UNIVERSIDADE LUSÓFONA

Centro Universitário de Lisboa

Faculdade de Educação Física e Desporto

Doutoramento em Educação Física e Desporto

A RELAÇÃO DO ÂNGULO DE FASE DA BIOIMPEDÂNCIA ELÉTRICA E A FORÇA MUSCULARNOS JOGOS DESPORTIVOS COLETIVOS

Tese de Doutoramento defendida em provas públicas para a obtenção do Grau de Doutor em Educação Física e Desporto, orientada pelo Professor Doutor Filipe LuisMartins Casanova

Everton Luís Rodrigues Cirillo / Nº 21909194

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Tese defendida em provas públicas na Universidade Lusófona Centro Universitário de Lisboa no dia 07/02/2024, perante o júri, nomeado pelo Despacho de Nomeação n.º: 518/2023, de 12 de dezembro de 2023, com a seguinte composição:

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Este trabalho também foi orientado pelo Professor Doutor António Carlos Dourado, U. Estadual de Londrina Brasil.

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RESUMO

Com base na medição da resistência total do corpo em relação à passagem de uma corrente elétrica de baixa amplitude e alta frequência, o teste de bioimpedância elétrica (BIA) mede vários indicadores como: resistência, a reatância e o ângulo de fase (PhA). A presente Tese de Doutoramento teve como objetivo geral estudar o PhA e a sua relação com a força muscular em atletas de diversos esportes coletivos. E como objetivos específicos: (i) realizar uma revisão sistemática da literatura, com meta-análise, para verificar a relação do PhA e a força em atletas; (ii) verificar qual esporte coletivo de invasão (basquetebol, futebol, futsal, handebol e rugby) que apresenta maior probabilidade de obter um maior valor do PhA, considerando a idade, tempo de prática esportiva, testes de salto vertical e força de preensão manual em jovens atletas; e (iii) verificar a relação entre o PhA e a força muscular de membros inferiores em jovens atletas de voleibol masculino. No primeiro estudo as bases de dados utilizadas foram: PubMed, Scielo, Scopus, SPORTDiscus e Web of Science e o critério de eligibilidade foi o PECOS. No segundo estudo, 248 jovens atletas foram avaliados para se estabelecer correlações entre o PhA e variáveis categóricas (desporto e sexo) e covariáveis (idade, tempo de prática, squat jump- SJ, countermovement jump- CMJ, e força de preensão manual esquerda ou direita - HGSl or HGSr), e se desenvolveu uma equação a partir do modelo de regressão logística para melhor interpretar a probabilidade em obter um valor superior do PhA. No terceiro estudo, 38 voleibolistas foram avaliados nos testes de impulsão vertical (CMJ and SJ) e na bioimpedância. Os nossos resultados evidenciaram: (i) uma relação do PhA e o countermovement jump (CMJ) ($r = 0.691$ [95% CI 0.249 to 0.895], $Z = 2.797$; $p = 0.005$); (ii) os praticantes de futebol como tendo 2.2 maior probabilidade de apresentar um PhA mais alto; e (iii) uma correlação positiva entre PhA o CMJ e SJ ($r = 0.550$, $r = 0.559$; respectivamente) para jovens atletas de voleibol. Desta forma, foi possível concluir que (i) existe uma relação do PhA com a força muscular de membros inferiores e superiores em atletas; (ii) maiores valores de PhA predispõem os atletas de futebol, futsal e rugby a expressarem maior desempenho de força durante testes de salto ou preensão manual, sendo o futebol o esporte que proporciona maior probabilidade de desenvolver um PhA superior; e (iii) existe uma relação entre o PhA e a força de membros inferiores em jovens atletas de voleibol.

Palavras-chave: Jovens atletas; Rendimento esportivo; Composição corporal; Força muscular.

ABSTRACT

Based on the measurement of total body resistance in relation to the passage of a low amplitude and high frequency electrical current, the bioelectrical impedance test (BIA) measures several indicators such as: resistance, reactance, and phase angle (PhA). The present PhD Thesis had as its main goal to study the PhA and its relationship with muscle strength in athletes from several team sports. And as specific aims (i) to review systematically the literature, with meta-analysis, verifying the relationship between the PhA and strength in athletes; (ii) to verify which team invasion sport (basketball, soccer, futsal, handball and rugby) is more likely to obtain a higher PhA value, considering age, time of sport practice, vertical jump tests and handgrip strength of young athletes; and (iii) to study the relationship between PhA and muscle strength of lower limbs in male volleyball players. In the first study the data sources used were: PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science and the study eligibility criteria were based on the PECOS. In the second study, a total of 248 young athletes were evaluated, after performing the correlations between the PhA and categorical variables (sport and sex) and covariables (age, time of practice, squat jump- SJ, countermovement jump- CMJ, and handgrip strength left or right- HGSl or HGSr), and we developed an equation from a logistic regression model to better interpret the probability to obtain a higher PhA. In the third study, 38 volleyball athletes were evaluated in vertical jump tests (CMJ and SJ) and bioimpedance. Our findings showed a relationship between PhA and the countermovement jump (CMJ) ($r = 0.691$ [95% CI 0.249 to 0.895], $Z = 2.797$; $p = 0.005$); (ii) soccer players as being 2.2 more likely to present a higher PhA; and (iii) a positive correlation between PhA and CMJ and SJ ($r = 0.550$, $r = 0.559$; respectively) for young volleyball players. It was possible to conclude (i) the relationship between PhA and muscle strength of lower and upper limbs in athletes; (ii) higher PhA values predisposed soccer, futsal and rugby athletes to express greater strength performance during jump or handgrip tests, being soccer the sport that provided the greatest probability of developing a higher PhA; and (iii) the relationship between PhA and lower limb strength in young volleyball athletes.

Keywords: Young athletes; Sports performance; Body composition; Strenght.

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	INGLÊS	PORTUGUÊS
BIA	Bioeletrical Impedance	Bioimpedância Elétrica
R	Resistence	Resistência
Xc	Reactance	Reactância
PhA	Phase Angle	Ângulo de Fase
HGS	Hand Grip Strength	Prensão Manual
1RM	1 Maximum Repetition	1 Repetição Máxima
WB	Whole Body	-
CMJ	Counter Movement Jump	Salto com Contra Movimento
JDC	-	Jogos Desportivos Coletivos
IC ou CI	Confidence Interval	Intervalo de Confiança
LST	Lean Soft Tissue	-
OSF	Open Science Framework	
PhD	Doctoral Degree	
SLJ	Standing Long Jump	
t	Time Sports Practice	Tempo de Prática Esportiva
VO_2max	Maximum Volume of Oxygen	
U-17	Under Seventeen	
BMI	Body Mass Index	

INTRODUÇÃO GERAL

Durante as últimas três décadas, o teste de bioimpedância elétrica (BIA) tem sido amplamente utilizado pela comunidade científica, visando ampliar o conhecimento e estado da arte a respeito da composição corporal, quer seja para a área da saúde ou para esporte (Bongiovanni et al., 2021; Cirillo et al., 2023a; Lukaski et al., 2017; Tomeleri et al., 2018).

Devido à inerente falta de homogeneidade no corpo humano, isto é, alterações na resistividade do material condutivo, variações na relação entre altura e comprimento condutivo e na forma do corpo e dos seus segmentos, o termo altura^2/R (Resistência) descreve um cilindro equivalente que deve corresponder à geometria real por um coeficiente apropriado, onde esse coeficiente depende de vários fatores, entre eles, a anatomia dos segmentos corporais (Kyle et al., 2004).

Assim, o princípio básico da BIA se baseia no fato de o corpo humano ser composto por um conjunto de cinco "cilindros" (ou seja, dois braços, duas pernas e tronco) que oferecem diferentes resistências à passagem de corrente elétrica de baixa intensidade (Horie et al., 2008). Desta forma, uma divisão do corpo humano em dois grandes compartimentos pode ser inferida pelo fato de os compartimentos humanos serem compostos principalmente por água e eletrólitos (massa corporal magra) e por gordura e tecidos que não continham água (Kyle et al., 2004). Com base na medição da resistência total do corpo em relação à passagem de uma corrente elétrica de baixa amplitude (800 mA) e alta frequência (50 kHz), a BIA mede vários indicadores, tais como: resistência (R), a reatância (Xc) e o ângulo de fase (PhA), sendo um método confiável, de baixo custo e fácil de utilização (Cirillo et al., 2023a; Kyle et al., 2004).

A resistência bioelétrica é a pura oposição de um condutor biológico ao fluxo de uma corrente elétrica alternada, enquanto a reactância é a efeito resistivo devido à capacitância produzida pelas interfaces dos tecidos e membranas celulares (Baumgartner et al., 1988). A capacitância, ou o armazenamento de carga elétrica por um condensador, faz com que a corrente fique atrás da tensão, criando uma mudança de fase (Baumgartner et al., 1988). Essa mudança é quantificada geometricamente como a transformação angular da razão da Xc para a R, ou PhA (Baumgartner et al., 1988).

O PhA é considerado um parâmetro importante, onde parece refletir a saúde celular, a massa celular corporal e a integridade da parede celular (Norman et al., 2012). Além disso, em sujeitos que apresentem alguma debilidade do seu estado de saúde, o PhA parece ser menor do que indivíduos saudáveis, o que pode prever pior desfecho para a saúde e, até mesmo, a mortalidade (Mundstock et al., 2018). Inicialmente, o PhA foi proposto como fator para o diagnóstico e acompanhamento de diversas doenças (Colín-Ramírez et al., 2012; Tanaka et al., 2018). Porém, na atualidade, pesquisadores de vários países tem buscado entender como se comporta o PhA em atletas, considerando a performance e, também, relacionando-o a parâmetros de força muscular (Bongiovanni et al., 2022; Campa et al., 2022; Cirillo et al., 2023b; Di Vincenzo et al., 2019).

Valores de PhA (masculino: 7,50º ± 0,60; feminino: 6,71º ± 0,69) são propostos como um índice de aptidão muscular (Ribeiro et al., 2017), com a relação entre a PhA e a saúde celular aumentando quase linearmente (Ott et al., 1995). Valores baixos de PhA (Idade dos indivíduos: 18-19 anos - Masculino: 6,82º ± 0,77; Feminino: 5,93º ± 0,69) são consistentes com uma incapacidade das células de armazenar energia (Bosy-Westphal et al., 2006) e altos valores de PhA (Idade dos indivíduos: 14-18 anos - Masculino: 8,01º ± 0,83; Feminino: 7,23º ± 0,89) são consistentes com grandes quantidades de membranas celulares intactas, refletindo a proporção de massa celular corporal para massa isenta de gordura (Cirillo et al., 2023a). Fatores como a idade, o índice de massa corporal e o sexo são determinantes primários da PhA (Bosy-Westphal et al., 2006; Gonzalez et al., 2016). Teoricamente, a variação do PhA entre indivíduos em uma frequência fixa pode ser devido a diferenças no comportamento capacitivo de seus tecidos associados à variabilidade no tamanho da célula e permeabilidade da membrana (Baumgartner et al., 1988).

Concomitantemente, e no que diz respeito à força muscular, uma pesquisa científica destacou sua importância em relação às habilidades esportivas gerais e específicas e suas características de força subjacente, além de contribuir com a redução da taxa de incidência de lesões (Suchomel et al., 2016). Dada a relação que a força tem, uma variedade de atributos parece existir necessidade de se obter informações sobre como melhorar a força e fatores fisiológicos que a afetam (Suchomel et al., 2016). Esta capacidade é altamente dependente da idade, sexo, características morfológicas e nível de aptidão física, devendo ser consideradas durante um teste e na interpretação dos seus resultados (Hansen et al., 1999; Nescolarde et al., 2015; Suchomel et al., 2016).

Assim, para os membros superiores, o teste da força de preensão manual (HGS) é considerado importante para fornecer um índice objetivo da integridade das funções dos membros superiores, sendo uma forma de medir a força muscular de baixo custo, de fácil aplicação e clinicamente confiável, associado ao estado geral de força muscular (Moura et al., 2008). Do ponto de vista do desempenho esportivo, é interessante entender como a HGS se relaciona e afeta as ações e padrões de movimento específicos do esporte (cf., Cronin et al., 2017).

Com relação à força de membros inferiores, a melhora dessa habilidade está acoplada a um maior rendimento em esportes, principalmente naqueles em que são realizados sprints ou saltos de maiores alturas, determinantes das metas de desempenho, onde para se avaliar a força dos membros inferiores podem ser utilizados testes de salto vertical (Squat Jump-SJ e Counter Moviment Jump-CMJ, que são explicados pelo ciclo do alongamento encurtamento) e uma repetição máxima (1RM), por exemplo (Bongiovanni et al., 2021; Cesanelli et al., 2022; Cirillo et al., 2023a). O mecanismo que utiliza a energia armazenada nos componentes elásticos e reutilizada na próxima ação muscular, o qual propicia uma maior potência quando a ação muscular excêntrica é imediatamente seguida por uma ação muscular concêntrica (Coelho et al., 2011; Komi & Bosco, 1978).

Neste sentido, estudos tem buscado explicar a relação do PhA com a força muscular, quer seja para membros superiores ou inferiores em atletas de diversos esportes e idades, como por exemplo o estudo realizado por Hetherington-Rauth et al. (2021) que verificaram a associação do PhA de corpo inteiro (WB) com o desempenho muscular em 117 atletas adultos de diferentes esportes, em particular com força de preensão manual e potência de salto com contramovimento (CMJ). Os autores concluíram que o PhA pode ter potencial para ser usado como marcador de massa muscular funcional, o que é importante quando se trata de avaliar o desempenho muscular de atletas.

