled that the length of the run-up had varying impacts on jump success among athletes, and it also emphasized the influence of grip and pole size parameters on performance. Notably, when considering only jumps at 90% of the season's best performance in the "Clear the bar"category, specific parameters showed a strong correlation with success. For Athlete M, these parameters included grip, pole size, maximum velocity (v_max), average velocity between 16-11 meters (vmed16-11m), average velocity between 11-6 meters (vmed11-6m), and ($\Delta v_{male} = Vmed(11-6m) - Vmed(16-11m)$). For Athlete F, the significant parameters were grip, flex of the pole, (dis_vmax), and ($\Delta v_{female} = Vmed(10-5m) - Vmed(15-10m)$). From the data observed in this study, it becomes evident that technical constraint parameters and kinematic parameters are interconnected, and understanding this relationship is crucial for improving performance in pole vaulting.

Keywords: pole vault, kinematic parameters, technical parameters, constraints.

5.1.2 Introduction

In athletics, pole vault is distinguished as one of the most spectacular, exciting, and complex events. At the elite level, numerous variables, possibilities, and constraints come into play, influencing overall performance. Identifying the critical performance indicators is of paramount importance when it comes to customizing individualized training programs (Pfaff, 2018). Analyzing performance in a competitive training environment enables the identification of these key constraints (McCosker et al., 2019).

Biomechanical analysis aims to identify the essential variables for a successful pole vault jump (Frère et al., 2019). In pole vaulting, the athlete runs as fast as possible with a pole during the approach run (Frère & Chollet, 2009). This requires the ability to interact with the pole, execute precise planting into the box (Frère et al., 2010; Schade & Arampatzis, 2012; Schade et al., 2004), and perform an accurate take-off (Angulo-Kinzler et al., 1994; Needham et al., 2018; Tamura et al., 2017). Numerous studies have focused on the take-off phase, which is considered highly relevant for jump success (Makaruk et al., 2017; Needham et al., 2018; Tamura et al., 2017). They have analyzed angles (Gravestock et al., 2017; Hanley et al., 2019; Linthorne, 1994; Peter et al., 2014) and forces (Angulo-Kinzler et al., 1994; Ekevad & Lundberg, 1997; Linthorne, 1994; Schade et al., 2006) during the jump phase. However, one of the most critical parameters for jump success is the preservation of velocity between the last stride and take-off. Several authors have emphasized velocity as a key variable and cited it as one of the most crucial parameters for the success of the jump (Cassirame, Sanchez & Morin, 2017; Frère et al., 2010; Garcia et al., 2012; Linthorne & Weetman, 2012; Mcginnis, 2004).

It's essential to take into account other variables that are intricately connected with the daily training process and play a substantial role in achieving success in competition. These variables, especially those associated with technical constraints such as pole selection, grip height, run length, and take-off technique, have not consistently been the focus of research. However, they are factors that coaches and athletes can directly control and influence during their training and competitive activities, and they have a direct impact on performance. These variables represent tangible aspects that coaches and athletes work with in their day-to-day training and competition routines.

In the pursuit of peak performance, coaches and athletes both share the common goal of excelling in competitions. Timely feedback plays a critical role in this endeavor and can be effectively integrated into the training process. By accurately measuring vaulting data without significantly disrupting the daily training routine, it is possible to use straightforward research methods to assess training performance in pole vault. This approach has raised several important questions: 1 - Does the length of the approach run impact the success of the jump? 2 - Do factors like maximum velocity and the point at which it's achieved influence the jump's success? 3 - How do technical constraint parameters affect jump performance? The objective of this study is to explore how the length of the approach run and various kinematic and technical constraints influence the success of a pole vault jump.

5.1.3 Methods

This study employed a longitudinal analysis to identify the key kinematic parameters and technical constraints that exert the most significant influence on the performance of pole vault jumps.

Participants

Two elite athletes, one female aged 27 and one male aged 28, were involved in this study. Both of these athletes had represented their respective countries at the international level. All participants were informed about the study's objectives and provided their consent by signing the protocol, which had been approved by the ethics council of Universidade Lusofona, following the principles of the Declaration of Helsinki.

Instruments

This study used a Laser Displacement Measure - Jenoptik LDM301, Germany (Dickwach et al., 1994).

Data processing

The position data were smoothed using a polynomial equation. The velocity-time data was obtained through the position derivative. The velocity-time data was transferred to RStudio, Version 1.2.1335 (c 2009-2019 RStudio, Inc.) to perform the kinematic analysis of all jumps performed by athletes. Then the data was converted to Excel from (Microsoft Corporation Inc. Albuquerque, NM, USA.

Procedures

The participants were informed about the study's objectives, and data collection took place during the coach's pre-scheduled technical training sessions. A Lidar laser system was positioned at the beginning of the run behind the athletes, ensuring that it did not disrupt their activities. The athletes followed the warm-up routine prescribed by the coach. Before each jump, the athletes communicated the height they intended to jump, the particular pole they would use, and provided information about the pole's characteristics, including its size, weight, and flexibility.

Parameters analysed

The technical constraint parameters included the type of pole used (size and flexibility), grip height, the number of steps in the run-up, and the "push"(a technical index). The "push"was calculated as the difference between the vaulter's effective grip height and the height of the crossbar. For both athletes, the kinematic parameters were maximum velocity (v_max) obtained in the run-up, the distance where the maximum velocity was performed (dis_vmax). For men, the average velocity from 16m to 11m (vmed16-11m) and 11m to 6m (vmed11-6m) from the box, and the Δv_{male} - the difference between (vmed11-6m) and (vmed16-11m). For women, the average velocity from 15m to 10m (vmed15-10m) and 10m to 5m (vmed10-5m) from the box and calculate the Δv_{female} - the difference between (vmed10-5m) and (vmed15-10m).

The performance of each jump was classified into four categories: 0 - aborted the jump; 1- performed a jagodin; 2- performed the jump but touched the bar; 3 - performed the jump successfully.

Statistical analysis

All statistical analysis was conducted using jamovi® (Version 1.2), retrieved from https://www.jamovi.org, and graphical data were compiled using Microsoft Excel (Microsoft 2016, USA). Shapiro-Wilk normality tests were performed for all cases, and when the p-value was greater than 0.05, normality was not assumed. Descriptive analyses were presented to summarize and explore the behavior of the collected data in the study. Contingency tables were used to assess the relationship between pairs of categorical variables. In this study, the correlation between success and the number of steps in the run was examined.

The non-parametric Kruskal-Wallis test was applied to compare the kinematic and technical constraint parameters with the four categories of pole vault performance.

A Spearman's Rho correlation analysis was utilized to analyze the correlation between kinematic and technical constraint parameters for all successful jumps equal to or higher than 4.90 meters for athlete M and 3.80 meters for athlete F.

Multiple Logistic regression was applied to describe the contribution of a set of covariates (Grip, Pole size, Flex of the pole, Push, v_max (m/s), v_16- 11 (m/s), v_m11-6 (m/s), v_15-10 (m/s), v_10-5 (m/s), Δv_{male}, Δv_{female}) in the dichotomous outcome of a pole vaut event (Sucess/Insucess).

For the parameters in which there were significant differences, a Dwass-Steel-Critchlow-Fligner pairwise comparison was performed.

5.1.4 Results

To achieve the proposed objectives, 464 jumps were analysed (155 for athlete F and 309 for athlete M).

Size of the approach run

The impact of the length of the approach run on various success categories is detailed in Table 5.1 and Table 5.2. Despite variations in the number of observations for different run-up sizes (unalterable process of the training planned by the coach), the following findings were observed:

When observing the success category (0 - Fail), the highest percentage of runs performed during athlete M's training process was with 12-step runs. Interestingly, there were no observed failures in runs with 8 and 10 steps for athlete M. This suggests that with 8- and 10-step runs, there may be less velocity, allowing the athlete to have more control over the run-up. Additionally, the athlete tends to use smaller and generally softer poles for these run lengths. However, as the length of the run-up increases, the failure percentage dramatically rises to 42.9% for 12-step runs and 21.4% for 14-step runs. In this case, the observations indicate that there is a notable influence of the run-up's size on the increasing percentage of failed jumps, especially when transitioning from 8 to 18-step run-ups.

For athlete F, the highest percentage of runs performed in total was with a 10-step run-up. Interestingly, the 10-step run-up had the highest percentage of observed failures (category 0 - Fail), with athlete F experiencing a 44.2% failure rate. However, this failure rate decreased when the athlete used 12 and 14-step run-ups, with percentages of 20.9% and 23.3%, respectively.

When observing the success category (3 - clear the bar) for athlete M, the highest percentage of successful runs occurred with 12-step run-ups (33.3%). Interestingly, as the number of steps in the run-up increased, there was a decrease in the percentage of success. With a 14-step run-up, the success rate decreased to 26.7%, dropped to 6.7% for the 16-step run-up, and was only 2.2% for the 18-step run-up. In this case, the number of steps in the run-up had a significant influence on the success of athlete M's jumps.

For athlete F, the highest percentage of successful runs was achieved with 10-step run-ups, accounting for 47.4% of the observed jumps. Very close to this, the athlete had a success rate of 42.1% with 12-step run-ups. Interestingly, athlete F did not have any observed successful jumps with 14 and 16-step run-ups. In the success category (3 - clear the bar), it can be concluded that the size of the run-up is directly related to the jump's success, as the athlete did not achieve successful jumps with 14-step run-ups. For this specific category, the observations suggest that the run-up size significantly influences the athlete's performance.