Assim, considerando que nesta presente Tese de Doutoramento foram realizados estudos com foco nos jogos desportivos coletivos (JDC), importa salientar que os JDC são: baseados na ação do jogo resultante das interações entre os atletas; realizadas num espaço comum, para alcançar um determinado objetivo; na disputa com a oposição dos adversários; exige um conjunto de capacidades específicas para a organização interna da equipe, no sentido de conseguir o melhor desempenho das ações tático-técnicas durante o jogo; onde um sistema de relações recíprocas de comunicação-cooperação é coordenado através das ações coletivas; onde este sistema de inter-relações é realizado de forma contínua durante o jogo; e na utilização das ações dos atletas de forma adequada no espaço e no tempo disponíveis (Tavares & Casanova, 2017).

Os esportes coletivos de invasão em equipe (e.g., basquetebol, futebol, futsal, handebol e rugby) caracterizam-se por serem jogos de bola disputados por dois adversários com o objetivo de fazer pontos ou gols enquanto tentam evitar que o adversário marque, invadindo o seu próprio espaço (Lord et al., 2020). Diferentes esportes de invasão de equipe são conhecidos, incluindo aqueles em que a bola é lançada em uma rede (e.g., basquetebol ou netball) ou a bola é rebatida com o pé ou um bastão em um gol (e.g., futebol, futebol australiano ou hóquei em campo) ou a bola é carregada através de uma linha (e.g., futebol americano, rugby league ou rugby union) (Lord et al., 2020), onde o voleibol se configura como esporte coletivo, porém, de não-invasão (Afonso, Garganta, McRobert, Williams, & Mesquita, 2014).

Em suma, parece-nos prioritário reforçar que para melhorar o desempenho dos desportistas dos JDC se depende, em grande parte, da habilidade das comissões técnicas em selecionar e organizar eficientemente os métodos e meios de treino, e seus conteúdos, e procedimentos de controle e avaliação do desempenho dos praticantes que estejam relacionados à prática competitiva dessa mesma modalidade (Braz et al., 2012).

Face ao acima exposto, a presente Tese de Doutoramento teve como objetivo geral estudar o ângulo de fase da bioimpedância elétrica e a sua relação com a força muscular em atletas de diversos esportes de equipe. Para se dar cumprimento ao anteriormente exposto, se definiram a realização de 3 estudos, a saber:

(i) Realizar uma revisão sistemática da literatura, com meta-análise, sobre a relação do ângulo de fase e a força muscular em atletas;

(ii) Verificar qual esporte coletivo de invasão, de entre o basquetebol, futebol, futsal, handebol e rugby, apresenta maior probabilidade de obter um maior valor do PhA, considerando a idade, tempo de prática esportiva, testes de salto vertical e força de preensão manual de jovens atletas;

(iii) Verificar a relação entre o PhA e a força muscular de membros inferiores em jovens atletas de voleibol do sexo masculino.

Assim, e considerando o anteriormente objetivado, definiram-se como hipóteses da presente Tese de Doutoramento:

(i) A existência da relação do PhA e força de membros inferiores (CMJ e SJ) e superiores (HGS) nos JDC;

(ii) Os esportes de invasão em equipes que apresentam maior nível de contato físico, bem como na realização de movimentos físicos variados, manifestam maior probabilidade de obter um maior valor do PhA, a partir de outras covariáveis, tais como: tempo de prática esportiva, idade e força muscular de membros superiores e infeiores;

(iii) Por último, a existência de uma correlação positiva entre o PhA e a força muscular dos membros inferiores através do desempenho do CMJ e SJ em jovens voleibolistas.

Por fim, a presente Tese de Doutoramento se encontra organizada em Introdução Geral, onde se introduz o tema em estudo, seu racional científico e se descreve os principais objetivos e respectivas hipóteses; os três capítulos seguintes (I, II e III) se apresentam estudos originais publicados em revistas científicas internacionais, com revisão de pares, de acordo com as suas normas de redação; Discussão Geral, onde se estabelece uma relação das evidências científicas neste domínio; as conclusões se encontram descritas na Conclusão; elencam-se nas referências bibliográficas a literatura consultada e utilizada na Introdução Geral e Discussão Geral; e, por fim, se apresenta os Anexos.

CAPÍTULO I

ESTUDO I

Relationship between Bioelectrical Impedance Phase Angle and Upper and Lower Limb Muscle Strength in Athletes from Several Sports: A Systematic Review with Meta-Analysis.

(Sports 2023, 11, 107. https://doi.org/ 10.3390/sports11050107)

Estudo I

Relationship between Bioelectrical Impedance Phase Angle and Upper and Lower Limb Muscle Strength in Athletes from Several Sports: A Systematic Review with Meta-Analysis ***(Sports 2023, 11, 107. https://doi.org/ 10.3390/sports11050107)***

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1.1. ABSTRACT

The phase angle (PhA) of bioelectrical impedance is determined by primary factors such as age, body mass index and sex. The researchers' interest in applying PhA to better understand the skeletal muscle property and ability has grown, but the results are still heterogeneous. This systematic review with a meta-analysis aimed to examine the existence of the relationship between PhA and muscle strength in athletes. The data sources used were PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science and the study eligibility criteria were based on the PECOS. The searches identified 846 titles. From those, thirteen articles were eligible. Results showed a positive correlation between PhA and lower limb strength ($r = 0.691$ [95% CI 0.249 to 0.895]; $p = 0.005$), while no meta-analysis was possible for the relationships between PhA and lower limb strength. Furthermore, GRADE shows very low certainty of evidence. In conclusion, it was found that most studies showed a positive correlation between PhA and vertical jump or handgrip strength. The meta-analysis showed the relationship between PhA and vertical jump, however, little is known for the upper limbs as was not possible to perform a meta-analysis, and for the lower limbs we performed it with four studies and only with vertical jump.

Keywords: sport; performance; physical-physiological assessment; body composition

1.2. INTRODUCTION

During the past three decades, the bioelectrical impedance test (BIA) has been widely used by the research community to extend knowledge about body composition [1,2]. The BIA offers a simple approach to identifying biomarkers of cell damage and cell death in many populations (e.g., athletes, elderly, college students), determining the quality of the cell membrane throughout the body, and representing fluid distribution in individuals [1,2]. Albeit the body and its conductivity are not a uniform cylinder and constant, respectively, some relationship can be established between the impedance quotient (Length2/R [R stands for resistance]) and the volume of water, which contains electrolytes that conduct the electrical current through the body. Therefore, it is easier to measure height than conductive length, which is usually from wrist to ankle [3].

Moreover, due to the inherent field inhomogeneity in the body, the empirical relationship between lean body mass (typically 73% water) and height^2/R describes an equivalent cylinder, which must be matched to real geometry by an appropriate coefficient [3]. The basic principle is based on the fact the human body is composed of a set of five "cylinders" (i.e., two arms, two legs and trunk) that offer different resistances to the passage of low-intensity electrical current and that stability of the tissue hydration [4]. Moreover, it is analyzed based on measurements of the total resistance of the body to the passage of electrical current of low-amplitude (800 mA) and high-frequency (50 kHz). For this purpose, we have chosen to use the BIA, which measures several indicators such as resistance (R), reactance (Xc), and the phase angle (PhA), and it is also a reliable, low-cost and easy to use method [3].

The PhA is acquired through the relationship between the measurements of R and Xc, in which the electrical current passes through the body and is briefly stored in cell membranes. This storage causes a drop in the current voltage, creating a phase shift and resulting in an angle transforming the relationship between Xc and R, respectively [3]. These values (men: 7.50° ± 0.60, women: 6.71° ± 0.69) are proposed as an index of muscle fitness [5], with the relationship between PhA and cellular health increasing almost linearly [6]. Low values of PhA (18–19 years: men: 6.82° ± 0.77; women: 5.93° ± 0.69) are consistent with an inability of cells to store energy [7], and high values of PhA (14–18 years: men: 8.01° ± 0.83; women: 7.23° ± 0.89) are consistent with large amounts of intact cell membranes, reflecting the ratio of body cell mass to fat-free mass [8]. Factors such as age, body mass index and sex are primary determinants of PhA [7].

Muscle strength and power in the lower limbs are both important physiological characteristics in sports practitioners, especially in sports involving high-speed running and jumping, where their development is linked to high performance in high-level physical abilities [9]. These abilities are highly dependent on age, sex, morphological characteristics and level of physical fitness and must be considered during a test and the interpretation of its results [7,9–12]. To assess lower limb strength, vertical jump tests (e.g., counter-movement jump: CMJ) and one repetition maximum (1 RM), for example, can be used, especially where sprints or jumps are determinants of performance goals [8,13]. For the upper limbs, handgrip strength (HGS) provides an objective index of the integrity of upper limb functions, is a low-cost and easily applicable way to measure muscle strength, and has been established as a reliable clinical method associated with the general state of muscle strength [14].

Research interest in the application of PhA in athletes as an index of skeletal muscle properties, especially body water distribution in the whole body (WB) and/or limbs, has grown, but data delivered heterogeneous results. In healthy subjects, the PhA ranges from 5 degrees (°) to 7° and in well-trained athletes it may reach 8.5° [15]. The association of WB PhA with muscle performance in 117 adult athletes from different sports was evaluated in order to investigate whether regional PhA could be a better indicator of muscle performance compared to the WB while accounting for lean soft tissue (LST) [16]. The authors reported that PhA may have the potential to be used as a marker of functional muscle mass, which is important when it is intended to assess the muscular performance of athletes.

According to the pattern established for the searches of the present study, systematic reviews were found dealing with the connection between PhA in physical activities and sports and the evaluation of body composition, non-athletic children and adolescents, resistance training for older adults, muscle strength and aerobic fitness in different populations, oxidative stress, factors related to maturity in adolescent athletes and diseases (e.g., cardiovascular, cancer, and obesity). No reviews reported specifically the relationships between PhA with strength in athletes (lower and upper limbs), perhaps denoting the interest in the field still has not achieved critical mass. This demonstrates there is a gap in the literature in this domain, in which we expected that this research may contribute to the construction of knowledge and state of the art for the sport sciences. Therefore, the goal of this systematic review with meta-analysis was to assess the relationship between PhA (assessed through BIA) and the strength of lower and upper limbs of athletes of both sexes in different sports.

1.3. MATERIALS AND METHODS

This review was registered on the OSF platform on 30 November 2021, one day before the searches were performed (project: https://osf.io/pmhgq/; registration: https://osf.io/f5vxy). PRISMA 2020 recommendations [17] (checklist presented in Supplementary material Table S1), and Cochrane's guidelines [18] were followed.

1.3.1 Eligibility Criteria

We included original research published in peer-reviewed journals, with no date or language limit. Conference abstracts, even if published in peer-reviewed journals, were excluded. Eligibility criteria followed the PECOS approach: (i) participants were healthy athletes from any sport, regardless of sex or age; (ii) participants had exposure to regular sports training; (iii) comparators were optional; (iv) outcomes had to include PhA assessed through bioelectrical impedance and at least one of the following outcomes: lower limb strength (e.g., vertical jump, 1RM leg-press) and/or upper limb strength (e.g., medicine ball throwing, 1RM bench press); (v) no limitation was placed regarding study design.

1.3.2 Information Sources

Initial searches were performed on December 1st of 2021, with updates on September 30th of 2022, in the following databases without applying filters: Scielo, PubMed, Scopus, Web of Science and SPORTDiscus. Manual searches were also performed within the reference lists of the studies that were included. Subsequently, a snowballing citation tracking was performed on Web of Science. Then two external experts (Ph.D. holders who had published research on the topic in many publications on the Web of Science) were consulted to provide further suggestions for potentially relevant studies. Following the recommendations of Higgins [18], we searched errata and retractions of the included studies. In cases where there were pre-registered protocols and/or complementary files related to the included studies, these were also retrieved.

1.3.3 Search Strategy

The full search strategies for each database are presented in Table 1.

Table 1. Full search strategies for each database.

Database	Search strategy
PubMed	(((bioimpedance OR "bioelectrical impedance") AND ("phase angle")) AND (strength OR force OR power OR potenc* OR muscle OR muscul*) AND (athlet* OR sport*)))
Scielo	(bioimpedance OR "bioelectrical impedance") AND ("phase angle") AND (stregth OR force OR power OR potenc* OR muscle OR muscul*) AND (athlet* OR sport*)
Scopus	(ALL (bioimpedance OR "bioelectrical impedance") AND ALL ("phase angle") AND ALL (strength OR force OR power OR potenc* OR muscle OR muscul*) AND ALL (athlet* OR sport*))
SPORTDiscus	TX (bioimpedance OR "bioelectrical impedance") AND TX "phase angle" AND TX (strength OR force OR power OR potenc* OR muscle OR muscul*) AND TX (athlet* OR sport*)
Web of Science	ALL FIELDS: (bioimpedance OR “bioelectrical impedance”) AND ALL FIELDS: (“phase angle”) AND ALL FIELDS: (strength OR force OR power OR potenc* OR muscle OR muscul*) AND ALL FIELDS: (athlete* OR sport*)

1.3.4 Selection Process

EC and JA independently screened each record retrieved. In cases of disagreements between the two authors, FC provided arbitration until consensus was achieved. Auto-mated removal of duplicates was performed using EndNoteWeb (ClarivateTM), but further manual removal of duplicates was required.