Tabela 5.1: Contingency table from athlete M

Success		Nº Steps						
		8	**10**	**12**	**14**	**16**	**18**	**Total**
0 - Fail	Observed	0	0	6	3	1	4	14
	% within row	0.0%	0.0%	4.9%	6.8%	1.9%	33.3%	
1 - Just Jagodin	Observed	4	20	41	12	19	3	99
	% within row	22.2%	32.8%	33.3%	27.3%	37.3%	25.0	
2 - Jump but touch the bar	Observed	7	34	61	17	28	4	151
	% within row	38.9%	55.7%	49.6%	38.6%	54.9%	33.3%	
3 - Clear the bar	Observed	7	7	15	12	3	1	45
	% within row	38.9%	11.5%	12.2%	27.3%	5.9%	8.4%	
Total	**Observed**	**18**	**61**	**123**	**44**	**51**	**12**	**309**

Tabela 5.2: Contingency table from athlete F

Success		Nº Steps					
		8	**10**	**12**	**14**	**16**	**Total**
0 - Fail	Observed	5	19	9	10	0	43
	% within row	21.7%	30.2%	18.0%	55.5%	0.0%	
1 - Just Jagodin	Observed	2	7	4	1	1	15
	% within row	8.7%	11.1%	8.0%	5.6%	100.0%	
2 - Jump but touch the bar	Observed	14	28	29	7	0	78
	% within row	60.9%	44.4%	58.0%	38.9%	0.0%	
3 - Clear the bar	Observed	2	9	8	0	0	19
	% within row	8.7%	14.3%	16.0%	0.0%	0.0%	
Total	**Observed**	**23**	**63**	**50**	**18**	**1**	**155**

Kinematics and Technical Constraint parameters

Descriptive statistics of the kinematic and constraint parameters for athlete M are presented in Table 5.3. It possible to observe that when comparing the two categories that the athlete jumps with some success and totally success (categories 2 - Jump but touch the bar and 3 – Clear the bar), the differences are minimums. Inside of some categories of success, it is possible to verify that the run where the athlete is more stable in terms of v_max, Δv_{male} and push it was with 16 steps. This can show that this run is more consistent, as we can see in the height clear "Result" with better medium values of success 5.452m from category 2 and 5.33m from category 3.

Descriptive statistics of the kinematic and constraint parameters for athlete F are presented in Table 5.4. It possible to observe some differences between (categories 2 - Jump but touch the bar and 3 – Clear the bar). This athlete had more problems with the bar, not showing better performance when clearing the bar. She never clears the bar with 14 and 16 steps. This shows us a tremendous difficulty using long runs in the training environment. We can also verify that the greater is the run-up, the lower is the value of the Δv_{female}.

Tabela 5.3: Descriptive table from athlete M from the mean data of different success categories

Success	**Nº Steps**	**v_max (m/s)**	**v_16-11 (m/s)**	**v_11-6 (m/s)**	**Result**	**Grip**	**Push**	Δv_{male}
0 - Fail	8	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	10	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	12	8.829	7.917	8.242	5.250	4.680	0.890	0.326
	14	9.173	8.380	8.572	5.367	4.783	0.903	0.192
	16	10.355	8.475	8.929	5.500	4.850	0.970	0.454
	18	9.560	8.811	9.010	5.200	4.780	0.740	0.199
1 - Just Jagodin	8	8.238	5.866	7.274	4.925	4.487	0.758	1.408
	10	8.706	7.221	7.899	5.055	4.600	0.775	0.678
	12	9.097	7.867	8.334	5.185	4.666	0.839	0.467
	14	9.299	8.439	8.609	5.250	4.776	0.794	0.170
	16	9.535	8.662	8.797	5.492	4.828	0.984	0.135
	18	9.603	8.824	8.876	5.233	4.780	0.773	0.052
2 - Jump but touch the bar	8	8.126	5.815	7.307	4.871	4.479	0.713	1.492
	10	8.671	7.134	7.930	5.109	4.600	0.829	0.795
	12	9.016	7.944	8.325	5.197	4.668	0.849	0.381
	14	9.293	8.394	8.613	5.341	4.784	0.877	0.219
	16	9.555	8.654	8.778	5.452	4.813	0.959	0.125
	18	9.554	8.811	8.850	5.275	4.780	0.815	0.039
3 - Clear the bar	8	8.152	5.814	7.277	4.786	4.450	0.656	1.463
	10	8.720	7.248	7.955	5.057	4.600	0.777	0.708
	12	8.984	7.929	8.316	5.090	4.667	0.743	0.388
	14	9.356	8.357	8.634	5.217	4.768	0.768	0.277
	16	9.556	8.572	8.774	5.333	4.807	0.847	0.202
	18	9.563	8.929	8.929	5.200	4.780	0.740	0.000

It is possible to verify that when the athlete performs the jumps with higher grips, the tendency is to have more failed jumps, as we can see in table 5.4.

Concerning the average velocity of the last 5 meters (v_10-5 (m/s), it is possible to observe higher values are obtained with longer runs, but there is also an increase in the fails.

Tabela 5.4: Descriptive table from athlete F from the mean data of different success categories

Success	Nº Steps	v_max (m/s)	v_15-10 (m/s)	v_10-5 (m/s)	Result	Grip	Push	Δv_{female}
0 - Fail	8	6.257	4.852	5.373	3.800	4.070	0.050	0.522
	10	6.509	5.649	5.523	3.921	4.074	0.167	-0.126
	12	7.629	6.604	6.665	4.133	4.144	0.309	0.061
	14	7.858	6.927	7.250	4.200	4.139	0.381	0.323
	16	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1 - Just Jagodin	8	7.300	4.951	6.329	3.850	4.035	0.135	1.378
	10	7.767	5.933	6.731	3.957	4.067	0.210	0.798
	12	8.441	6.735	7.169	4.100	4.112	0.308	0.435
	14	7.894	6.944	7.353	4.200	4.100	0.420	0.408
	16	9.419	7.353	7.463	4.200	4.180	0.340	0.110
2 - Jump but touch the bar	8	7.787	4.907	6.302	3.838	4.011	0.145	1.394
	10	7.816	5.936	6.777	3.904	4.037	0.186	0.841
	12	8.029	6.785	7.227	4.079	4.092	0.307	0.442
	14	8.607	7.202	7.400	4.200	4.126	0.394	0.198
	16	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3 - Clear the bar	8	8.374	4.902	6.410	3.800	4.000	0.120	1.508
	10	7.773	5.906	6.738	3.856	4.054	0.121	0.831
	12	7.926	6.690	7.158	3.987	4.096	0.211	0.468
	14	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	16	NaN	NaN	NaN	NaN	NaN	NaN	NaN

The differences between the constraint technical parameters and the different success categories for athlete M are presented in Tables 5.5. The Push was identified significant differences when comparing the success criteria 1 – Just Jagodin with 3 – Clear the bar and 2 – Jump but touch the bar with 3 - Clear the bar. In NSteps was identified significant differences when comparing the success criteria 0 – Fail with 2 – Jump but touch the bar and 0 – Fail with 3 - Clear the bar.

Tabela 5.5: Analysis of variance between the parameters of the technical constraints with significant differences of the athlete M with the different categories of success

success criteria		p **- Push**	p **- NSteps**
0 - Fail	1 - Just Jagodin	1.000	0.077
0 - Fail	2 - Jump but touch the bar	0.947	0.041*
0 - Fail	3 - Clear the bar	0.062	0.050
1 - Just Jagodin	2 - Jump but touch the bar	0.651	0.966
1 - Just Jagodin	3 - Clear the bar	0.003*	0.708
2 - Jump but touch the bar	3 - Clear the bar	$< .001*$	0.852

The differences between the constraint technical parameters and the different success categories for athlete M are presented in Tables 5.6. The Grip was identified significant differences when comparing the success criteria from 0 – Fail with 2 –Jump but touch the bar. In the Push was identified significant differences when comparing the success criteria from 2 –Jump but touch the bar with 3 - Clear the bar.

Tabela 5.6: Analysis of variance between the parameters of the technical constraint with significant differences of the athlete F with the different categories of success

success criteria		p **- Grip**	p **- Push**
0 - Fail	1 - Just Jagodin	0.382	0.917
0 - Fail	2 - Jump but touch the bar	0.002*	0.775
0 - Fail	3 - Clear the bar	0.081	0.088
1 - Just Jagodin	2 - Jump but touch the bar	0.572	0.985
1 - Just Jagodin	3 - Clear the bar	0.897	0.060
2 - Jump but touch the bar	3 - Clear the bar	0.979	0.033*

The differences between the kinematics parameters and the different success categories for athlete M are presented in Tables5.7. The dis_vmax was identified significant differences when comparing the success criteria from 0 – Fail with 1 – Just Jagodin, 2 –Jump but touch the bar and 3 - Clear the bar.

Tabela 5.7: Analysis of variance between kinematic parameters with significant differences between the athlete M and the different success categories

success criteria		p **- dis_vmax (m)**
0 - Fail	1 - Just Jagodin	$< .001*$
0 - Fail	2 - Jump but touch the bar	$< .001*$
0 - Fail	3 - Clear the bar	$< .001*$
1 - Just Jagodin	2 - Jump but touch the bar	1.000
1 - Just Jagodin	3 - Clear the bar	0.167
2 - Jump but touch the bar	3 - Clear the bar	0.157

The differences between the kinematics parameters and the different success categories for athlete F are presented in Tables 5.8. The v_max, dis_vmax, Velocity profile were identified significant differences when comparing the success criteria from 0 – Fail with 1 – Just Jagodin, 2 –Jump but touch the bar and 3 - Clear the bar. For the v10-5 (m/s) was identified significant differences when comparing the success criteria from

0 – Fail with 2 –Jump but touch the bar.

Tabela 5.8: Analysis of variance between kinematic parameters with significant differences between the athlete F and the different success categories

success criteria		p - v_max (m/s)	p - dis_vmax (m)	p - v_10-5 (m/s)	p - Δv_{female}
0 - Fail	1 - Just Jagodin	0.004*	0.003*	0.208	0.001*
0 - Fail	2 - Jump but touch the bar	$< .001*$	$< .001*$	0.0005*	$< .001*$
0 - Fail	3 - Clear the bar	0.001*	$< .001*$	0.193	$< .001*$
1 - Just Jagodin	2 - Jump but touch the bar	1.000	0.633	0.940	0.999
1 - Just Jagodin	3 - Clear the bar	0.998	1.000	1.000	0.994
2 - Jump but touch the bar	3 - Clear the bar	0.988	0.639	0.913	0.989

The correlation between the kinematic and constraints parameters with the result for athlete M is presented in Tables 5.9. All kinematic and constraints parameters had a significant correlation with the result.

Tabela 5.9: Statistical correlation between kinematic parameters and constraints parameters with all the success jumps equal or higher to 4.90(m) for athlete M

		Grip	Pole size	Flex of the pole	v_max (m/s)	dis_vmax (m)	v_16-11 (m/s)	v_11-6 (m/s)	Δv_{male}
Result	Spearman's rho	0.521***	0.523***	0.323*	0.610***	0.477**	0.583***	0.589***	-0.444**
	p-value	$< .001$	$< .001$	0.040	$< .001$	0.002	$< .001$	$< .001$	0.004

Note. *$p< .05$; **$p< .01$; ***$p< .001$

The correlation between the kinematic and constraints parameters with the result for athlete F is presented in Tables 5.10. The kinematic parameters that had a significant correlation with the result were dis_vmax, v_15-10, Velocity profile. For the parameters of the constraints, the pole flex had the Grip had a significant correlation with the result.

Tabela 5.10: Statistical correlation between kinematic parameters and constraints parameters with all the success jumps equal or higher to 3.80(m) for athlete F

		Grip	Pole size	Flex of the pole	v_max (m/s)	dis_vmax (m)	v_16-11 (m/s)	v_11-6 (m/s)	Δv_{female}
Result	Spearman's rho	0.702***	0.211	-0.708***	-0.060	0.715***	0.658**	0.567*	-0.645**
	p-value	$< .001$	0.386	$< .001$	0.808	$< .001$	0.002	0.011	0.003

Note. *$p< .05$; **$p< .01$; ***$p< .001$

The correlation test was developed several regression models for athlete M and athlete F (Table 5.11), showing the differences between the different categories of success. The model presented for athlete M showed that the parameters correlated with the several success' category were the Grip and dis_vmax for (0 – 3) category. The category of success (1 – 3) was the Push, and for the category of success (2 – 3,) the variable that has a significance level was equally the Push.

Tabela 5.11: Logistic regression for each category success of bouth athletes

		M				F			
Success	**Predictor**	**Estimate**	**SE**	**Z**	p	**Estimate**	**SE**	**Z**	p
0 - Fail - 3 - Clear the bar	Intercept	-38.240	12.146	-3.148	0.002	-46.063	30.541	-1.508	0.131
	Grip	16.300	8.332	1.956	0.050	11.966	12.590	0.950	0.342
	Pole size	-13.704	9.879	-1.387	0.165	3.253	15.509	0.210	0.834
	Flex of the pole	0.771	0.826	0.933	0.351	1.513	0.811	1.865	0.062
	Push	4.118	3.363	1.224	0.221	19.360	7.329	2.641	0.008
	v_max (m/s)	-2.484	2.506	-0.991	0.322	-6.357	1.769	-3.593	$<.001$
	dis_vmax (m)	0.621	0.159	3.904	$<.001$	0.069	0.240	0.286	0.775
	v_16-11 (m/s)	0.963	1.179	0.817	0.414	1.286	1.009	1.274	0.203
	v_11-6 (m/s)	2.138	1.967	1.087	0.277	-1.418	1.215	-1.167	0.243
	Δv_{male}	1.175	1.577	0.745	0.456	-2.704	1.290	-2.096	0.036
1 - Just Jagodin - 3 - Clear the bar	Intercept	-19.622	14.206	-1.381	0.167	-8.232	30.988	-0.266	0.791
	Grip	8.520	6.034	1.412	0.158	8.411	10.242	0.821	0.412
	Pole size	-4.772	4.800	-0.994	0.320	-8.879	14.796	-0.600	0.548
	Flex of the pole	-0.095	0.280	-0.338	0.736	0.960	0.762	1.259	0.208
	Push	3.859	1.567	2.462	0.014	17.445	6.492	2.687	0.007
	v_max (m/s)	1.464	1.261	1.160	0.246	-0.347	0.964	-0.360	0.719
	dis_vmax (m)	0.209	0.112	1.871	0.061	-0.130	0.240	-0.543	0.587
	v_16-11 (m/s)	-0.670	0.480	-1.395	0.163	-0.653	0.628	-1.041	0.298
	v_11-6 (m/s)	-0.900	1.116	-0.806	0.420	-0.605	1.699	-0.356	0.722
	Δv_{male}	-0.230	0.941	-0.245	0.807	0.048	1.608	0.030	0.976
2 - Jump but touch the bar - 3 - Clear the bar	Intercept	-13.341	13.271	-1.005	0.315	1.961	25.303	0.077	0.938
	Grip	11.158	5.714	1.953	0.051	1.087	7.943	0.137	0.891
	Pole size	-8.811	4.601	-1.915	0.056	-8.267	11.837	-0.698	0.485
	Flex of the pole	0.111	0.269	0.413	0.679	1.412	0.621	2.273	0.023
	Push	5.819	1.531	3.800	$<.001$	18.799	5.102	3.685	$<.001$
	v_max (m/s)	0.121	1.245	0.097	0.923	-0.566	0.808	-0.700	0.484
	dis_vmax (m)	0.169	0.109	1.549	0.121	-0.618	0.247	-2.506	0.012
	v_16-11 (m/s)	-0.293	0.461	-0.635	0.526	-0.153	0.508	-0.301	0.764
	v_11-6 (m/s)	-0.289	1.075	-0.269	0.788	0.822	1.262	0.651	0.515
	Δv_{male}	0.004	0.904	0.004	0.996	0.974	1.208	0.807	0.420

The model presented for athlete F showed that the parameters correlated with the category of success (0 – 3) were the Push and v_max. The category of success (1 – 3) was the Push, and for the category of success (2 – 3,) the variable that has significance is equal to the Push, the Flex of the pole and the dis_vmax.

5.1.5 Discussion and implications

This study aimed to analyze kinematic parameters and technical constraints associated with the pole vault event and their influence on jump performance. The main objective was to provide coaches with timely and valuable feedback on the technical and kinematic aspects of their athletes. This information assists coaches in gaining a deeper understanding of the different facets of their athletes' performance and helps optimize their performance during competitions.

The influence of the approach run in the different categories of success

The pole vault event is a complex activity influenced by numerous parameters (Frère et al., 2010). Analyzing the contingency table provides an independent overview of these parameters and their relationship with the size of the run-up and the various categories of success.

The approach run plays a crucial role in the final result of the pole vault jump. Increasing the length of the run-up can lead to higher approach velocity at the take-off phase, but it also increases the difficulty of maintaining correct technique for the take-off, as noted by (Linthorne & Weetman, 2012). his study further supports that a longer run-up can result in a higher frequency of failed jumps for both athletes. Coaches can use full approach runs on the track to train the rhythm of the run with or without take-offs. They can also utilize the long jump pit for full approach runs with poles and perform exercises like the Jagodin exercise. (Plessa et al., 2010) found no significant differences between the long jump take-off and the pole vault take-off in terms of kinematic parameters. This scientific evidence suggests that coaches can use the long jump pit to conduct take-off exercises in full approach runs, helping athletes refine their run-up technique and take-off skills.

Technical constraints and performance

Technical constraints in pole vault, such as grip, pole size, and pole flexibility, play a significant role in the athlete's performance. The findings of this study are consistent with the research of others, including (Linthorne, 2000; Linthorne & Weetman, 2012; Petrov, 2004; Zagorac et al., 2008), which also emphasize the importance of grip, pole size, and pole stiffness (flex) in determining the success of the pole vault jump. Coaches can use these technical constraints as areas for intervention during their training sessions, providing athletes with the necessary adjustments and guidance to optimize their performance. By understanding the impact of these technical parameters on jump success, coaches can tailor their training programs to address specific needs and improve an athlete's pole vaulting technique.

It is important to note that when isolating only, the jumps with categories of success (3 - Clear the bar) with equal or above 4.90m marks for the male athlete and all 3.80m mark from the female athlete that was the 90% of the season-best from each athlete, was possible to verify that the athlete's success is related to the combination of several parameters (table 5.9). The kinematic parameters are present, as well as the technical constraints.

Kinematic parameters and performance

The kinematic parameters that had the most relationship with success were the maximum speed obtained in the run-up (v_max), and the distance that maximum velocity was reached in the run-up (dis_vmax), the average velocity between 16-11m from the box (v_16-11), and the average velocity between 11-6m from the box (v_11-6), and lastly the velocity variation (Δv_{male}).

Velocity had a high correlation, but not the maximum velocity, the most important was where this maximum velocity was achieved. As reported by (Cassirame, Sanchez, Homo et al., 2017), the take-off speed explains the large majority of variability in vault height for both men (74%) and women (58%). The velocities are essential for women, but the most important is where it is achieved and the decision to attack the take-off phase, allowing stronger poles.

For athlete M, the run-up location where the highest value of the velocity was fundamental, having significant differences between the category (0 - Fail) and the other categories of success. If higher velocities were obtained closer to the box, the more success the athlete achieved. This evidence is in line with (Frère et al., 2010; Linthorne, 2000; Linthorne & Weetman, 2012), which also refers to its importance, where the athlete's reach the maximum velocity in the run-up.

Through the observed data, for athlete F the velocity has more relevance for the jump's success. As referred by (Cassirame, Sanchez, Homo et al., 2017),women performance is primarily affected by the ability to transform speed into pole flexion to convert energy. Therefore, velocity is the primary parameter to the success of the jumps.