1.3.5 Data Collection Process

AP and EC independently collected data from the reports. In cases of disagreements between two authors, FC provided arbitration until consensus was achieved. In cases where relevant data was missing and/or additional details were required, the authors of the studies were contacted by e-mail and ResearchGate, and the required information was solicited. In cases with no response, the studies were only excluded if the missing data were directly linked to the eligibility criteria. No automation tools were used.

1.3.6 Data Items

Outcomes: PhA assessed through bioelectrical impedance and at least one of the following outcomes: lower limb strength (vertical jump, 1RM leg-press) and/or upper limb strength (medicine ball throwing, 1RM bench press).

Additional variables: participant-related characteristics (sample size, age, sex, competitive level, sport, sport type, exposure to regular sports training), assessment-related features (specific assessments that were performed, number and blinding of testers, familiarization with testing procedures, time of season during the assessments, reliability of assessments), and other study-related information (country, funding, competing interests).

1.3.7 Study Risk of Bias Assessment

Risk of bias was performed at the outcome level using Cochrane's RoBANS [19], with a worst-case scenario provided for the study level. Six domains were assessed: selection of participants, confounding variables, measurement of intervention (exposure), blinding of outcome assessment, incomplete outcome data and selective outcome reporting. EC and JA independently assessed the risk of bias. In cases with disagreements between the two authors, FC provided arbitration until consensus was achieved.

1.3.8 Effect Measures

For the main outcomes, means and standard deviations were presented (or median and interquartile range when appropriate). Correlation values between PhA and strength tests were presented alongside their confidence intervals.

1.3.9 Synthesis Methods

We established a minimum of three studies that provided data (e.g., correlation) for the same outcome [20,21] to avoid small sample sizes [22,23]. The main meta-analysis was based on correlation coefficients (r) as a well-known effect size estimate. Correlational data was used to compute the effect size (and its variance) for each study. For correlations, all computations were carried out using Fisher's *Z*-transformed values. Correlation coefficients were entered along with the corresponding sample size or related data (i.e., standard error; variance; Fisher's Z; t value; p-value), and the software (Comprehensive Meta-Analysis program, version 2; Biostat, Englewood, NJ, USA) was set to produce pooled r or with 95% confidence interval (CI) using random effects models. The inverse variance random effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors [24] to better account for inaccuracy in the estimation of between-study variance [25] and enables analysis while accounting for heterogeneity across studies [26]. The pooled effect size for r was classified as small (≤ 0.1), moderate ($0.1 – 0.29$) or large (≥ 0.30) [27].

The impact of study heterogeneity was assessed using the I2 statistic, with values of <25%, 25–75%, and >75% representing low, moderate and high levels of heterogeneity, respectively [28]. Computation of meta-regression was planned with at least 10 studies per covariate [18].

1.3.10 Risk of Reporting Bias Assessment

Risk of reporting bias was not assessed as the minimum number of 10 studies per comparison was not achieved. Planned assessments can be consulted in the registered protocol.

1.3.11 Certainty Assessment

Certainty or confidence in the body of evidence for each outcome was assessed using GRADE [29], considering five dimensions: risk of bias in studies, indirectness, inconsistency, imprecision and risk of publication bias [30,31].

1.4. RESULTS

1.4.1 Study Selection

The initial searches (12/01/2021), plus update, (09/30/2022) retrieved 846 (786 + 60) records: PubMed: (56 + 21 = 77); Scielo: (1 + 0 = 1); Scopus: (545 + 0 = 545); SPORTDiscus: (83 + 6 = 89); and Web of Science: (101 + 33 = 134), of which 260 were duplicates. Of the 586 records screened, 158 were excluded due to not being empirical studies in peer-reviewed journals, and 407 were excluded due to not fulfilling one or more PECOS criteria. Four records fulfilled PECOS criteria, but were published in conference proceedings, not in peer-reviewed journals [32,35]. Seventeen studies were deemed eligible for full text analysis [9,11,15,16,36,48]. Of these, two studies were excluded since PhA was not assessed [39,46] and one because strength was not assessed [36]. Two studies assessed PhA and strength but had no correlation data reported, which was required to fulfil eligibility criteria. All the authors of these studies were contacted through email and, when available, through ResearchGate. The authors of two studies provided the necessary data [40,47], while no response was obtained for the other two studies [42,44], which were therefore excluded. Therefore, ten studies were included after the database searches [9,11,16,37,38,40,41,43,45,47]. The reference lists of these studies were then searched to retrieve potentially relevant titles that had not emerged in our initial searches. Two titles were promising but were excluded as they did not assess PhA [48,49].

Afterwards, searches were carried out in the reference lists of the ten articles, where four studies were found, of which two were removed because they were duplicates and two were included [50,51]. We also performed a snowballing citation tracking for the 12 included studies in Web of Science on December 20th of 2021.Two studies were not found in Web of Science; thus citation tracking was performed in ResearchGate [40,47]. Of the 28 identified records, two were duplicates and 15 had emerged during our initial searches. The remaining 11 records were screened for titles and abstracts and one study required full-text analysis [52], but was excluded because PhA was not assessed. Two experts were also contacted, with three additional articles being suggested; since two of them had al-ready been eliminated in the initial searches, only one new study [13] was included.

Ultimately, thirteen studies were included in our review [9,11,13,16,37,38,40,41,43,45,47,50,51]. Of these, only one had a pre-registered protocol [37], which we retrieved. Some studies provided a specific code for ethics registration, and the authors were contacted through email and, if available, by ResearchGate. Five authors provided protocols submitted to ethics committees [16,37,40,43,45]. These protocols were especially relevant for assessing risk of bias due to selective reporting. Figure 1 synthesizes the search and selection process.

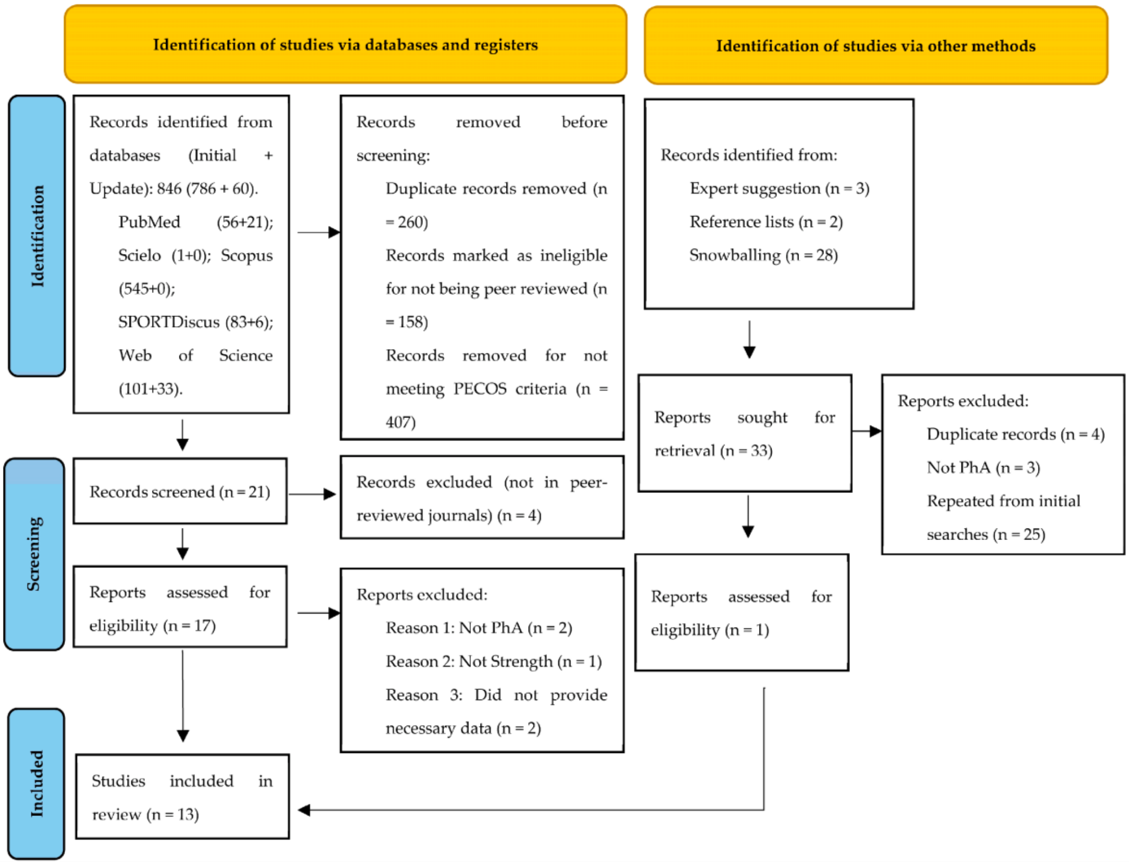

Figure 1. PRISMA flow diagram highlighting the selection process for the studies included in the systematic review.

Table 2. Characteristics of the included studies.

Study Country where the research took place	n Sex	Age	Competitive Level	Physical outcomes	Description of interventions
Alvero-Cruz et al. [37] Spain	Total: 256 Male: 162 Female: 91	58.0 ± 12.0	Master Athletes	PhA CMJ	A brief questionnaire-guided interview was performed with the participants to assess information on athletic specialization, training habits, and medical conditions. All participants were subjected to BIA device (InBody S10, South Korea) with a segmental multifrequency approach. The test was performed with a Leonardo ground reaction force platform (Novotec Medical, Pforzheim, Germany) with the integrated software in its 4.4b01.35 version (research addition).
Bongiovanni et al. [50] Italy	Male: 15	28.7 ± 5.0	Elite	PhA CMJ	To assess PhA, a BIA 101 Biva Pro, Akern, Florence, Italy was used. Whole-body and lower hemisoma PhA were obtained with a phase-sensitive 50kHz BIA and legs lean soft tissue. It was estimated using specific bioimpedance-based equation developed for athletes. Vertical jump performance was assessed using CMJ.
Campa et al. [40] Italy	Female: 20	23.8 ± 3.4	Elite	PhA CMJ	The procedures were synchronized individually with all participants, so to have a familiarization session before the first early follicular phase and 4 testing assessments. Particularly, the testing assessments were performed in the second day of each early follicular phase and 14 days later when the participants were in their ovulatory phase. To assess body composition, BIA (BIA 101 Anniversary; Akern Srl, Florence, Italy) was performed, and BIVA procedures were applied. To assess performance, CMJ and 20-m sprint tests were used.
Cattem et al. [41] Brazil	Total: 273 Male: 161 Female: 112	12.9 ± 0.9	Beginners	PhA HGS	The school adolescents were classified as athletes, according to Sports Dietitians Australia Position Statement. To evaluate the PhA, the BIA measurements were always performed in the morning, using a tetrapolar analyzer RJL (Quantum 101; Systems, Clinton Township, MI USA), at a single frequency of 50kHz. Participants were in the supine position with a leg opening distant from the median line of the body and the upper limbs distant from the trunk. HGS was assessed with a hand JAMAR-dynamometer (Asimow Engineering Co., Los Angeles, CA, USA) in both hands alternately, three times, and the mean value was recorded to obtain a single value of HGS.
Čerňanová et al. [47] Slovakia	Male: 21	G1: 15.18 ± 0.75 G2: 17.14 ± 0.9	Competitive	PhA CMJ HGS	Ice-hockey players were divided in two training groups, one group with collective training (n=18; 13 completed the study) and one group with individual training procedure (n=8). Physical performance parameters included upper and lower limbs power, force and velocity. Body composition analysis was determined by BIA device (BIA 101-Akern S.r.l.) and BODYGRAM software (version 1.3 for Windows) and MYOTEST PRO diagnosed the force and speed-force components of the upper and lower limbs.
Di Vicenzo et al. [11] Italy	Female: 12	23.8 ± 3.6	Competitive	PhA HGS	Participants included elite female volleyball players on a team of the Italian Serie B League and twenty-two young women, with similar characteristics, who served as the control group. They trained six days/week for about 4 hours/day. Control women were selected among the Federico II University students. Assessment for PhA was carried out using a tetrapolar unifrequency BIA device (BIA 101 Anniversary Akern/RJL Systems; Florence, Italy) at a frequency of 50 kHz. Upper limb muscle strength was based on HGS assessed using a Jamar handgrip