Performance model between the different categories of success

Athletes performance is affected by several factors and from different orders of relief. When applying a correlation regression model test, showing the differences between categories of success, it was possible to see the existence of parameters with different relevance to the success of the jump. These parameters are individual. For the athlete M, the model identifies $R^2 = 0.098$ with (Grip; dis_vmax; Push) as parameters with more success. For athlete F, the model showed $R^2 = 0.428$ and the parameters more relevant to success were (Push; v_max; Flex of the pole; Push; dis_vmax).

We may find that the value of p is low for athlete F. Still, the athlete's performance is probably more affected by other physical, psychological, emotional or technical parameters that may not be present in the study. Despite in this study, the intention was to individualize the process and identify which parameters were most relevant for each athlete the result from the regression model for the athlete F was not high.

Studies usually take into account the most relevant parameters between groups (Gudelj et al., 2015; Pavlović et al., 2019; Zagorac et al., 2008) but in this study, the intention was to find the specific parameters from each athlete. As report by Needham et al. (2018) athlete should be considered on an individual basis in order to effectively and safely improve performance.

5.1.6 Conclusions

This study allowed us to recognize the significance of kinematic parameters and technical constraints closely linked to the performance of the pole vault event. The initial conclusion suggests that the length of the run-up has an impact on jump performance. A longer run with more steps results in greater variability and a higher number of failed attempts. For the male athlete, the kinematic parameter (disvmax), as well as the technical constraint parameters (Push and NSteps), had a more pronounced influence on jump performance. For the female athlete, the kinematic parameters that influenced sports performance were (vmax; disvmax; v_10-5 (m/s); Velocity profile), while the technical constraint parameters included (Grip and Push). When analysing just jumps in the success category (3 - Clear the bar), and only the jumps at 90% of the season-best, it was identified that the parameters that have the most correlation were: athlete M Kinematics (vmax; disvmax; v_16-11 (m/s); v_11-6 (m/s); Δv_{male}) and technical constraint (Grip; Pole size) and for athlete F Kinematics (disvmax; v_15-10 (m/s); v_10-5 (m/s); Δv_{female} and technical/constraint (Flex of the pole). This analysis allowed for the creation of individual predictive models to understand which parameters are most relevant for jump success for both athletes, highlighting the interconnection between technical constraint and kinematic parameters.

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"Toda arte e toda investigação, assim como toda ação e toda escolha, tem em mira um bem qualquer; e por isso foi dito, com muito acerto que o bem é aquilo a que todas as coisas tendem."

Aristóteles

Capítulo 6

Estudo Experimental III

6.1 Non-linear and linear methods to analyze pole vault run-up in successful and unsuccessful jumps

6.1.1 Abstract

Purpose: Despite the vast research on running in pole-vaulting, in-depth analysis of pole vault runs, which involve intricate time series data and various factors, remains underexplored. This study aimed to scrutinize the running component of pole-vaulting using both nonlinear and linear methodologies. Specifically, we compared time series data from different jumps, evaluating both successful and unsuccessful attempts, to discern any correlation between the running aspect of pole-vaulting and overall athletic performance.
Methods: The case study examined 215 jumps from a single elite male athlete, 28 years of age, who had represented his country internationally. We employed fractal analysis techniques such as CoDim, sample entropy (SampEn), and CV to quantify the intricacies in the nonlinear method. Our goal was to observe variations in run-up phase velocity and correlate it with the athlete's performance. Additionally, the linear analysis considered the parameter Δv_{male} which assessed velocity changes in the final 10 meters of the run-up.
Results: No significant findings were identified for SampEn as the values remained consistent with a minimal standard deviation across all jumps. However, there was a notable influence on CoDim at 8nStp and 18nStp for successful jumps. Also, the CV presented significant findings at 12, 14, 16, and 18 steps.
Conclusion: The analytical tools employed in this study offer valuable insights for coaches. Nonetheless, only minor disparities in time series were pinpointed using nonlinear methodologies. The CV parameter effectively highlighted differences between jumps of varying run lengths. Moreover, heightened values of the Δv_{male} parameter suggested a pronounced impact on the success of the jump.

Keywords: pole vault, run-up, non-linear dynamics, complexity; variability.

Abbreviations:
CoDim - Correlation dimension
CV - Coefficient of variation
Δv_{male} – Velocity variation between the average velocities obtained in the run-up between ($v_{med11-6m}$) and ($v_{med16-11m}$) from the box
SampEn - Sample entropy
sd - Standard deviation
Box - Pole vault box

6.1.2 Introduction

Everyday activities necessitate intricate motor abilities, vital not only in daily routines but also in sports sciences. Activities like playing the piano, handwriting, and drawing epitomize complex motor skills, as researched extensively by (Shea et al., 1993). The intricacy in these skills arises due to the myriad musculoskeletal components intertwined with each motor action, necessitating several degrees of freedom. Successful execution demands impeccable coordination among these degrees. The pole vault exemplifies a sport requiring intricate motor skills, demanding peak-speed coordination while handling an object (Arampatzis et al., 2004). As athletes elevate their performance levels, their exposure and susceptibility to errors in executing these multifaceted tasks increase, compounded by the inherent risks and potential fear of injury (Rebella, 2015). Hence, pole-vault training strategies should prioritize minimizing risks, especially when actions occur at top speeds. Factors unique to pole vaulting, such as run-up length, pole stiffness, and grip, can substantially influence both the approach run and the final performance outcome.

Given the plethora of variables within a pole vault performance, data selection and interpretation should stem from a robust theoretical framework. The 'ecological dynamics' framework emerges as a recommended model, providing insights into athletes' performance and learning across sports (Araujo et al., 2006; Vilar et al., 2012; Warren, 2006). It postulates that human behaviors evolve through continuous interactions with available opportunities (affordances) during a performance. Multiple constraints influence the athlete-environment system, offering ample information for self-regulation (Araujo et al., 2006; Araujo et al., 2007; Gibson, 1979). Applying this framework to pole vault performance analysis transcends mere variable documentation, acknowledging the intertwined constraints that shape athlete performance (Vilar et al., 2012).

The run-up phase, the pole vault's initial stage, sees athletes sprinting to harness maximum energy systematically. A lack of organization impedes the subsequent take-off phase. The running cycle, characterized by rhythmic, repeated movements, suggests predictability and regularity (Jordan et al., 2006). This run can be represented as a time series. Past research has employed metrics like standard deviation (SD), coefficient of variation (CV), and root mean square to study movement variability during running (Belli et al., 1995; Cher et al., 2017). Increased movement variability signals stability loss and diminished external shock responsiveness.

While linear measures gauge variability magnitude, non-linear measures delve into time series' dynamic and temporal attributes, shedding light on underlying motor control's complexity (Stergiou & Decker, 2011). Complexity, the temporal regularity or randomness of a time series, is measurable through fractal scaling and entropy metrics (Pincus et al., 1994). For instance, sample entropy (SampEn) assesses time-based fluctuations (Pincus, 1991; Richman et al., 2000), whereas fractal metrics like the detrended fluctuation analysis exponent evaluate long-range correlations (Hausdorff et al., 1995). The correlation dimension (CoDim) measures system dimensions, capturing fractal time series properties and reflecting structures that, while not random, aren't overly predictable, recording the so-called "optimal movement variability"(Stergiou, 2020). Such fractal patterns have been detected in running cycles, indicating stride interval fluctuations (Hausdorff et al., 1996; Jordan et al., 2006). Stride time variation, determined using the CV, discerns velocity changes during the run-up phase by assessing the average time interval variations between steps (mVs) and their corresponding standard deviation (sdVs).

$$CV = \frac{sdVs}{mVs}$$

The aim of this study was to examine the dynamics of running with a pole by employing both non-linear and linear analytical methods. We assessed time series data from various competitions, contrasting successful and unsuccessful jumps to determine their correlation with athletic performance. Simultaneously, we incorporated the linear parameter of velocity variation in the final 10 meters of the run-up (Δv_{male}) to analyze its association with performance outcomes. By situating our analysis within the framework of ecological dynamics, we seek to uncover richer, context-specific insights to better inform the design of training environments.

This research delves into non-linear data, capturing the intricate interplay between factors that influence an athlete's performance, including their objectives, perceptions, and actions. Our analysis will pinpoint crucial constraints spanning human, environmental, and task-related factors that mold performance, using elite pole vaulters' feats as a reference point.

6.1.3 Methods

We conducted a longitudinal analysis, examining data derived from pole vault runs. Specifically, we compared the variability between successful and unsuccessful jumps.

Participants

The study centered on one elite male athlete, aged 28, who represented his country at the international level. Before participating, the athlete was briefed about the research objectives and provided consent in accordance with the ethical guidelines established by the Universidade Lusófona and the principles outlined in the Declaration of Helsinki.

Measurements

A non-intrusive Lidar laser system was positioned at the start of the run, ensuring no interference with the athlete's performance. The athlete adhered to a warm-up routine as prescribed by his coach. Before executing each jump, the athlete documented the intended height of the jump, the specific pole selected, and its attributes, including size, weight, and flexibility.

In our analysis, we employed fractal metrics, utilizing the CoDim and Sample entropy to gauge complexity. The CV was utilized to discern variations in the run-up phase's velocity.