					dynamometer (Asimow Engineering, Santa Fe Springs, CA, USA). Maximum relative lower limb power and maximum average power of the lower limbs was assessed in the form of a CMJ using the Leonardo Mechanograph Ground Reaction Force Plate (GRFP; Novotec Medical GmbH, Germany).
Hetherington-Rauth et al. [16] Portugal	Total: 117 Male: 57 Female: 60	20.9 ± 3.5 21.1 ± 4.1	Competitive	PhA CMJ HGS	Muscle performance was assessed in athletes from several sports, which consisted of a measure of upper body strength and lower body power. PhA of the upper and lower limbs were correspondingly measured. WB assessment for PhA was carried out using a tetrapolar unifrequency BIA device (BIA 101 Anniversary Akern/RJL Systems; Florence, Italy) at a frequency of 50kHz. Upper limb muscle strength was based on HGS assessed using a Jamar handgrip dynamometer (Asimow Engineering, Santa Fe Springs, CA, USA). Maximum relative lower limb power and maximum average power of the lower limbs was assessed in the form of a CMJ using the Leonardo Mechanograph Ground Reaction Force Plate (GRFP; Novotec Medical GmbH, Germany).
Mala et al. [9] Czech Republic	Total: 59 Male: 39 Female: 20	12.08 ± 1.47	Cadet and junior teams	PhA HGS	Judo athletes gripped the dynamometer with maximal effort in a sitting position with full extension of the elbow in two trials for each limb and with a rest interval lasting 60 secs between the trials. To assess whole-body bio-impedance, we used a Tanita MC-980MA multi-frequency bio-impedance analyser (Tanita Corporation, Japan). Only the best performance in the trial was processed in the further analysis. As the preferred upper limb, it was used the participants' writing hand.
Martins et al. [43] Brazil	Male: 62	15.0 ± 1.4		PhA CMJ	Male youth soccer players were evaluate in PhA and physical performance attributes, composed of standing long jump (SLJ), IER capacity, sprinting speed, and repeated-sprint ability (RSA) in. The first week of testing included only body composition assessments, by means of BIA. To assess the PhA, a BIA octopolar multi-frequency equipment (Biospace, Los Angeles, CA, USA). During the second week, two days of the training microcycle were dedicated to the application of the following physical tests with all players: (i) on the first day: standing long jump (SLJ) and Carminatti's test (T-CAR) and (ii) on the second day: sprint test straight and RSA protocol.
Obayashi et al. [45] Japan	Total: 170 Male: 110 Female: 60	13.9 ± 1.6	Competitive	PhA CMJ	All participants were assessed in the height and weight and entered the device before starting BIA (In Body S10 Body Water Analyzer; InBody Co., Seoul, Korea). The measurements were taken in the supine position with no limbs in contact with each other. CMJ height and squat jump (SJ) height were measured as jump parameters.
Bongiovanni et al. [38] Italy	Male: 16	14.3 ± 1.0	Elite	PhA CMJ	An observational study design was adopted to assess the contribution of whole-body and regional raw bioelectrical BIA parameters on performance in a group of U14 elite soccer players. Athletes underwent whole-body and regional BIA analysis in a fasted state. All players were requested to abstain from using dietary supplements, from drinking caffeinated drinks, and from exercising at moderate-to-high intensity (except during the tests included in the experimental design) before (within 48h) and the day of the study. To assess PhA, a BIA 101 Biva Pro (Akern, Florence, Italy) was used. For CMJ, the Optojump next system (Optojump Next System, Microgate, Bolzano, Italy) was used to indirectly record vertical-jump height for each participant.

Honorato et al. [51] Brazil	Male: 10	30.0 ± 4.5	Elite	PhA CMJ	The present research was a quasi-experimental study delineated to assess the effects of a six-week pre-season period on BIA-derived parameters, body composition components, power, and aerobic abilities in professional soccer players. The Quantum V Segmental BIA® 152 bioimpedance device (RJL Systems®) at a fixed frequency of 50 kHz was used for whole-body 153 and regional BIA measurements.
Cesanelli et al. [13] Italy	Male: 30	26.33 ± 3.61	Amateurs and sub-elite	PhA 1RM	This was a longitudinal study in which data were acquired at a one-year strength and conditioning training program of well-trained cyclists. Pre- and post-values of performance indicators, body mass composition and strength were compared to assess the impacts of the one-year strength programme. The BIA was performed to evaluate body composition using a BIA Akern 101 device (Akern, Florence, Italy).

The studies reported an average age ranging from 13.9 to 58.0 years, with the lowest age being 13 years [45] and the highest being 91 years [36], who, in this case, treats the elderly in his sample with master athletes. As for weight (sample size), only the volleyball group was included for the purposes of our review, considering the study by Di Vincenzo et al. [11]. Some studies aimed to verify the relationship between PhA (WB BIA or parts of the lower/upper limbs) and the strength of upper and lower limbs (e.g., vertical jump, hand grip, isokinetic), whereas in some of the aforementioned studies, they carried out, in their methodologies, dissimilar BIA devices, analyzes between the control group and the intervention group, and also analyzed collectively or individually [16,37,43,45]. One study sought to verify the effects of age on body composition parameters, BIA data, and performance in vertical jump or HGS, and to better understand these effects during the menstrual cycle [39].

1.4.2 Risk of bias in studies

Table 3 described the results of the risk of bias by using Cochrane's RoBANS [19].

Table 3. Risk of Bias (RoBANS).

Study	Selection of participants	Confounding variables	Measurement	Blinding outcome assessment	Incomplete outcome data	Selective outcome reporting
Alvero-Cruz et al. [37]	Low risk	Low risk	Low risk	Low risk	Low risk	High risk
Bongiovanni et al. [50]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear
Campa et al. [40]	Low risk	Low risk	Low risk	Low risk	Low risk	High risk
Cattem et al. [41]	Low risk	High risk	Low risk	Low risk	Unclear	Unclear
Čerňanová et al. [47]	Low risk	High risk	High risk	Low risk	High risk	Unclear
Di Vincenzo et al. [11]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear
Hetherington-Rauth et al. [16]	Low risk	High risk	Low risk	Low risk	Unclear	Unclear
Mala et al. [9]	Low risk	Low risk	Unclear	Low risk	Low risk	Unclear
Martins et al. [43]	Low risk	Low risk	High risk	High risk	Low risk	Unclear
Obayashi et al. [45]	Low risk	High risk	Low risk	Low risk	Unclear	Unclear
Bongiovanni et al. [38]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear
Honorato et al. [51]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear
Cesanelli et al. [13]	Low risk	Low risk	Low risk	Low risk	Low risk	Unclear

Of all 13 studies analyzed, none were considered at overall low risk of bias, that is, 54% were deliberated as unclear and 46% having judgment of high risk of bias in at least one domain. For the selection of participants, all studies were considered at a low risk of bias, while in the case of the study conducted by Di Vincenzo et al. [11], for the purposes of our analysis, we only considered the group of volleyball players. As for confounding variables, nine studies were considered at low risk of bias [9,11,13,37,38,40,43,50,51]; and four studies at high risk of bias [16,41,43,47] for having differences between sex, age, competitive levels, and sport practiced, or else the arbitrary division of analysis of groups and, also, division of analysis groups with sample number too different between groups, with no randomization without even justifying.

Regarding the measurement domain, ten studies were considered at a low risk of bias [11,13,16,37,38,40,41,45,50,51]. In contrast, two studies [43,47] were considered at a high risk of bias, because there were several concerns regarding endurance tests and the long jump was evaluated by a rudimentary method, respectively. As for the study conducted by Mala et al. [9], it is unclear, because there was incomplete information provided for the measurements. As for the blinding evaluation of the result, all studies were considered at a low risk of bias, where, although there was no blinding, the procedures described for the tests denoted that it is unlikely the testers could have influenced the results, except for the study of Martins et al. [43], which was considered as high risk of bias, as there was no blinding that could have interfered with the standing long jump (SLJ) assessment.

For the incomplete outcome data domain, nine studies were considered to be at low risk of bias [9,11,13,37,38,40,43,50,51]. In contrast, three studies [16,41,45] were unclear due to insufficient information to assess, but it is a possibly the base-recruitment was larger than the reported group. Furthermore, the study conducted by Čerňanová et al. [47] was considered to be at high risk of bias, as data from only 21 of the 26 players declared to participate in the study were presented.

Finally, two studies were at high risk in selective outcome reporting [37,40], whereas the other eleven studies [9,11,13,16,38,41,43,45,47,50,51] were unclear as there was no pre-test protocol registered or ethics document available for comparison and evaluation.

1.4.3 Results of individual studies

The results of each study included in this research are presented in Table 4.

Table 4. Results of individual studies.

	Authors of the Study	Type of Study	Aim	Main results and findings
PhA and Lower Limb Strength	Alvero-Cruz et al. [37]	Experimental study composed with 256 master athletes, of these 240 athletes were between 35 and 91 (58.0 ± 12.0 years)	To investigate whether age related effects in body composition could explain the age-related decline in vertical jumping performance in master athletes.	The results obtained demonstrated PhA moderate correlations in males (r = -0.32 to 0.67, p < 0.0001) and larger correlation coefficients in females (r = -0.470 to 0.820, p < 0.0001) with CMJ.
	Bongiovanni et al. [50]	A pilot-longitudinal study design composed with fifteen elite soccer players (28.7 ± 5.0 years) of the first Italian division (Serie A).	To verify the association between changes in lower PhA and CMJ in elite soccer players.	The results were PhA Pre- 7.9°±0.5; Post: 8.0°±0.4; 95% CI: -0.35, 0.09; t: -1.2 and CMJ Pre- 49.5cm±7.8; Post: 50.1± 4.8; 95% IC: -1.63, -0.20; t: -2.7. The major findings were that changes in lower PhA were more strongly related with changes in CMJ (r^2 = 0.617, p = 0.001) than changes in WB PhA (r^2 = 0.270, p = 0.047).
	Bongiovanni et al. [38]	Experimental study used sixteen male elite soccer players (14.3 ± 1.0 years), from the same club competing in the Italian first division.	To examine the association between regional (UPhA and LPhA) and total (WB PhA) PhA with sprint and jump performance in soccer players.	The results showed monitoring regional PhA was more informative than total PhA on sprint and vertical-jump performance in elite young soccer players. This study showed a moderate correlation between PhA and CMJ (r = 0.680; p < 0.001).
	Campa et al. [40]	Experimental study used a total of 20 female soccer players (23.8 ± 3.4 years).	To analyze the fluctuations in body composition and bioelectrical parameters assessed by BIA and CMJ in jumping, running and flexibility abilities of elite soccer players.	The results of PhA (6.7°± 0.6°) in elite soccer players, CMJ (29.4cm±4.1) and sprinting capacity was not affected, whereas flexibility decreased during the early follicular phases. Also showed a moderate correlation between PhA and CMJ (r = 0.568; p = 0.009).

	Honorato et al. [51]	Experimental study that evaluated the effects of a six-week pre-season period on whole-body and regional BIA derived parameters in professional soccer players.	To assess body composition components, neuromuscular and aerobic performance changes in response to the pre-season training period.	The results suggested it is possible to infer the regional BIA-derived parameters, more specifically the hamstrings PhA (M1 = 10.9°±2.3; M2 = 10.8°±2.3; M3 = 11.7°±2.4) was augmented after six-week of pre-season training in athletes. The same was not observed for the WB PhA. This study showed a weak correlation between the PhA and CMJ both for the pre- and post-test time (pre - 0.180 and post - 0.250).
	Martins et al. [43]	Cross-sectorial study that evaluated sixty-two male adolescent players (15.0±1.4 years) from two professional soccer academies of the Brazilian National League (14 were Under-13, 25 were Under-15, and 23 were Under-17).	To verify the association between PhA and components of physical performance in male youth soccer players.	The results verified PhA (U13 =6.1°±0.6; U15 = 5.2°±0.4; U17 = 6.2°± 0.4; F = 26.8; p ≤ 0.01) is associated with 10 m and 30 m sprint times and RSA performance in young male soccer players, regardless of age-related variability and body composition measures. The multiple regression analysis outputs showed that PhA remained inversely related to test 10 m (β = -0.379; p = 0.012), and 30 m (β = -0.438; p < 0.001) sprint times, while the association with standing long jump (SLJ) performance were statistically non-significant.
	Obayashi et al. [45]	Experimental study that included 170 adolescent athletes (13.9±1.6 years) who underwent a sports medical check-up, including body composition and physical performance tests.	To investigate the association between PhA and physical performance in adolescent athletes.	The results were: PhA (6.0°±0.7; W = 0.98; p = 0.04) and CMJ (28.2cm±5.9; W = 0.98; p < 0.01). They concluded that WB PhA correlated with upper and lower limb muscle strength and jump performance in adolescent athletes.
	Cesanelli et al. [13]	Experimental study that analyzed thirty well-trained male (26.33±3.61 years) competitive cyclists (amateurs and sub-elite categories).	To investigate the effect of a combined one-year strength and conditioning training programme on performance indicators, body composition and to determine the possible relationships between these variables	The results (PhA: 6.89°±0.43 and 6.97°±0.46; 1RMtot (kg) 62.85±28.0 and 105.42±47.4) of this study indicated beneficial impacts of one-year combined strength and conditioning training on cycling performance indicators and demonstrated correlation between the performance indicators (athletes' threshold power, body composition and strength), suggestting the possible existence of different adaptation zones. Also showed a very weak correlation between PhA and 1RM (Leg Press) (r = 0.160; p = 0.001).
PhA and Upper Limb Strength	Cattem et al. [41]	Cross-sectorial study that 273 Brazilian healthy adolescents (161 males, 12.9±0.9 years) engaged in different sports were evaluated.	To analyze the efficiency of BIA device (PhA), considering chronological age and HGS in female and male adolescent athletes.	Although PhA is often associated with strength and physical fitness in adult athletes and in male adult and adolescent athletes, the PhA was also associated with HGS in healthy adult men (β = 0.058; p = 0.114).
	Di Vicenzo et al. [11]	Experimental study that twelve volleyball players (23.8±3.6 years) and 22 non-athletic females, who served as a control group (23.6±2.0 years), were evaluated.	To evaluate body composition and segmental PhA for both WB and segmental limbs in twelve elite female volleyball players compared to a group of twenty-two non-athletic controls and to investigate the possible relations between PhA and muscular strength assessed by HGS.	The results obtained for Volleyball players group was WB PhA (6.8°±0.43; p<0.001); HGS (25.4kg±4.3; p = 0.358). They conclude there is a clear relationship between HGS and PhA in athletes (r=0.696, p=0.012).
	Mala et al. [9]	Experimental study that 59 judo athletes (39 boys and 20 girls), all members of the Czech cadet and junior teams, were used.	To investigate the gender differences in body composition, muscle strength in upper limbs, upper and lower limb morphology, and upper limb strength among adolescent judo athletes.	In the non-dominant upper limb, we detected a significant correlation between the PhA and the level of muscle strength (boys: r = 0.64, p<0.01, girls: r = 0.61, p<0.01).

PhA and Lower and Upper Limb Strength	Hetherington-Rauth et al. [16]	Experimental study that 117 adult athletes were recruited from different national clubs in the Lisbon, Portugal.	To examine the associations of muscle strength and power with PhA in national and international level athletes from different sports and to assess if these associations were independent of lean soft tissue (LST).	In the results obtained (PhA - Female = 6.8° ± 0.6, Male = 7.9° ± 0.7, All = 7.3° ± 0.8; HGS - Female = 33.4kg ± 5.0; Male = 49.8kg ± 7.9; All = 41.4kg ± 10.5), the WB PhA was related to both upper (β = 0.86) body strength and lower (β = 0.81) body power.
	Čerňanová et al. [47]	Experimental studied that 21 young male ice hockey players (15-18 y) were used.	To evaluate potential differences in body composition and physical performance between ice hockey players with different training approaches during preseason preparation.	The average of the results (PhA: Colletive = 7.84°±0.31; Individual = 8.84°±0.65, p=0.043; Force of lower limbs: Collective = 1909.70N±175.89; Individual = 2710.77N±261.33, p < 0.001) showed that regarding the athletes who received the collective training approach, both for upper limb power (p=0.809) and for lower limbs (p=0.888), there was a correlation for the PhA variable. As for the athletes who received training in the individual approach, there was a correlation of power in the upper limbs (p=0.911), with no such correlation for the lower limbs in relation to the PhA. The average correlation in the two training approaches (Collective and Individual) between PhA and strength performance parameters were: Upper limb strength (N): r=0.767, p=0.001 and Lower limb strength (N): r=0.726, p=0.002.

1.4.4 Data Synthesis

Considering the reduced number of studies and their heterogeneity, only one meta-analysis could be performed. The results of the meta-analysis that aimed to examine the relationship between PhA and Lower Limb Strength (assessed by CMJ) are described in the Figure 2.

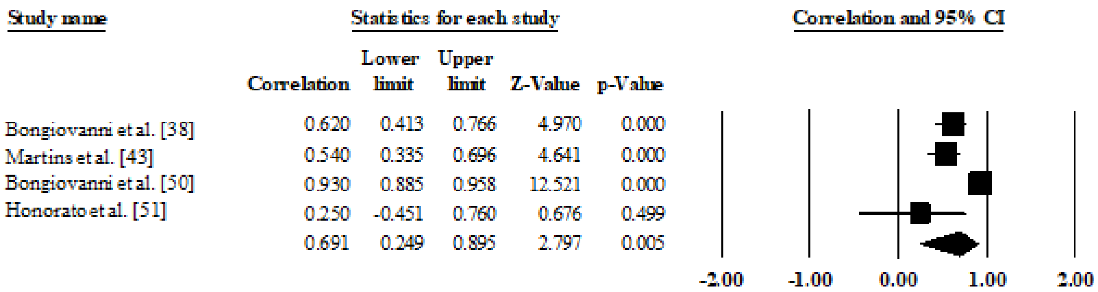

Figure 2. Forest plot outlining the association between CMJ height and PhA. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Black diamond: overall results.

Four studies were considered due to their similarity [38,43,50,51]. The CMJ height was significantly associated with PhA (r = 0.691 [95% CI 0.249 to 0.895], Z = 2.797; p = 0.005). Tests for heterogeneity were identified as significant and high (I2 = 92.7%, Q = 41.3; p < 0.001).

Thus, we observed a positive and significant correlation between PhA and CMJ. However, it was also noticed that one of the studies is a clear outlier, and as such, separate analyses were carried out (excluding one study at time) to examine whether a probable value of I2 could be smaller, as well as the amplitude of the CIs (Figures 3, 4, 5 and 6).

Study name	Statistics for each study				
	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Bongiovanni et al. [38]	0.620	0.413	0.766	4.970	0.000
Bongiovanni et al. [50]	0.930	0.885	0.958	12.521	0.000
Honorato et al. [51]	0.250	-0.451	0.760	0.676	0.499
	0.730	0.136	0.938	2.298	0.022

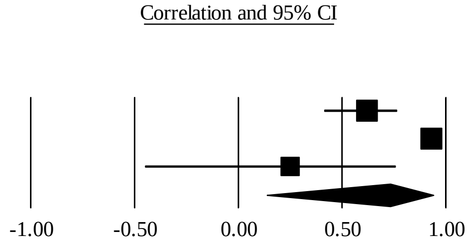

Figure 3. Forest plot describing the association between CMJ height and PhA removing the study of Martins et al. [43]. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Black diamond: overall results.

Study name	Statistics for each study				
	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Martins et al. [43]	0.540	0.335	0.696	4.641	0.000
Bongiovanni et al. [50]	0.930	0.885	0.958	12.521	0.000
Honorato et al. [51]	0.250	-0.451	0.760	0.676	0.499
	0.706	0.023	0.940	2.013	0.044

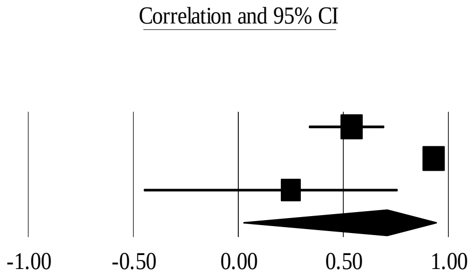

Figure 4. Forest plot describing the association between CMJ height and PhA removing the study of Bongiovanni et al. [38]. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Black diamond: overall results.

Study name	Statistics for each study				
	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Bongiovanni et al. [38]	0.620	0.413	0.766	4.970	0.000
Martins et al. [43]	0.540	0.335	0.696	4.641	0.000
Honorato et al. [51]	0.250	-0.451	0.760	0.676	0.499
	0.560	0.421	0.674	6.727	0.000

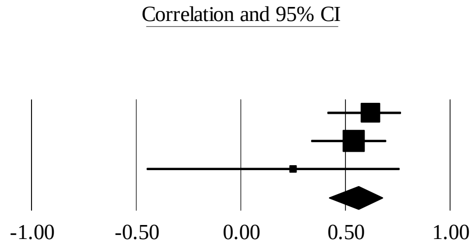

Figure 5. Forest plot describing the association between CMJ height and PhA removing the study of Bongiovanni et al. [50]. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Black diamond: overall results

Study name	Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study				
Bongiovanni et al. [38]	0.620	0.413	0.766	4.970	0.000
Martins et al. [43]	0.540	0.335	0.696	4.641	0.000
Bongiovanni et al. [50]	0.930	0.885	0.958	12.521	0.000
	0.760	0.319	0.931	2.931	0.003

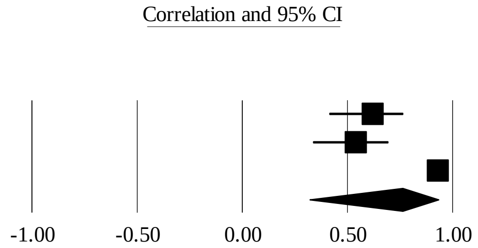

Figure 6. Forest plot describing the association between CMJ height and PhA removing the study of Honorato et al. [51]. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Black diamond: overall results.

The study conducted by Honorato et al. [51] (Figure 6) was removed for analysis because presented a bias in the meta-analysis, with a large CI and not being significant in the relationship between PhA and CMJ. This study appeared to bias the general analysis, since it was a clear outlier in the analysis, as it was not statistically significant, since it had a very large CI.

1.4.5 Certainty of evidence

Indirectness could be considered low for all outcomes, deriving from highly specific eligibility criteria. For the relationship between PhA and upper limb strength, the studies were few and heterogeneous, precluding a pooling of data (i.e., meta-analysis). In addition, there was a reduced number of participants (< 800) and an unclear to high overall risk of bias. Therefore, currently the certainty of evidence should be deemed [53] very low for the relationship between these two outcomes.

Regarding the relationship between PhA and lower limb strength, meta-analytical treatment was possible as four studies had sufficiently similar interventions and outcomes (i.e., CMJ) to pool their data. The reduced number of participants, unclear to high risk of bias in studies, impossibility to assess risk of publication bias (< 10 studies available), and high impact of statistical heterogeneity suggest very low confidence in evidence, despite a clear direction of effects showing a positive association between PhA and lower limb strength as assessed through CMJ.

1.5. DISCUSSION

This systematic review reports a meta-analysis that evaluated the relationship between PhA (assessed by BIA devices) and lower and upper limb strength in athletes of both sexes in different sports. Of the 13 studies selected in this systematic review, it was observed a certain variety of studies that related PhA and strength. Studies were found where the sample was composed of male and female athletes, between 13 and 91 years, as well as several sports (e.g., soccer, volleyball, judo, hockey, cycling) in several countries (Brazil, Portugal, Japan, Spain, Italy, Slovakia, and Czech Republic). Albeit different brands of equipment to perform the BIA test were used in the studies, the equation used to calculate the PhA was always the same [(PhA = arctangent (Xc / R) * (180 / π)]. Moreover, 11 studies presented results that related the PhA with the strength of the upper and lower limbs, while only 2 studies that did not show this correlation, and where a variety of physical tests were used to evaluate the lower limbs (CMJ, SLJ, 1RM, MYOTEST, 10m and 30m sprint times) and upper limbs (HGS and MYOTEST). All this plurality made us better understand the present theme has aroused interest in the international sports science community.

In the nine studies where the relationship between PhA and lower limb strength was verified, eight of them presented positive correlations [13,37,38,43,45,47,50,51] and only 1 study [40] had no correlation. Moreover, five of the abovementioned studies had at least one domain with a high risk of bias and other four demonstrated at least one unclear do-main, as in most domains of these studies there was a low risk of bias. Other strength tests for lower limbs were also used, such as 1RM (squat with barbell and leg press) and MYOTEST, and both showed positive correlations, respectively [13,47].

The four studies analyzed [40,43,50,51] which intended to verify the relationship between PhA and Lower Limb Strength revealed to have a great impact of statistical heterogeneity (I2 = 92.7%) and very wide confidence intervals, as such, everything will contribute to a GRADE the certainty of the evidence being very low. Moreover, one of the abovementioned studies [51] presented a bias in the meta-analysis, with a large CI and not being significant in the relationship between PhA and CMJ.

The relationship between PhA and upper limb strength was verified in four studies, where three of them [9,11,16] presented these positive correlations (moderate and strong) and only one study [41] had no correlation. Probably because these last-mentioned authors reported that PhA was often associated with strength and physical fitness in adult and adolescent athletes, just as PhA was also associated with strength of manual prehension in healthy adult men. Additionally, this study was carried out in an age group with little variation in PhA, therefore the PhA could present a constant behavior in the regression models, and it was not found any significant difference in all the analyses used. Moreover, three of these studies [13,16,45] were considered with at least one domain at high risk of bias and only one [11] was assessed in an unclear domain. However, in most domains of these studies there was a low risk of bias.

1.6. CONCLUSIONS

In summary, the present research found that most studies showed a positive correlation between PhA and CMJ or HGS. The meta-analysis showed the relationship between PhA and lower limbs strength during CMJ. However, little is known, as for the upper limbs it was not possible to perform a meta-analysis and for the lower limbs, we per-formed it with four studies and only with CMJ. Furthermore, GRADE showed very low certainty of evidence. In addition, we detected a high heterogeneity in meta-analysis results.

1.6.1 Other information

This systematic review was registered on the Open Science Framework (OSF) on November 30, 2021, i.e., one day before the initial searches were performed. Link to project: https://osf.io/pmhgq/. Link to registration: https://osf.io/f5vxy.

Author Contributions: Everton Luis Rodrigues Cirillo: research concept and study design, literature review, data collection, data analysis and interpretation; Alberto Pompeo: data collection and data analysis and interpretation; Fabiane Tavares Cirillo: research concept, study design and writing the manuscript, or reviewing/editing a draft of the manuscript; José Vilaça-Alves: research concept and writing the manuscript, or reviewing/editing a draft of the manuscript; Pablo Costa: reviewing/editing a draft of the manuscript; Rodrigo Ramirez-Campillo: data analysis and interpretation and statistical analyses; Antonio Carlos Dourado: research concept and study design and editing a draft of the manuscript; José Afonso Neves: data collection, data analysis and interpretation, statistical analyses and reviewing/editing a draft of the manuscript; Filipe Casanova: research concept and study design, literature review, writing of the manuscript, or reviewing/editing a draft of the manuscript.