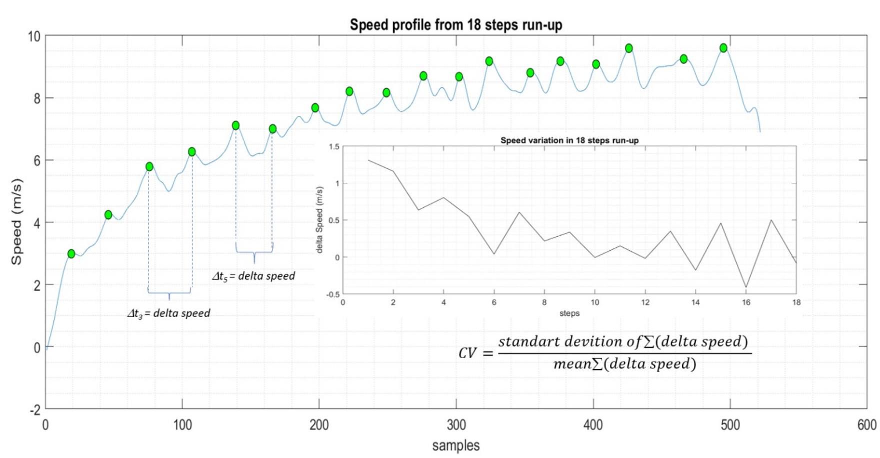

Figura 6.1: Speed profile from 18 steps time serie touch down in the run-up

Furthermore, we integrated the velocity variation parameter (Δv_{male}) into our research. This parameter was chosen due to its evident correlation with the success of pole-vaulting performance. This parameter's significance was previously discussed in the chapter titled, "Pole vault performance analysis utilizing kinematic parameters and technical restrictions in training: a longitudinal study".
Δv_{male}denotes the difference in average velocities observed in the run-up between (vmed11-6m) and (vmed16-11m) from the box. Assessing the velocity in the final 10 meters leading up to the take-off offers insights into potential acceleration. Exploring the correlation between potential acceleration in this segment and the overall jump performance remains a central aspect of our investigation.

$$\Delta v_{male} = (vmed11 - 6m) - (vmed16 - 11m)$$

Instruments

For data collection, this study utilized the Laser Displacement Measure - Jenoptik LDM301, sourced from Germany (Dickwach et al., 1994).

Data processing

Positional data from the Lidar displacement measure (Jenoptik LDM 301) were refined using a polynomial equation. By deriving this positional data, we obtained the velocity-time information. This data was subsequently imported into Rstudio (Version 1.2.1335; © 2009-2019 Rstudio, Inc.) for kinematic analysis of all jumps executed by the athlete. Finally, for easier visualization and further analysis, this data was exported to Microsoft Excel (Microsoft Corporation Inc., Albuquerque, NM, USA).

Procedures

The participant was thoroughly briefed regarding the objectives of the study. Data collection was aligned with the technical training schedule pre-decided by the coach.

Statistical analysis

All statistical evaluations were performed using jamovi® (Version 1.2), which can be accessed at https://www.jamovi.org (originating from Australia). For data visualization and graphical representation, we employed Microsoft Excel (Microsoft 2016, USA).

6.1.4 Results

Nonlinear Analysis

Table 6.1 displays the SampEn, CoDim, and CV values for all the jumps, both successful (clear) and unsuccessful (not clear). The SampEn values didn't present any significant evidence ($p > 0.05$), maintaining stability with a minimal standard deviation, irrespective of the jump's success. There was a notable impact on the CoDim values during the 8nStp and 18nStp runs. Specifically, the values were 10.6 ± 3.01 for 8-step runs that resulted in successful jumps and 6.56 ± 0.71 for 18-step runs leading to successful jumps, as shown in Table 6.1. The coefficient of variation (CV) was only significant in successful jumps. Specifically, runs with 12, 14, 16, and 18 steps demonstrated significant evidence in terms of CV.

Tabela 6.1: Data from statistical analasys of sample entropy (SampEn), correlation dimension (CoDim), velocity variation in the last 10m of the run-up (Δv_{male}) and coeffient variation (CV) values from all analized runs

nStp	nJumps	Clear	SampEn mean ± sd	CoDIm mean ± sd	Δv_{male} mean ± sd	CV %
8nStp	4	No	0.258 ± 0.052	6.91 ± 1.87	1.408 ± 0.116	9.667
	11	Yes	0.254 ± 0.042	10.6 ± 3.01*	1.477 ± 0.085	9.307
10nStp	18	No	0.239 ± 0.028	9.92 ± 2.10	0.678 ± 0.091	4.147
	32	Yes	0.254 ± 0.027	9.08 ± 2.16	0.780 ± 0.099***	9.133
12nStp	38	No	0.269 ± 0.041	7.02 ± 1.49	0.449 ± 0.131	4.853
	46	Yes	0.269 ± 0.039	7.33 ± 1.22	0.383 ± 0.126*	1.825***
14nStp	11	No	0.257 ± 0.038	7.02 ± 1.21	0.174 ± 0.060	0.329
	18	Yes	0.279 ± 0.033	6.46 ± 1.12	0.243 ± 0.148*	0.437***
16nStp	11	No	0.271 ± 0.030	5.79 ± 0.99	0.143 ± 0.160	0.929
	18	Yes	0.270 ± 0.035	5.41 ± 0.57	0.131 ± 0.172	0.220
18nStp	5	No	0.252 ± 0.022*	4.94 ± 0.46	0.136 ± 0.143	0.120
	3	Yes	0.230 ± 0.015	6.56 ± 0.71*	0.031 ± 0.131	0.046*

*$p < 0.05$; $*** < 0.001$;
nStp = number os steps of the run-up;
nJumps = total number of jumps performed;
Clear = "**No**" no pass the bar in the jump; "**yes**"pass the bar in the jump.

Table 6.2 presents the results after applying Welch's t-test, which compares the means of two independent sample sets. This test is especially suitable for samples with unequal variances or different sizes. Significant differences were identified in SampEn levels during the runs. In terms of CoDim, noteworthy differences emerged only for runs of 8 steps and 18 steps. The nonlinear variable showing a significant p-value was the CV. As illustrated in Table 6.2, all runs (comprising 8, 10, 12, 14, 16, and 18 steps) exhibited a significant p-value.

Tabela 6.2: Statistics Independent Samples T-Test (Welch's t)

	nStp (8)			**nStp (10)**			**nStp (12)**		
	CoDim	SampEn	CV	CoDIm	SampEn	CV	CoDIm	SampEn	CV
Statistic	-2.832	0.142	-2.092	1.33	-1.76	-13.27	-1.0287	0.0223	-11.4971
df	8.95	4.51	5.77	36.1	34.2	42.2	71.5	77.9	47.3
p	**0.020**	0.893	0.083	0.191	0.088	< .001	0.307	0.982	< .001
	nStp (14)			**nStp (16)**			**nStp (18)**		
	CoDIm	SampEn	CV	CoDIm	SampEn	CV	CoDIm	SampEn	CV
Statistic	1.240	-1.591	-14.701	1.139	0.140	-4.011	-3.485	1.706	-4.306
df	19.9	19.0	25.9	14.1	23.8	10.7	3.04	5.73	5.51
p	0.229	0.128	< .001	0.274	0.890	**0.002**	**0.039**	0.141	**0.006**

*$p < 0.05$; $*** < 0.001$; nStp = number os steps of the run-up

Linear Analysis

In the preceding chapter, the analysis of performance against a set of kinematic parameters in successful jumps (categorized as 3 - Clear the bar) highlighted Δv_{male} s a key parameter closely correlated with performance.

In the table below, the relationship between Δv_{male} and jump success is depicted. It's evident that acceleration was crucial for the success of the jumps with 10, 12, and 14 steps. However, for jumps with an 8-step approach, this factor wasn't as significant. Additionally, for longer runs (16 and 18 steps), the acceleration in the concluding steps didn't yield a significant p-value for this particular athlete.

Tabela 6.3: Statistics of Δv_{male} kinematic parameter with the performance

	nStp (8)	**nStp (10)**	**nStp (12)**	**nStp (14)**	**nStp (16)**	**nStp (18)**
Statistic	-1.113	-3.9767	2.7743	-2.176	0.228	1.310
df	3.98	40.9	94.5	40.5	38.0	9.25
p	0.329	$< .001$	**0.007**	**0.035**	0.821	0.222

*$p< 0.05$; $*** < 0.001$; nStp = number os steps of the run-up

6.1.5 Discussion and implications

This study aimed to examine the time series from different run-up lengths in the pole vault event, distinguishing between successful and unsuccessful jumps. We employed both linear and nonlinear methods to determine the relationship between these series and athletic performance. Within the realm of linear parameters, our focus was on the Δv_{male}, which quantifies the velocity variation in the last 10 meters of the run-up, to ascertain its predictive value for performance.

Linear Analysis

Linear methods dominate research regarding the pole vault run-up analysis, given their frequent application in the field (Cassirame, Sanchez, Exell et al., 2019; Frère et al., 2017; Gross et al., 2019; Peter et al., 2014). An essential facet of this analysis is assessing the velocity variation in the concluding 10 meters of the run-up. This can provide insights into whether the athlete is gaining momentum or accelerating as they transition into the take-off phase.

For this study, linear methods were utilized to scrutinize the pole vault event run-up. Our objective was to identify linear relationships in the data, such as how velocity and its fluctuations during the run-up might influence the jump's outcome.

In our study, Δv_{male} emerged as a pivotal parameter, exhibiting a robust correlation with successful jumps, as elucidated in the preceding chapter. The data revealed a marked statistical significance of Δv_{male} on the jump outcomes, with successful jumps demonstrating pronounced acceleration as they neared the take-off phase. This observation aligns with prior studies suggesting that peak velocities achieved close to the box yield superior jump results (Frère et al., 2010; Linthorne, 2000; Linthorne & Weetman, 2012). These findings underscore the criticality of achieving maximal velocity during the run-up.

For extended runs (16 and 18 steps), Δv_{male} significance diminished. This may arise from the athletes' already high velocities during longer runs, making further acceleration challenging. While acceleration might be less critical for these longer runs, maintaining a steady high velocity remains imperative. This observation corroborates the assertions made by (Cassirame, Sanchez, Exell et al., 2019), emphasizing the importance of sustaining high velocities during the latter stages of the run-up, even if it doesn't lead to acceleration at take-off.