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1.7. REFERENCES

1. Lukaski, H. C., Kyle, U. G., & Kondrup, J. Assessment of adult malnutrition and prognosis with bioelectrical impedance analysis: Phase angle and impedance ratio. *Curr. Opin. Clin. Nutr. Metab. Care* (2017), 20(5), 330-339. https://doi.org/10.1097/MCO.0000000000000387

2. Tomeleri, C. M., Cavaglieri, C. R., de Souza, M. F., Cavalcante, E. F., Antunes, M., Nabbuco, H. C. G., Venturini, D., Barbosa, D. C., Silva, A. M., Cyrino, E. S., Phase angle is related with inflammatory and oxidative stress biomarkers in older women. *Exp. Gerontol.* (2018), 102, 12-18. https://doi.org/10.1016/j.exger.2017.11.019

3. Kyle, U. G., Bosaeus, I., De Lorenzo, A. D., Deurenberg, P., Elia, M., Gómez, J. M., Heitmann, B. L., Kent-Smith, L., Melchior, J. C., Pirlich, M., Scharfetter, H., Schols, A. M. W. J., Pichard, C. Bioelectrical impedance analysis - Part I: Review of principles and methods. *Nutrition* (2004), 23(5), 1226-1243. https://doi.org/10.1016/j.clnu.2004.06.004

4. Horie, L. M., Barbosa-Silva, M. C. G., Torrinhas, R. S., de Mello, M. T., Cecconello, I., & Waitzberg, D. L. New body fat prediction equations for severely obese patients. *Clin. Nutr.* (2008), 27(3), 350-356. https://doi.org/10.1016/j.clnu.2008.03.011

5. Ribeiro, A. S., Avelar, A., dos Santos, L., Silva, A. M., Gobbo, L. A., Schoenfeld, B. J., Sardinha, E. S., Cyrino, E. S. Hypertrophy-type resistance training improves phase angle in young adult men and women. *Int. J. Sports Med.* (2017), 38(01), 35-40. https://doi.org/10.1055/s-0042-102788

6. Kyle, U. G., Genton, L., Slosman, D. O., & Pichard, C. Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. *Clin. Nutr.* (2001), 17(7-8), 534-541. https://doi.org/10.1016/s0899-9007(01)00555-x

7. Bosy-Westphal, A., Danielzik, S., Dörhöfer, R. P., Later, W., Wiese, S., & Müller, M. J. Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. *JPEN* (2006), 30(4), 309-316. https://doi.org/10.1177/0148607106030004309

8. Cirillo, E. L. R., Cirillo, F. T., Pompeo, A., Osiecki, R., Avelar, A., Casanova, F., & Dourado, A. C. As relações entre a composição corporal, ângulo de fase da bioimpedância e força em adolescentes atletas paranaenses. *Motricidade* (2023), https://doi.org/10.6063/motricidade.278341

9. Mala, L., Maly, T., Camilleri, R., Dornowski, M., Zahalka, F., Petr, M., Hrasky, P., Bujnovský, D. Gender differences in strength lateral asymmetries, limbs morphology and body composition in adolescent judo athletes. *Arch. Budo* (2017), 13, 377-385.

10. Barbosa-Silva, M. C. G., & Barros, A. J. D. Bioelectric impedance and individual characteristics as prognostic factors for post-operative complications. *Clin. Nutr.* (2005), 24(5), 830-838. https://doi.org/10.1016/j.clnu.2005.05.005

11. Di Vincenzo, O., Marra, M., Sammarco, R., Speranza, E., Cioffi, I., & Scalfi, L. Body composition, segmental bioimpedance phase angle and muscular strength in professional volleyball players compared to a control group. *J. Sports Med. Phys. Fitness* (2020), 60(6), 870-874. https://doi.org/10.23736/S0022-4707.20.10548-6

12. Oliveira, S. D., Oliveira, S. L., Menezes, R. K., Miranda, L. G., Pedrosa, H. C., & Prestes, J. Análise da força de preensão manual e risco cardiovascular de adolescentes com diabetes melitos tipo 1. *Rev. Bras. Ciên. Mov.* (2016), 24(2), 5-14.

13. Cesanelli, L., Ammar, A., Arede, J., Calleja-González, J., & Leite, N. Performance indicators and functional adaptive windows in competitive cyclists: Effect of one-year strength and conditioning training programme. *Biol. Sport* (2021), 39(2), 329-340. https://doi.org/10.5114/biolsport.2022.105334

14. Moura, P. M. d. L. S., Moreira, D., & Caixeta, A. P. L. Força de preensão palmar em crianças e adolescentes saudáveis. *Rev. Paulis. Pediat.* (2008), 26, 290-294.

15. Di Vincenzo, O., Marra, M., Di Gregorio, A., Caldara, A., De Lorenzo, A., & Scalfi, L. Body composition and physical fitness in elite water polo athletes. In Proceedings of the 7th In Proceedings of the 7th International Conference on Sport Sciences Research and Technology Support icSPORTS, Vienna Austria, (20-21/09/2019), (pp. 157-160). *Science and Technology Publications*, Lda. https://doi.org/10.5220/0008161401570160

16. Hetherington-Rauth, M., Leu, C. G., Júdice, P. B., Correia, I. R., Magalhães, J. P., & Sardinha, L. B. Whole body and regional phase angle as indicators of muscular performance in athletes. *Eur. J. Sport. Sci.* (2021), 1-9. https://doi.org/10.1080/17461391.2020.1858971

17. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C.,

Welch, V. A., Whiting, P., Moher, D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* (2021), 372, 71. https://doi.org/10.1136/bmj.n71

18. Higgins, T., Chandler, C., Li, P., & Welch. Cochrane handbook for systematic reviews of interventions. John Wiley & Sons (2019).

19. Park, J., Lee, Y., Seo, H., Jang, B., Son, H., Kim, S., Shin, S., Hahn S. Risk of bias assessment tool for non-randomized studies (RoBANS): development and validation of a new instrument. *In Abstracts of the 19th Cochrane Colloquium* (2011), (pp. 19-22). Madrid, Spain. John Wiley & Sons.

20. García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. *Sports Med.* (2019), 49(7), 1079-1094. https://doi.org/10.1007/s40279-019-01098-6.

21. Skrede, T., Steene-Johannessen, J., Anderssen, S. A., Resaland, G. K., & Ekelund, U. The prospective association between objectively measured sedentary time, moderate-to-vigorous physical activity and cardiometabolic risk factors in youth: a systematic review and meta-analysis. *Obes. Rev.* (2019), 20(1), 55-74. https://doi.org/10.1111/obr.12758

22. Abt, G., Boreham, C., Davison, G., Jackson, R., Nevill, A., Wallace, E., & Williams, M. Power, precision, and sample size estimation in sport and exercise science research. *J. Sports Sci.* (2020), 38(17), 1933-1935. https://doi.org/10.1080/02640414.2020.1776002

23. Lohse, K. R., Sainani, K. L., Taylor, J. A., Butson, M. L., Knight, E. J., & Vickers, A. J. Systematic review of the use of "magnitude-based inference" in sports science and medicine. *PloS One* (2020), 15(6), e0235318. https://doi.org/10.1371/journal.pone.0235318

24. Deeks, J. J., Higgins, J. P., & Altman, D. G. Analysing data and undertaking meta-analyses. In J. P. Higgins & S. Green (Eds.), Cochrane Handbook for Systematic Reviews of Interventions: *The Cochrane Collaboration* (2008), (pp. 243-296). https://doi.org/https://doi.org/10.1002/9780470712184.ch9

25. Hardy, R. J., & Thompson, S. G. A likelihood approach to meta-analysis with random effects. *Stat. Med.* (1996), 15(6), 619-629.

26. Kontopantelis, E., Springate, D. A., & Reeves, D. A re-analysis of the Cochrane Library data: the dangers of unobserved heterogeneity in meta-analyses. *PloS One* (2013), 8(7), e69930. https://doi.org/10.1371/journal.pone.0069930

27. Cohen, J. Statistical power analysis for the behavioural sciences (2nd edn). Hillsdale, NJ: Lawrence Earlbaum Associates (1988), *Publishers.*

28. Higgins, J. P., & Thompson, S. G. Quantifying heterogeneity in a meta-analysis. *Stat. Med.* (2002), 1539-1558. https://doi.org/doi:10.1002/sim.1186

29. Guyatt, G. H., Oxman, A. D., Akl, E. A., Kunz, R., Vist, G., Brozek, J., Norris, S., Falk-Ytter, Y., Glasziou, P., DeBeer, H., Jaeschke, R., Rind, D., Meerpohl, J., Dahm, P., Schünemann, H. J. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J. Clin. Epidemiol.* (2011), 64(4), 383-394. https://doi.org/10.1016/j.jclinepi.2010.04.026

30. Schünemann, H. J., Mustafa, R. A., Brozek, J., Steingart, K. R., Leeflang, M., Murad, M. H., Bossuyt, P., Glasziou, P., Jaeschke, R., Lange, S., Meerpohl, J., Langendam, M., Hultcrantz, M., Vist, G. E., Akl, E. A., Helfand, M., Santesso, N., Hooft, L., Scholten, R., Roses, M., Rutjes, A., Crowther, M., Muti, P., Raatz, H., Ansari, M. T., Williams, J., Kunz, R., Harris, J., Rodriguez, I. A., Kohli, M., Guyatt, G. H. GRADE guidelines: 21 part 1. Study design, risk of bias, and indirectness in rating the certainty across a body of evidence for test accuracy. *J. Clin. Epidemiol.* (2020a), 122, 129-141. https://doi.org/10.1016/j.jclinepi.2019.12.020

31. Schünemann, H. J., Mustafa, R. A., Brozek, J., Steingart, K. R., Leeflang, M., Murad, M. H., Bossuyt, P., Glasziou, P., Jaeschke, R., Lange, S., Meerpohl, J., Langendam, M., Hultcrantz, M., Vist, G. E., Akl, E. A., Helfand, M., Santesso, N., Hooft, L., Scholten, R., Rosen, M., Rutjes, A., Crowther, M., Muti, P., Raatz, H., Ansari, M. T., Williams, J., Kunz, R., Harris, J., Rodriguez, I. A., Kohlo, M., Guyatt, G. H. GRADE guidelines: 21 part 2. Test accuracy: inconsistency, imprecision, publication bias, and other domains for rating the certainty of evidence and presenting it in evidence profiles and summary of findings tables. *J. Clin. Epidemiol.* (2020b), 122, 142-152. https://doi.org/10.1016/j.jclinepi.2019.12.021

32. Ballarin, G., Monfrecola, F., Alicante, P., Chierchia, R., Marra, M., Sacco, A. M., & Scalfi, L. Raw Bioelectrical Impedance Analysis Variables (Impedance Ratio and Phase Angle) and Physical Fitness in Cross-Fit® Athletes. In Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support icSPORTS (2021), Online Streaming, (pp. 103-108). *Science and Technology Publications*, Lda 28-29/10/2021. https://doi.org/10.5220/0010066001030108

33. Ballarin, G., Monfrecola, F., Alicante, P., Di Gregorio, A., Marra, M., Sacco, A. M., & Scalfi, L. Raw bioelectrical impedance analysis (BIA) variables and physical fitness in semi-professional basketball players. In Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support icSPORTS (2021), Online Streaming, (pp. 133-138). *Science and Technology Publications*, Lda 28-29/10/2021. https://doi.org/10.5220/0010066101330138

34. Di Vincenzo, O., Marra, M., & Scalfi, L. Bioelectrical impedance phase angle in sport: A systematic review. *J. Int. Soc. Sports Nutr.* (2019), 16(1), 1. https://doi.org/10.1186/s12970-019-0319-2

35. Di Vincenzo, O., Marra, M., Morlino, D., Speranza, E., Sammarco, R., Cioffi, I., & Scalfi, L. Relationship between handgrip strength, anthropometric and body composition variables in different athletes. In Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support icSPORTS (2021), Online Streaming, (pp. 148-151). *Science and Technology Publications*, Lda 28-29/10/2021. https://doi.org/10.5220/0010110401480151

36. Aksenov, M. O., & Aksenova, A. V. Weight lifter training process organization based on bioimpedance analysis data. Teor. *Prakt. Fiz. Kult* (2015), (12), 74-76. https://www.teoriya.ru/en/node/6914

37. Alvero-Cruz, J. R., Brikis, M., Chilibeck, P., Frings-Meuthen, P., Vico Guzmán, J. F., Mittag, U., Michely, S., Mulder, E., Tanaka, H., Tank, J., Rittweger, J. Age-related decline in vertical jumping performance in masters track and field athletes: Concomitant influence of body composition. *Front. Physiol.* (2021), 12, 643649. https://doi.org/10.3389/fphys.2021.643649

38. Bongiovanni, T., Trecroci, A., Rossi, A., Iaia, F. M., Pasta, G., & Campa, F. Association between change in regional phase angle and jump performance: a pilot study in serie a soccer players. *Eur. J. Investig. Health Psychol. Educ*. (2021), 11(3), 860-865. https://doi.org/10.3390/ejihpe11030063

39. Bunc, V., Hráský, P., & Skalská, M. Changes in body composition, during the season, in highly trained soccer players. *Open Sports Sci. J.* (2015), 8(1), 18-24. https://doi.org/10.2174/1875399×01508010018

40. Campa, F., Micheli, M., Pompignoli, M., Cannataro, R., Gulisano, M., Toselli, S., Greco, G., Coratella, G. The influence of menstrual cycle on bioimpedance vector patterns, performance, and flexibility in elite soccer players. *Int. J. Sports Physiol. Perform*. (2021), 1-9. https://doi.org/10.1123/ijspp.2021-0135

41. Cattem, M. V. O., Sinforoso, B. T., Campa, F., & Koury, J. C. Bioimpedance vector patterns according to age and handgrip strength in adolescent male and female athletes. *Int. J. Environ. Res. Public Health* (2021), 18(11), Article 6069. https://doi.org/10.3390/ijerph18116069

42. Lawson, S.T, Gardner, J. C., Carnot, M. J., Lackey, S. S., Lopez, N.V., & Sutliffe, J.T. Assessing the Outcomes of a Brief Nutrition Education Intervention Among Division I Football Student-Athletes at Moderate Altitude. *The Sport Journal* (2020), 62

43. Martins, P. C., Teixeira, A. S., Guglielmo, A. L. G., Francisco, J. S., Silva, D. A. S., Nakamura, F. Y., & de Lima, L. R. A. Phase angle is related to 10 m and 30 m sprint time and repeated-sprint ability in young male soccer players. *Int. J. Environ. Res. Public Health.* (2021), 18(9), 4405. https://doi.org/10.3390/ijerph18094405