Nonlinear analisys

Frère et al. (2010) describe the pole vault event as a multifaceted endeavor influenced by a myriad of factors, with the run-up approach being paramount. The run-up, when observed, can be analyzed as a time series. Nonlinear parameters like SampEn, CoDim, and CV often serve to dissect the complexity of such time series. Our approach utilized nonlinear methods to distinguish time series based on jump outcomes. The intention was to unearth significant variations in time series influenced by varying run lengths and jump performances. However, only minor disparities were detected. Among the parameters, CV manifested the most substantial differences for varying run lengths.

This resonates with findings from other investigations, like (Cassirame, Sanchez, Garnier et al., 2019), which also pinpointed only marginal differences between successful and unsuccessful jumps. These negligible variations could be attributed to the limited size of the time series, though it's not conclusive. Yentes et al. (2013) did allude to the feasibility of discerning entropy in brief data sets. While these observations can't be universally applied, they underscore the method's potential.

6.1.6 Limitations

While linear analysis offers valuable insights into data patterns and predictions and has been a mainstay in competitions and studies for years, it predominantly explores linear relationships. For intricate or nonlinear phenomena, this method might fall short, and nonlinear techniques may provide more comprehensive insights. One hurdle with nonlinear methods is their perceived complexity.
One of the primary challenges with nonlinear methods is the intricacy involved, which often results in delayed delivery of insights to coaches and the broader audience. Rapid data dissemination to coaches and athletes can be instrumental, allowing for timely adjustments to training regimens, thereby enhancing sports performance. The crux of the issue isn't the significance or relevance of nonlinear models; rather, it's about their practicality in routine training scenarios and the velocity at which the data is processed, analyzed, and relayed to coaches.

6.1.7 Conclusions

Both linear and nonlinear methods prove valuable in delivering insights for coaching strategies. Employing nonlinear approaches, this study discerned no significant alterations in the time series corresponding to various run lengths and jump outcomes within the given case study. Only minute disparities in the time series were observed, with CV emerging as the sole parameter indicating the most pronounced differences across jumps of varied run lengths.

Conversely, using linear methodologies, the study concluded that heightened Δv_{male} values significantly influenced the success of jumps. Successful jumps were distinctly marked by amplified acceleration as they approached the take-off phase.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval The study was approved by the Etics Commission from Faculdade de Educação Física e Desporto – ULHT - (protocol number: PARECER M1021) and adhered to the Declaration of Helsinki.

Consent to participate All participants gave their informed consent prior to their inclusion in the study.

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"A vida sem ciência é uma espécie de morte."

Sócrates

Capítulo 7

Discussão Geral

Este trabalho é composto por três estudos que caracterizam o percurso da pesquisa realizada. A revisão sistemática da literatura e os três estudos longitudinais representam os resultados desta extensa investigação. A discussão dos resultados de cada um dos estudos pode ser encontrada nos respetivos capítulos (IV, V e VI). O capítulo seguinte buscará estabelecer conexões entre esses estudos de acordo com cada etapa da pesquisa.

7.1 Ligação entre os estudos

A realização de uma tese de doutoramento requer que uma questão atual e relevante seja o ponto de partida para a pesquisa, incentivando o desenvolvimento do pensamento crítico na procura de respostas. É amplamente reconhecido que a velocidade na corrida desempenha um papel fundamental no desempenho desportivo, sendo um fator determinante em muitas disciplinas do Atletismo. Vários autores também destacam a importância da velocidade no contexto do salto com vara (Hay, 1988; Linthorne & Weetman, 2012; McGinnis, 1997; Mcginnis, 2004; Yang et al., 2020). A pesquisa, nesta direção, tem o potencial de fornecer informações valiosas no âmbito do treino para a compreensão e melhoria do desempenho dos atletas.

Entretanto, durante a revisão da literatura sobre este assunto, não encontrámos nenhuma revisão sistemática que abordasse a relação entre a velocidade e a disciplina do ScV em atletas de elite, pelo que surgiu a necessidade de realizar essa revisão sistemática, que nesta tese é apresentada no Capítulo II. Esta revisão da literatura permitiu identificar os métodos mais frequentemente utilizados na recolha de dados de velocidade em ambiente competitivo com atletas de elite e estabelece que atletas mais rápidos têm uma maior probabilidade de sucesso. Foi também possível reconhecer cientificamente uma relação entre a velocidade máxima do atleta e diferentes componentes técnicas na disciplina de ScV, especificamente, valores mais elevados de velocidade possibilitam o uso de varas maiores e mais rígidas, alturas de pegas maiores e a realização da chamada mais longe do encaixe. Além disso, os atletas que conquistaram medalhas apresentaram valores médios de velocidade superiores em comparação com os outros atletas finalistas.

O Estudo I, conforme apresentado no Capítulo IV, teve como objetivo esclarecer a relação existente entre a velocidade máxima e a velocidade obtida na CA, bem como a sua relação a sua relação com o desempenho desportivo. O estudo foi conduzido longitudinalmente em formato de estudo de caso e abrangeu três macrociclos de treino. Foram analisados dois atletas de elite da disciplina do ScV, um feminino e um masculino. Os resultados mostraram que as velocidades em T1 (velocidade máxima do atleta sem vara) e em T2 (velocidade máxima alcançada na CA com vara) apresentaram um comportamento semelhante, com uma correlação significativa, para ambos os atletas. Durante os três macrociclos, observou-se uma variação nos valores da velocidade máxima dos atletas, possivelmente relacionada com o estado de forma física dos mesmos.

Este estudo veio corroborar os resultados descritos na revisão de literatura (Cassirame, Sanchez, Exell et al., 2019; Cassirame, Sanchez, Garnier et al., 2019; Tamura et al., 2017; Yang et al., 2020), reforçando a preponderância da velocidade para o sucesso do salto. Frère et al. (2017) acentuou a importância da transferência da velocidade máxima do atleta para a CA, tornando imperativo a necessidade de capacitar os atletas a correrem rápido com vara. A investigação permitiu ainda identificar a influência da velocidade noutros parâmetros técnicos fundamentais no sucesso do salto.

No Estudo II, conforme apresentado no Capítulo V, o objetivo foi determinar que parâmetros cinemáticos e técnicos que mais influenciam o desempenho no ScV, em ambiente de treino. Participaram neste estudo dois atletas de elite e foram considerados para análise um total de 464 saltos, dos quais se mediram os seguintes parâmetros: v_max, dis_vmax, v_med16-11m, v_med15-10m, v_med11-6m, v_med10-5m, v_profile, run-up size, Grip, pole lenght, flex of the pole, kg of the pole, push height, jump hight (mark), success of the jump.

Embora fosse comum supor que um aumento no tamanho da CA resultaria em maiores velocidades e, portanto, melhor desempenho desportivo, a pesquisa não confirmou essa expetativa, ao contrário, os resultados indicam que, embora CAs mais longas permitam de facto alcançar maiores velocidades, essa melhoria não se traduz necessáriamente em taxas mais consistentes de sucesso nos saltos. O estudo permite ainda levantar a hipótese de que o aumento da velocidade está associado a uma maior variabilidade do comportamento motor do atleta, mais erros técnicos e um aumentos dos constrangimentos específicos do salto. Estudos anteriores, como o de (Needham et al., 2018) já havia demonstrado a ocorrência de alterações do padrão locomotor e técnico em consequência de alterações dos valores cinemáticos.

O Estudo III (Capítulo VI), pretendeu apresentar algo inovador, investigando o comportamento da velocidade alcançada durante CA através de métodos lineares e não lineares. Neste estudo foram considerados 215 saltos com comprimentos de corrida diferentes (8, 10, 12, 14, 16 e 18nStp) de um único atleta, 128 com sucesso e 87 sem sucesso, tendo sido registado para cada salto o perfil de velocidade do atleta, capturado pelo registo contínuo da velocidade ao longo da corrida. Assim, pretendeu-se estudar a relação existente entre a variabilidade desse registo e o desempenho desportivo (sucesso vs. insucesso). As medidas não lineares utilizadas para quantificar a variabilidade e complexidade do perfil de velocidade foram a SampEn, CoDim e CV%, respetivamente, e como medida linear utilizou-se o Δv_{male}.

Neste estudo podemos concluir que, ao nível da SampEn, não existiu diferenças significativas entre a variabilidade dos perfis de velocidade com e sem sucesso, ou seja, a variabilidade do perfil não está relacionada com o desempenho desportivo; todavia, através da análise fractal com a CoDim, foi possível encontrar diferenças significativas entre saltos com e sem sucesso, particularmente para 8nStp e 18nStp. Os resultados obtidos para CV% mostram que em todas as corridas, exceto para 8nStp, existem diferenças significativas entre saltos com e sem sucesso. Nas restantes corridas o padrão da série temporal manteve-se muito estável.

Em comparação com métodos lineares, foi possível identificar diferenças entre saltos com comprimentos de corrida diferentes, sendo obtido valores mais altos do parâmetro Δv_{male} indicarem um maior efeito no sucesso do salto.

7.2 Limitações

Na realização do presente trabalho foram identificadas limitações inerentes a cada um dos estudos realizados. Particularizando, as principais limitações da revisão sistemática centraram-se na reduzida amostra de estudos considerados, após a inclusão do critério "atletas de elite". A heterogeneidade dos desenhos de estudo e das metodologias utilizadas dificultou a comparação dos resultados entre relatórios e artigos científicos. Também, em estudos envolvendo atletas de elite é natural que o tamanho da amostra seja reduzido, , e isso foi igualmente identificado como uma limitação. Quanto aos estudos I, II e III, a inexistência de um elevado número de atletas de elite de ScV em Portugal, não permitiu que fossem considerados mais participantes, embora fossem recolhidos vários saltos para cada atleta no estudo.

7.3 Perspetivas Futuras

É compreensível que a pesquisa com atletas de elite, devido à sua natureza seletiva, possa resultar em uma amostra limitada. Contudo, o reconhecimento dessas limitações é um passo importante para futuras pesquisas. A realização de estudos com uma amostra maior, sempre que possível, é uma abordagem positiva que pode ajudar a obter resultados mais generalizáveis e significativos. Conduzir pesquisas com atletas de elite pode ser desafiador devido à sua disponibilidade limitada, mas os conhecimentos obtidos podem ser valiosos para entendendimento do desempenho desportivo de elite.

Como resultado da evolução tecnológica, tem-se verificado uma maior riqueza na recolha e análise de dados (local da chamada, variação do padrão da corrida, consistência da componente técnica e variação de parâmetros cinemáticos), anteriormente menos estudados. O surgimento de métodos de recolha mais sofisticados e adaptáveis ao ambiente, tornou a recolha de dados mais fidedigna e a utilizacão de instrumentos de recolha de tamanho reduzido e com menor impacto no gesto de execucão, como a Unidade de Medida Inercial (IMU), permitiu a recolha de valores em tempo e contexto real (Camomilla et al., 2018; Rantalainen et al., 2020).

A análise de séries temporais tem-se tornado cada vez mais comum no estudo do desempenho desportivo; no entanto, a maioria dos estudos concentram-se em métodos lineares, limitando a identificação de padrões complexos e não-lineares nos dados. Assim, a utilização de métodos não-lineares, como análise fractal, entropia de amostragem e coeficiente de variação, tem-se mostrado promissora para a compreensão de aspetos complexos do desempenho desportivo que dificilmente podem ser identificados com métodos lineares.

A análise de séries temporais com métodos não-lineares permite melhorar a identificação de padrões complexos com dados de desempenho desportivo que podem ser usados para prever o desempenho futuro, bem como entender as relações entre diferentes aspetos do desempenho desportivo.

7.4 Implicações Práticas

Revisão sistemática

Através dos instrumentos e protocolos utilizados para a identificação e caracterização do impacto da velocidade no sucesso do ScV, é disponibilizada, aos treinadores e atletas, informação relevante no sentido da obtenção de melhores desempenhos.

Estudo I

Este estudo veio reforçar a relação entre a velocidade máxima e a velocidade alcançada na CA e o, consequente, impacto na performance desportiva. A análise destas velocidades constitui uma importante ferramenta, possibilitando, ao treinador, organizar e individualizar o treino com base em informação científica e credível.

Estudo II

Este estudo permitiu identificar a importância dos parâmetros cinemáticos e constrangimentos técnicos mais associadas ao desempenho do ScV, possibilitando, aos treinadores, a utilização do mesmo protocolo com vista à identificação de constrangimentos que mais influenciam (positivamente ou negativamente) o desempenho dos seus atletas.

Estudo III

Com este estudo foi possível verificar que ambos os métodos são relevantes em termos de obtenção de dados para os treinadores. Através de métodos não-lineares, os resultados deste estudo identificaram que não houve variações significativas nas séries temporais com base em diferentes comprimentos de corrida de balanço e o desempenho no salto. Apenas pequenas diferenças nas séries temporais foram identificadas. Os resultados sugerem que o parâmetro CV% foi o único que mostrou as maiores diferenças entre saltos com diferentes tamanhos de corrida. O estudo mostrou que valores mais altos de Δv_{male} tiveram um efeito estatisticamente significativo no sucesso do salto, sendo que saltos bem-sucedidos foram caracterizados por uma aceleração maior na aproximação da chamada.

7.5 Conclusão Final

Este trabalho visou esclarecer a influência do parâmetro velocidade no desempenho da disciplina do ScV. O conjunto de estudos desenvolvido revelou-se um importante instrumento na avaliação da velocidade como parâmetro fundamental no desempenho da disciplina. Na tabela seguinte (Tabela 7.1) apresenta-se a síntese das questões colocadas e as conclusões, de cada estudo.

Sendo o conhecimento sempre limitado, imperfeito e passível de investigação contínua, mantém-se pertinente a necessidade de mais investigação sobre o impacto da velocidade no desempenho dos atletas no ScV.

Tabela 7.1: Tabela resumo das questões colocadas nos estudos realizados e respetivas conclusões

	Questões	**Conclusões**
Revisão Sistemática - The velocity in the Pole Vault event: a sistematic review (Capítulo 3)	(1) - Determinar o número de estudos e relatórios científicos existentes de acordo com os critérios de inclusão definidos, no evento de salto com vara.	(1) - Doze estudos científicos e nove relatórios científicos.
	(2) - Identificar os métodos (instrumentos e procedimentos) mais referenciados.	(2) - Video; Radar; Optojump; Optojump + Radar; Optojump + Video; Optojump + Radar + Video; Photocells + Video; Photocells + Video + Radar.
	(3) - Identificar as diferenças existentes nos dados das velocidades obtidas em função dos instrumentos e procedimentos utilizados.	(3) - Apesar da utilização de diferentes métodos na obtenção das velocidades, os valores encontrados verificaram-se muito consistentes.
	(4) - Esclarecer se a variação dos dados da velocidade (obtidos nas grandes competições) influenciaram a performance.	(4) - Verificou-se que atletas mais rápidos obtiveram melhores resultados.
	(5) - Esclarecer se o valor médio da velocidade dos três primeiros classificados das grandes competições foi superior ao valor de velocidade dos outros atletas.	(5) - Verificou-se que a média das velocidades dos atletas medalhados foi mais elevada que a dos restantes atletas finalistas.
Estudo I - The influence of the maximum velocity changes during periodised training seasons on full approach runs in the pole vault event (Capítulo 4)	(1) - Analisar de que forma a velocidade máxima sem vara e a velocidade máxima com vara na CA variam ao longo de três Macrociclos.	(1) - Os valores das velocidades máximas oscilaram ao longo dos três Macrociclos. Verificou-se um comportamento paralelo entre ambas as velocidades, estabelecendo-se uma correlação com significância estatística.
	(2) - Determinar que associação se estabelece entre as duas velocidades.	(2) - Verificou-se a existência de relação entre a tarefa T1 e T2 para ambos os atletas incluídos no estudo de caso.
	(3) - Esclarecer que relação existe entre as velocidades e o desempenho desportivo no evento de ScV.	(3) - Os resultados obtidos através da metodologia aplicada permitiram verificar a existência de relação entre a componente física, a velocidade e o desempenho desportivo.
Estudo II - Pole vault performance analysis using kinematic parameters and technical constraints in training - longitudinal study (Capítulo 5)	(1) - Determinar a existência de relação entre o tamanho da CA e o sucesso/performance no salto.	(1) - O tamanho da CA tem influência na performance do salto, com diferente impacto nos atletas.
	(2) - Determinar que parâmetros cinemáticos e técnicos têm mais influência na performance do ScV (saltos de sucesso: "3 - clear the bar").	(2) - Na categoria de "3 - clear the bar" verificou-se que, para saltos superiores a 90% do SB, os parâmetros com maior correlação com o sucesso foram: Atleta M (Grip; size of the pole; v_max; v_med16 -11m; v_med11-6m) e para Atleta F (Grip; flex of the pole; dis_vmax).
Estudo III - Non-linear and linear methods to analyze pole vault run-up in successful and unsuccessful jumps (Capítulo 6)	(1) - Analisar a corrida de salto com vara usando métodos não-lineares e lineares por meio da análise de séries temporais de diferentes saltos, comparando saltos bem-sucedidos e mal-sucedidos e determinando se estes apresentam relação com desempenho desportivo. (2) Identificar a relação entre o parâmetro linear de variação de velocidade nos últimos 10 metros da corrida (Δv_{male}) com o desempenho desportivo.	(1) - Pequenas diferenças nas séries temporais foram identificadas usando métodos não lineares. (2) - O parâmetro CV% foi capaz de mostrar diferenças entre saltos com comprimentos de corrida variados. (3) valores mais altos do parâmetro Δv_{male} indicaram um maior efeito no sucesso do salto.

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ANEXOS

ANEXO 1

(Parecer da Comissão de Ética da Faculdade de Educação Física e Desporto - ULHT)

UNIVERSIDADE LUSÓFONA
| Faculdade de Educação Física e Desporto [redacted]

Comissão de Ética da Faculdade de Educação Física e Desporto -ULHT

Parecer M1021

A Comissão de Ética da Faculdade de Educação Física e Desporto – ULHT, em reunião de 10 de Março de 2021, analisou o projeto de Doutoramento em Educação Física e Desporto de **Pedro Pinto**, subordinado ao tema *Análise da Velocidade na disciplina de salto com vara*, tendo decidido emitir parecer positivo sem recomendações.

O Diretor da Comissão de Ética da FEFD – ULHT

(Prof. Doutor José Gregório Viegas Brás)

ANEXO 2

(Carta Explicativa do Estudo aos Participantes)

UNIVERSIDADE LUSOFONA DE HUMANIDADES E TECNOLOGIA – FACULDADE DE EDUCAÇÃO FÍSICA E DESPORTO

DOUTORAMENTO EM EDUCAÇÃO FÍSICA E DESPORTO

Pedro Pinto

Análise da velocidade na disciplina de salto com vara

CARTA EXPLICATIVA DO ESTUDO AOS PARTICIPANTES

O meu nome é Pedro Pinto, sou estudante do Doutoramento em Educação Física e Desporto da Universidade Lusófona de Humanidades e Tecnologia da Faculdade de Educação Física e Desporto. Gostaria de convidá-lo(a) a participar num conjunto de estudos que estamos a desenvolver, para a tese de Doutoramento, tendo como principal objetivo a interpretação da velocidade como parâmetro fundamental para o sucesso na disciplina de salto com vara.

A informação recolhida neste estudo poderá, no futuro, ajudar a compreender e elaborar novas propostas que possam influenciar os treinadores a optarem por novos processos de treino.

A escolha de participar ou não no estudo é voluntária. Os presentes estudos não acarretam qualquer risco, não trazendo também qualquer vantagem direta para os que nela participam, e não irá interferir no plano de intervenção do seu treinador.