44. Micheli, M. L., Gulisano, M., Morucci, G., Punzi, T., Ruggiero, M., Ceroti, M., Marela, M., Castellini, E., Pacini, S. Angiotensin-converting enzyme/vitamin D receptor gene polymorphisms and bioelectrical impedance analysis in predicting athletic performances of Italian young soccer players. *J. Strength Cond.* (2011), 25(8), 2084-2091. https://doi.org/10.1519/JSC.0b013e31820238aa

45. Obayashi, H., Ikuta, Y., Fujishita, H., Fukuhara, K., Sakamitsu, T., Ushio, K., Kimura, H., Adachi, N. The relevance of whole or segmental body bioelectrical impedance phase angle and physical performance in adolescent athletes. *Physiol. Meas.* (2021), 42(3). https://doi.org/10.1088/1361-6579/abed35

46. Ojeda-Aravena, A., Herrera-Valenzuela, T., Valdés-Badilla, P., Cancino-López, J., Zapata-Bastias, J., & García-García, J. M. Effects of 4 weeks of a technique-specific protocol

with high-intensity intervals on general and specific physical fitness in taekwondo athletes: An inter-individual analysis. *Int. J. Environ. Res. Public Health.* (2021), 18(7), 3643. https://doi.org/10.3390/ijerph18073643

47. Čerňanová, V. C., Čerňan, J., Danková, Z., & Siváková, D. Body composition and physical performance of slovak ice hockey players with different training approach during pre-season preparation. *Anthropol. Rev.* (2018), 81(4), 379-392. https://doi.org/10.2478/anre-2018-0033

48. Mielgo-Ayuso, J., Zourdos, M. C., Calleja-González, J., Urdampilleta, A., & Ostojic, S. M. Dietary intake habits and controlled training on body composition and strength in elite female volleyball players during the season. *Appl. Physiol. Nutr. Metab.* (2015), 40(8), 827-834. https://doi.org/10.1139/apnm-2015-0100

49. Coratella, G., Beato, M., Milanese, C., Longo, S., Limonta, E., Rampichini, S., Ce, E., Bisconti, A. V., Shena, F., Esposito, F. Specific adaptations in performance and muscle architecture after weighted jump-squat vs. Body mass squat jump training in recreational soccer players. *J. Strength Cond.* (2018), 32(4), 921-929. https://doi.org/10.1519/jsc.0000000000002463

50. Bongiovanni, T., Rossi, A., Trecroci, A., Martera, G., Iaia, F. M., Alberti, G., Pasta, G., Lacome, M. Regional bioelectrical phase angle is more informative than whole-body phase angle for monitoring neuromuscular performance: A Pilot Study in Elite Young Soccer Players. *Sports* (2022), 10(5), 10.3390. https://doi.org/10.3390/sports10050066

51. Honorato, R. C., Soares, M. F. A., Kassiano, W., Martins, P. C., Silva, D. A. S., & Ceccatto, V. M. Regional phase angle, not whole-body, is augmented in response to pre-season in professional soccer players. Res *Sports Med.* (2022), 1-15. https://doi.org/10.1080/15438627.2022.2052069

52. Lijewski, M., Burdukiewicz, A., Pietraszewska, J., Andrzejewska, J., & Stachon, A. (2021). Asymmetry of muscle mass distribution and grip strength in professional handball players. *Int. J. Environ. Res. Public Health*, 18(4), Article 1913. https://doi.org/10.3390/ijerph18041913

CAPÍTULO II

ESTUDO II

The influence of team invasion sports' participation in the phase angle of youth athletes.

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Estudo II

The influence of team invasion sports' participation in the phase angle of youth athletes *(International Journal of Social Science and Human Research, 6(7), 4373-4381. https://doi.org/ 10.47191/IJSSHR)*

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2.1 ABSTRACT

Team invasion sports are characterized as ball games, played by two opponents, aiming to score points or goals. The aim intended to verify which team invasion sport presents a greater probability to obtain a higher phase angle (PhA) value, considering the age, time of practice, vertical jump tests and handgrip strength of young athletes. A total of 248 young athletes were evaluated. After performing the correlations between the PhA and categorical variables (sport and sex) and covariables (age, time of practice- t, squat jump- SJ, countermovement jump- CMJ, and handgrip strength left or right- HGSl or HGSr), we developed an equation from a logistic regression model, aiming to better interpret the probability to obtain a higher PhA. Our findings showed a significant correlation ($p < 0.05$) ranging from weak to moderate between the PhA and age ($r = 0.268$), t ($r = 0.206$), SJ ($r = 0.330$), CMJ ($r = 0.277$), HGSr ($r = 0.537$), and HGSl ($r = 0.523$). Considering the median value of the PhA (7.7º) as a cut-off point, youth soccer players were the most likely to have 2.2 more chances to reach a higher PhA, followed by Futsal (2.13), and Rugby (2.01) players. Considering our equation, we suggested that higher PhA values predisposed the Soccer, Futsal and Rugby players to express greater jumping capacity or handgrip tests. Considering the advantage of using PhA as a marker of a healthy body composition profile, the magnitude of these probabilities to reach higher values of strength performance in young athletes may depend on the sport practiced and their exposure to specific training.

Keywords: Sport Participation; Body Composition; Strength; Performance

2.2 INTRODUCTION

Team invasion sports are characterized by ball games played with two opponents, where their aim is scoring points or goals, while trying to prevent the opponent from invading their own space and scoring [1]. There are several team invasion sports, including those where the ball is thrown into a net (e.g. basketball or netball) or the ball is hit with the foot or a bat into a goal (e.g. Soccer, Australian Football, Field Hockey), or the ball is carried across a line (e.g. American Football, Rugby) [1].

These sports present frequent changes in the playing situation, imposing a high degree of unpredictability, where behaviors and actions are subject to randomness and variability, demanding a great adaptative ability from the practitioner [2]. Improvements in the performance of athletes in these sports depends, to a large extent, on the ability of technical committees to select and organize training methods and contents that are related to the competitive practice of a given modality [3].

Therefore, the practice of exercises has also been associated with the development of bone and muscle tissue, where fat-free mass is considered a predictor of muscle capacity to promote tension and physical abilities [4], in which body composition assessments and strength tests can help to verify the effects of physical activity and sports practice over time [4]. Moreover, the measurement of muscle strength has been used to optimize the results of athletes in competitions and to assess muscle balance in athletes, where the measurement of muscle strength can be performed by using methods requesting different types of contraction, such as: isometric (HGS), isokinetic and isotonic (CMJ and SJ) [5].

The capacity to express muscle dynamic power and maximal isometric force is widely recognized as an important component in the physical performance of young athletes, and it positively impacts sports' performance, daily activities, quality of life, growth, motor development, bone mineral density, and muscle mass development [4, 6, 7]. The evaluation of muscle strength expressions is therefore essential, whether for upper limbs (e.g., handgrip tests, 1 repetition maximum- RM), or lower limbs (e.g., vertical jump tests, 1 RM), and the information obtained from them is very useful to periodize the training programs for this population [4, 8, 9].

The phase angle (PhA) is obtained through the relationship between Resistance (R) and Reactance (Xc) measurements, using the bioelectrical impedance test (BIA). The PhA is equivalent to a direct measure of cell stability, which reflects the disposition of water in the intra and extracellular media [10]. Its values are proposed as an indirect indicator of functional muscle mass and muscle strength [11], as well as a muscle fitness index, expressing both the quantity and quality of soft tissue [12], and is being a strong predictor of total skeletal muscle participation and limb muscle mass [13]. For example, Hetherington-Rauth et al. [11] observed that regional measures of lower limb PhA explained a similar variation in muscle power compared to whole body (WB) PhA in athletes from different sports. Factors such as age, body mass index, and sex are primary determinants of PhA [14, 15], with values in healthy individuals varying from 5º to 7.5º [9, 14, 16, 17], while in trained athletes values can reach 8.5º [9, 18].

In addition, scientific evidence has shown a relationship between PhA and upper limb (handgrip strength: HGS) and lower limb strength tests (Squat jump: SJ, and countermovement jump test: CMJ) [19, 20, 21, 22]. There seems to be a consensus that PhA can be used to monitor physical condition and sports performance in adolescent athletes, and could be crucial to assess body composition in athletes, providing useful data on percentage of body cell mass and fat free mass [23].

Moreover, Koury et al. [24] verified the association of body composition, skeletal maturity and zinc biochemical indexes with PhA and BIA parameters, in 40 male adolescent soccer athletes (13.4 ± 0.6 years), since PhA values was significantly higher in adolescents classified by bone age as "Early" (6.8 ± 0.9°) compared to "Late" (5.7º ± 0.5).

However, it still seems uncertain to what level the PhA differs between several sports, and while the results are promising, large cross-sectional studies and, possibly, longitudinal studies are needed to confirm that the current use of BIA is valuable in assessing muscle quality, and in evaluating differences due to gender, training volume, and playing position, among others [18].

As far as we know, no studies have verified the viability to discriminate young team invasion sports participation accordingly to their PhA.

In view of the existence of similar particularities between the practice of team invasion sports and the information above, the aim of the present study intended to verify which team invasion sport (i.e., Basketball, Football, Futsal, Handball and Rugby) presents a greater probability to obtain a higher PhA value, considering the age, time of practice (t), vertical jump tests (CMJ and SJ) and handgrip strength (HGS) of young athletes. We hypothesized that sports with more contact could be more likely to obtain higher PhA value than those with less physical contact.

2.3 METHODS

2.3.1 Study design

A cross-sectional observational study design was adopted to perform full body BIA and vertical jump tests (i.e., CMJ and SJ) and handgrip strength tests (HGS) in athletes practicing team invasion sports (i.e., Basketball, Soccer, Futsal, Handball, and Rugby). Assessments were carried out during the season phase of the Paraná Youth Games, particularly during September of 2019. Athletes underwent full-body BIA analysis (in a fasted state for 4 hours) for PhA verification, in addition to motor testing of CMJ, SJ, and HGS (on both hands: Left and Right).

2.3.2 Participants

Two hundred and forty-eight Brazilian adolescent athletes (male = 152, 16.8±1.0 years; female = 96, 16.2±1.2 years) were recruited to participate in this study. Of these athletes, 28 practice Basketball (male = 15; female = 13), 14 Soccer (male = 14), 64 Futsal (male = 54; female = 10), 127 Handball (male = 60; female = 67), and 15 Rugby (male = 9; female = 6).

We performed the sample calculation using G*Power, version 3.1.9.7(Dusseldorf, Germany), considering Z tests, suitable for calculating the effect size within a logistic regression model, was used to calculate sample size and a minimum of 221 players were required (α=0.05 and β=0.95), which resulted in the appropriate sample size for carrying out this study [25]. The sample characteristics, organized by sport and sex, are presented in Table1.

Table 1. Mean (± SD) values obtained from the athletes (n) by sport, sex (male: M; female: F), age (y), weight (W; Kg), height (H; cm), body mass Index (BMI; Kg/m^2), and time of practice per years (t; years).

	Basketball		Soccer		Futsal		Handball		Rugby	
Sex	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
N	15	13	14	-	54	10	60	67	9	6
Age	16.7±1.1	16.4±1.4	16.6±1.2	-	17.3±0.9	16.7±0.8	16.5±0.9	16.2±1.2	16.9±0.8	15.2±1.5
W	77.9±10.2	69.7±16	66.2±8.5	-	70.3±9.1	57.7±8.2	72.9±10.1	63.1±9.6	79.5±15.1	55.5±5.9
H	180±1	170±1	170±1	-	170±1	160±0	180±1	170±1	180±1	160±1
BMI	23.5±2.8	24.1±3.5	22.3±2.2	-	23.5±2.7	23.7±3.4	23.4±2.9	23.0±3.3	25.6±3.6	23.1±2.2
t	4.4±2.7	5.6±2.2	8.3±2.6	-	9.6±2.2	7.1±1.9	5.1±2.3	5.3±1.9	3.0±2.4	2.2±2.4

2.3.3 Inclusion and Exclusion Criteria

Inclusion criteria were: (i) athletes who participated in all tests and (ii) being an active participant in the included competition. The exclusion criteria were: (i) refusal to participate in data collection; (ii) non-authorization of parents or guardians; and (iii) any physical problem that temporarily or permanently prevented the athlete from carrying out any of the measures.

After being fully informed about the experimental procedures, aims, and potential risks of the study, all participants and their parents/guardians provided written consent prior to starting the study. As there were a large number of athletes under the age of 18y, this term was signed by the coach responsible for the team. According to the Declaration of Helsinki, the study was approved by the Ethics Committee of the lead institution (protocol number S2121). We also received authorization through a consent form from the institution that is responsible for organizing the event, allowing the collection of data.

The tests were carried out in the following order, so that the effort of a test did not influence the result of the next assessment: 1) Brief questionnaire; 2) Weight and height; 3) BIA; 4) Manual grip on the dynamometer; 5) Vertical Jump.

2.3.4 Testing Procedures

2.3.4.1 Body composition and Bioelectrical Impedance analysis:

Before performing the BIA and body composition test, height and body mass were recorded to the nearest 0.1 cm and 0.1 kg, respectively, using a stadiometer (Cardiomed Model Avanutri, Ref. 5130332, Rio de Janeiro, Brazil) and a high-precision digital scale (Cristal Seven Plenna, Ref. SIM00530, São Paulo, Brazil), respectively.