Serão aproveitados todos os dados normalmente recolhidos pelos treinadores durante os seus treinos e mais alguns que propomos. Se decidir participar no estudo, poderá abandonar o mesmo em qualquer momento sem ter que fornecer qualquer tipo de explicação. Todo o material recolhido será codificado e tratado de forma anónima e confidencial, sendo conservado à responsabilidade do Professor Pedro Pinto.

ANEXO 3

(Declaração de Consentimento Informado)

UNIVERSIDADE LUSOFONA DE HUMANIDADES E TECNOLOGIA – FACULDADE DE EDUCAÇÃO FÍSICA E DESPORTO

DOUTORAMENTO EM EDUCAÇÃO FÍSICA E DESPORTO

Análise da velocidade na disciplina de salto com vara

DECLARAÇÃO DE CONSENTIMENTO INFORMADO

Reconheço que os procedimentos de investigação descritos na carta anexa me foram explicados e que todas as minhas questões foram esclarecidas de forma satisfatória. Compreendo igualmente que a participação no estudo não acarreta qualquer tipo de vantagens e/ou desvantagens potenciais.

Fui informado(a) que tenho o direito a recusar participar e que a minha recusa em fazê-lo não terá consequências para mim. Compreendo que tenho o direito de colocar agora e durante o desenvolvimento do estudo, qualquer questão relacionada com o mesmo. Compreendo que sou livre de, a qualquer momento, abandonar o estudo sem ter de fornecer qualquer explicação.

Assim, declaro que aceito participar nesta investigação, com a salvaguarda da confidencialidade e anonimato e sem prejuízo pessoal de cariz ético ou moral.

Professor responsável pelo estudo:

____

(Pedro Pinto)

O Participante:

____

______, ____ de ________________ de 20____

ANEXO 4

(Rotinas - Relatório Lidar - Salto com Vara)

```
[language=Python, caption={},label={lst:code}, mathescape=true, breaklines=true]

# Close all figures, clear variables and command window
graphics.off()
rm(list = ls())
cat("\014")

## *****************************************************************
## *         Relatorio Lidar - Salto com Vara
## *****************************************************************
## *       Started: 13-03-2017, Paulo Oliveira
## *       Edited:  12-12-2017, Paulo Oliveira
## *****************************************************************

## Abrir ficheiros
source("openfiles.R")

## Converter CELL em NUMS
data <- data[1:(length(data)-3), 1]
l <- nrow(data)
data_num1 <- vector("list", l)

for (i in 1:l) {
  data_num <- data[i, 1]
  data_num1[[i]] <- substr(data_num, 2, nchar(data_num))
  m1[i, 1] <- as.numeric(data_num1[[i]])
}

## Variaveis Temporais + Frequencia de Corte
SR <- 100
dt <- 1/SR
cut <- 12
n <- 2

## Selecionar Fase da Corrida de Balanco + Suavizacao de dados
h <- plot(m1)
p <- 2
xy <- locator(pch = 20, col = "red")
x <- round(xy$x)

pos_raw <- m1[x[1]:x[2], 1]
pos_L <- LPassF(pos_raw, cut, n, SR)

## %%%% Alterar em cada dia de avaliacoes
tam <- 39.63 #38.51 #33.12
pos_I <- tam - pos_L

## %%%% Definir Genero do Atleta
gen <- 'f'
if (gen == 'm') {
  ### Masculino - Tempo 6m-11m-16m
  m <- c(16, 11, 6)
  for (i in 1:3) {
```

```
    k <- m[i]
    index[i] <- which.min(abs(pos_I - k))
    closestValues[i] <- pos_I[index[i]] # Finds first one only!
  }
  t_16_11 <- (index[2] - index[1])/SR
  t_11_6 <- (index[3] - index[2])/SR
} else if (gen == 'f') {
  ### Feminino - Tempo 5m-10m-15m
  m <- c(15, 10, 5)
  for (i in 1:3) {
    k <- m[i]
    index[i] <- which.min(abs(pos_I - k))
    closestValues[i] <- pos_I[index[i]] # Finds first one only!
  }
  t_15_10 <- (index[2] - index[1])/SR
  t_10_5 <- (index[3] - index[2])/SR
}

## Velocity Parameters
vel <- diff(pos_L)/dt
vmax <- max(vel)
loc_vmax <- which.max(vel)
t <- which(vel == vmax)
t_max <- t*dt
x_max <- tam - pos_L[t]

## Acceleration Parameters
acc <- diff(vel)/dt

## Dados a colocar em BD
if (gen == 'm') {
  RADAR_data <- c(t_16_11, t_11_6, vmax, t_max, x_max)
} else if (gen == 'f') {
  RADAR_data <- c(t_15_10, t_10_5, vmax)
```

ANEXO 5

(Rotinas - Código utilizado para suavização da curva)

```

[language=Python, caption={},label={lst:code}, mathescape=true, breaklines=true]

Interpolar_Curva <- function(pos) {
  f <- min(which(!is.na(pos[, 1])))
  l <- max(which(!is.na(pos[, 1])))

  for (int in (f + 1):(l - 1)) {
    if (is.na(pos[int, 1])) {
      low <- int - 1
      high <- which(!is.na(pos[, 1]))
      highindex <- min(which(high > int))
      high <- high[highindex]

      H1 <- matrix(c(low, 1, high, 1), nrow = 2, byrow = TRUE)
      H2 <- c(pos[low, 1], pos[high, 1])
      cint <- solve(H1) %*% H2

      pos[int, 1] <- cint[1] * int + cint[2]
    }
  }

  return(pos)
}
```

ANEXO 6

(Rotinas - Código em Latex da paginação da Tese)

```
\documentclass{report}
\usepackage[style=apa]{biblatex}
\addbibresource{references.bib}
\usepackage{setspace}
\usepackage[left=3.0cm, right=2.0cm, top=2.8cm, bottom=2.5cm]{geometry}
\usepackage[portuguese]{babel}
\usepackage{pdfpages}
\usepackage{multirow}
\usepackage{graphicx}
\usepackage{epstopdf}
\usepackage{adjustbox}
\usepackage{color, colortbl}
\usepackage{tikz}
\usepackage[FIGTOPCAP]{subfigure}
\usepackage{pdflscape}
\usepackage{longtable}
\usepackage{amsmath}
\usepackage{array, booktabs, ragged2e}
\usepackage{booktabs}
\usepackage{float}
\usepackage{bm}
\definecolor{lightgray}{rgb}{0.83, 0.83, 0.83}
\usepackage{listings}
\usepackage{xcolor}
\definecolor{codegreen}{rgb}{0,0.6,0}
\definecolor{codegray}{rgb}{0.5,0.5,0.5}
\definecolor{codeorange}{rgb}{1,0.49,0}
\definecolor{backcolour}{rgb}{0.95,0.95,0.96}

\lstdefinestyle{mystyle}{
  backgroundcolor=\color{backcolour},
  commentstyle=\color{codegray},
  keywordstyle=\color{codeorange},
  numberstyle=\tiny\color{codegray},
  stringstyle=\color{codegreen},
  basicstyle=\ttfamily\footnotesize,
  breakatwhitespace=false,
  breaklines=true,
  captionpos=b,
  keepspaces=true,
  numbers=left,
  numbersep=5pt,
  showspaces=false,
  showstringspaces=false,
  showtabs=false,
  tabsize=2,
  xleftmargin=10pt,
}
\lstset{style=mystyle}

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


```

```
\usepackage{fancyhdr}
\pagestyle{fancy}
\fancyhf{}
\fancyhead[RE,LO]{\begin{footnotesize}Pedro Pinto - An lise da Velocidade na Corrida de Aproxima  o na Disciplina de Salto com Vara\end{footnotesize}}
\fancyfoot[CE,CO]{\begin{footnotesize}{Universidade Lus fona - Centro Universit rio de Lisboa \\ Faculdade de Educa   o F sica e Desporto   \end{footnotesize}}}
\fancyfoot[RE,RO]{\thepage} % Adi   o feita aqui
\renewcommand{\headrulewidth}{0.4pt}
\renewcommand{\footrulewidth}{0.4pt}

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
\begin{document}

  \begin{titlepage}
    \begin{center}
      \includegraphics[scale=0.25]{folder/logotipo.png}
      \vspace{1.5cm}\\
      \textbf{PEDRO DANIEL NUNES DA SILVA ONOFRE PINTO\\\vspace{3 cm}
        \begin{LARGE}
          AN LISE DA VELOCIDADE NA CORRIDA DE APROXIMA  O NA DISCIPLINA DE SALTO COM VARA\\\vspace{4cm}
        \end{LARGE}
        Orientador: Professor Doutor Jorge dos Santos Proen a Martins\\\vspace{0.5cm}
        Coorientador: Professor Doutor Orlando de Jesus Semedo Fernandes\\\vspace{3 cm}
        Universidade Lus fona - Centro Universit rio de Lisboa \\\vspace{0.5cm}
        Faculdade de Educa   o F sica e Desporto\\\vspace{0.5cm}
        Lisboa\\\vspace{0.5cm}2023
      }
    \end{center}
  \end{titlepage}
```

```

%\onehalfspacing
\tableofcontents % ndice  de conte dos
\listoffigures %Lista de figuras
\listoftables %Lista de tabelas

\clearpage
\pagenumbering{arabic}
\pagestyle{fancy}

\newpage

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
\include{CAP1/cap1}

\include{CAP2/cap2}

\include{CAP3/cap3}

\include{CAP4/cap4}

\include{CAP5/cap5}

\include{CAP6/cap6}

\include{CAP7/cap7}

\appendix

\cleardoublepage
\include{Acessorios/MyAppendixA}

\include{Acessorios/MyAppendixB}

\include{Acessorios/MyAppendixC}

% \nocite{*}
%\printbibliography
\end{document}
```