For body composition, WB BIA parameters of R, Xc, PhA, fat mass, lean mass, intra- and extracellular mass, total body water, intra- and extracellular water, and basal energy metabolism were obtained using a BIA (Biodynamics model 450, version 5.1, BiodynamicsR, Corp. Seattle, WA, USA) and Resting Tab ECG electrodes (Conmed R Corporation, Utica, NY, USA). This device provided the all the body parameters through the flow of an alternating current of low frequency and high voltage (800 mA and 50 kHz) and the accuracy was 0.1% in R, 0.2% in Xc and 0.2% in PhA.

The athletes were positioned in a comfortable supine position, without the use of metal objects (e.g., watches, bracelets, and earrings), without shoes, with the legs open at 45º in relation to the midline of the body and with the upper limbs positioned at 30º from the trunk. After cleaning the skin with pads soaked in alcohol, four adhesive electrodes were positioned in the recommended locations, namely: one electrode on the dorsal surface of the right wrist, one on the third metacarpal, one on the anterior surface of the right ankle between the prominent portions of the bones, and the last electrode on the dorsal surface of the third metatarsal. In order to minimize possible interference in the results, some recommendations were followed, such as: not drinking alcoholic beverages and diuretics and fasting for at least four hours.

The device allows the inclusion of information on age, sex, height, weight of the individual, and weekly training hours, and provides results in less than 1 min.

2.3.4.2 Handgrip Strength:

In the handgrip strength test (HGS), the athlete sat on a chair, holding a North Coast Medical dynamometer (Precision Instruments, Morgan Hill, California, USA), with their elbows at 90º. The power grip involved holding the object between partially flexed fingers, as opposed to the counter pressure generated by the palm, the thenar eminence, and distal segment of the thumb [26]. Each athlete prformed three attempts with the right hand (HGSr) and 3 attempts with the left hand (HGSl), alternately, with the greatest possible force, and the highest value in kg/f was recorded.

2.3.4.3 Vertical Jump Tests:

For the vertical jump tests, the CMJ and SJ were used [27] and the system for measuring and analyzing vertical jumps through opto-electronic sensors from the Sys Jump brand (Sys Jump, Systware, Miami, USA). Starting from half-flexion of the knees, the SJ involved the athlete remaining on the jumping area, in the position of half squat, with hands resting on the waist and knees at a 90º, for at least 5 seconds. The evaluator then gave a verbal signal for the athlete to perform the jump as high as possible without removing their hands from the waist, and without retracting the feet or throwing them forward. In the CMJ, the athlete was positioned on the jumping area in a standing position, hands resting on the waist and legs extended. After the evaluator's verbal command, the athlete performed a quick squat and then a jumped as high as possible, without removing their hands from their waist, and without retracting the feet or throwing them forward. Three attempts were performed at both vertical jump tests, with a five-second interval between them, and the best result was recorded in cm.

2.3.5 Statistical Procedures:

The distribution of data sets was analyzed using Kolmogorov-Smirnov tests. A Spearman correlation (r) analysis was performed, subsequently those variables who will show a significant correlation with PhA a binary logistic regression analysis [28] was used to verify the probabilities of an athlete practicing a team invasion sport reaching a PhA value greater than the median of all the sample. Instead of using the mean PhA value, we used the median value as cut-off point to avoid the influence of possible outliers. Furthermore, and in accordance with the proposed aims, an adjusted logistic model was defined by the equation below:

$$P(Af = 1|m_a, s_b, age, t, sj, cmj, hgsr, hgsl) =$$

$$\frac{e^{\beta_0 + \beta_1 m_a + \beta_2 s_b + \beta_3 age + \beta_4 t + \beta_5 sj + \beta_6 cmj + \beta_7 hgsr + \beta_8 hgsl}}{1 + e^{\beta_0 + \beta_1 m_a + \beta_2 s_b + \beta_3 age + \beta_4 t + \beta_5 sj + \beta_6 cmj + \beta_7 hgsr + \beta_{8hgsl}}} + \varepsilon$$

This model allowed us the interpretation of the probability of an individual presenting a PhA equal to or greater than the median value, based on the specifications for each covariate, represented respectively by ma (a = 1,....,5), as a categorical variable, which sequentially indexes the sports: Basketball (a = 1), Soccer (a = 2), Futsal (a = 3), Handball (a = 4), and Rugby (a = 5). The sex variable was defined by s=1 (male) and s=2 (female).

The other covariables follow continuous and discrete values, mentioning age, t, SJ, CMJ, HGSr, and HGSl. Finally, the term ε represents the random error on a continuous scale. For each term of the model, the parameter $\beta 0$ corresponding to the intercept was associated to give numerical restrictions. The first level of each factor of the categorical variables m and s are confounded and βu (u=1, ...,8) represents the parameters associated with the other covariates.

Validation of the goodness of fit of this model was determined using the simulated envelope technique, whose graph represents the quantiles obtained as a function of the deviation components and associated with a normal distribution. Thus, with the imposition of confidence bands, this adjustment was considered adequate, as the quantiles were in a position within the margins obtained through the simulation [29]. The collected information was organized and analyzed in a database in "R" statistics software. The alpha level for significance was set at $p < 0.05$.

2.4 RESULTS

The data obtained for the PhA and all other variables used in our research are presented in Table 2.

It was observed a similar PhA values of Basketball (M = 8.1º ± 0.8; F = 7.2º ± 0.6); Soccer (M = 8.1º ± 0.8); Futsal (M = 8.3º ± 1.2; F = 6.8º ± 0.4); Handball (M = 8.1º ± 0.6; F = 7.2º ± 0.6) and Rugby players (M = 7.7º ± 0.4; F = 7.4º ± 0.6).

Table 2. Mean (±SD) values obtained from all athletes, organized by sport, sex (male- M; female-F), phase angle (PhA; º), squat jump (SJ; cm), countermovement jump (CMJ; cm), handgrip strength right (HGSr; Kg/f), and handgrip strength left (HGSl; Kg/f).

	Basketball		**Soccer**		**Futsal**		**Handball**		**Rugby**	
Sex	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
N	15	13	14	-	54	10	60	67	9	6
PhA	8.1 ± 0.8	7.2 ± 0.6	8.1 ± 0.8	-	8.3 ± 1.2	6.8 ± 0.4	8.1 ± 0.6	7.2 ± 0.6	7.7 ± 0.4	7.4 ± 0.6
SJ	39.3 ± 5.4	31.7 ± 8.2	38.1 ± 6.3	-	37.2 ± 6.5	29.4 ± 6.2	38.9 ± 6.0	33.9 ± 7.9	35.9 ± 4.3	30.0 ± 3.6
CMJ	45.0 ± 6.2	33.5 ± 7.3	46.2 ± 9.2	-	42.8 ± 7.0	36.6 ± 9.2	45.3 ± 7.2	37.1 ± 10.2	42.1 ± 7.3	33.3 ± 2.7
HGSr	43.6 ± 7.8	26.6 ± 5.4	36.3 ± 8.9	-	34.4 ± 7.1	24.5 ± 4.1	40.5 ± 9.4	28.4 ± 5.4	43.1 ± 11.5	26.7 ± 4.5
HGSl	39.1 ± 6.5	25.1 ± 4.7	31.0 ± 7.5	-	30.9 ± 6.7	23.3 ± 3.9	35.8 ± 9.1	24.9 ± 5.5	41.1 ± 11.8	25.7 ± 5.3

The age, t, SJ, CMJ, HGSr, and HGSl, showed a significant correlation with PhA, ranging from weak to moderate (r = 0.268; r = 0.206; r = 0.330; r = 0.277; r = 0.537; r = 0.523), respectively (Table 3).

Table 3. Correlation values obtained between the phase angle (PhA; º) and age (y), time of practice (t), squat jump (SJ; cm), counter movimet jump (CMJ; cm), hangrip strength right (HGSr; Kg/f), and hangrip strength left (HGSl; Kg/f).

		Age	**t**	**SJ**	**CMJ**	**HGSr**	**HGSl**
PhA	R	268**	206**	330**	277**	537**	523**
	P	0.00	0.01	0.00	0.00	0.00	0.00

** The correlation is significant at 0.01.

The median PhA value stablished as the cut-off point was 7.7º (Table 4). Additionally, it was established the value of 1 (which represents success) to athletes who obtained PhA values equal to or greater than 7.7º, and value of 0 (which represents failure) to those who obtained PhA values lower than the median.

Table 4. Values of central tendency values obtained of the phase angle (PhA; º).

Statistical Variables	Value
Mean	7.8
Standard deviation	0.9
Minimum	6.0
Maximum	16.0
Median	7.7
Mode	7.5

The PhA mean value obtained were 7.8º ± 0.9, the smallest value measured of PhA was 6.0º and the largest was 16º, the median was 7.7º and the mode 7.5. Moreover, we detected an outlier (PhA value = 16º), which is not very common. The parameters estimated by the proposed logistic model are presented in Table 5.

All the parameters with a p-value greater than 5% had the same importance in relation to the predictive power of the model. These results did not make the model unfeasible, by the opposite, these results make perfect sense. Given the parameter estimates, it can be seen from the simulated envelope graph (Figure 1) that the quantiles of the normal distribution, considering the deviation component, were within the confidence bands generated by Monte Carlo simulation [29]. Thus, the model proposed provides a predictive power of probabilities considered adequate.

Table 5. Parameters values estimated by the logistic model and its significance.

Parameters	Estimates	P
(Intercept) $\beta 0$	-5.60257	0.0371
m_2 ($\beta_{1a=2}$)	0.24538	0.7899
m_3 ($\beta_{1a=3}$)	-0.21310	0.7564
m_4 ($\beta_{1a=4}$)	-0.30063	0.5774
m_5 ($\beta_{1a=5}$)	-0.33232	0.6988
se_1 ($\beta_{2b=1}$)	1.80642	0.0004
age (β_3)	0.10726	0.5037
t (β_4)	0.04147	0.5782
sj (β_5)	0.04780	0.1802
cmj (β_6)	-0.03288	0.2542
hgsd (β_7)	0.01380	0.7013
hgsl (β_8)	0.06769	0.0823

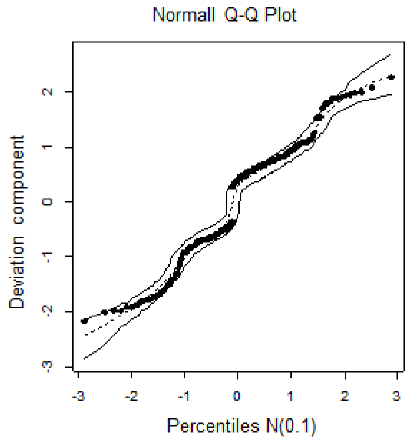

Figure 1. Simulated envelope to verify the adequacy of the logistic model.

Moreover, with the probabilities obtained by adjusting the model, the discrimination of the PhA in relation to sports and age of the practitioners are illustrated in Figures 2-6.

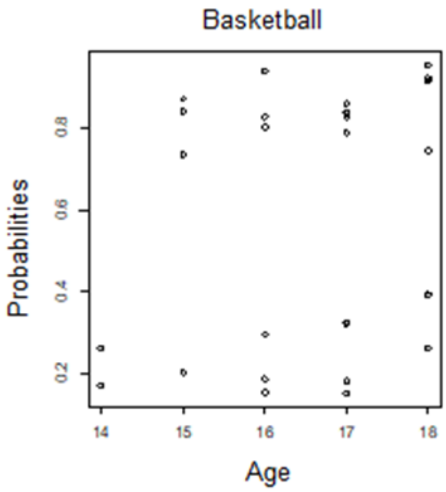

Figure 2. Representation of the probabilities presented by the phase angle (PhA; º) values equal to or greater than 7.7º of Basketball players.

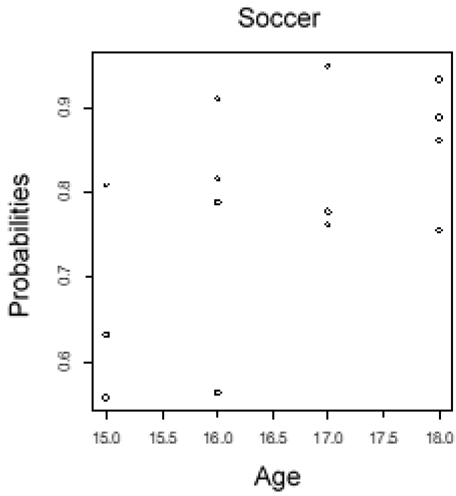

Figure 3. Representation of the probabilities presented by the phase angle (PhA; º) values equal to or greater than 7.7º of Soccer players.

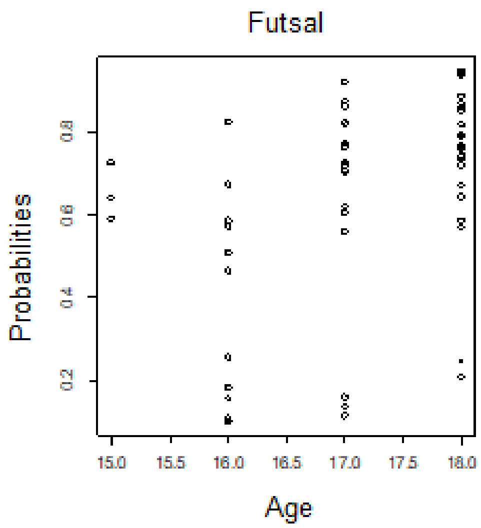

Figure 4. Representation of the probabilities presented by the phase angle (PhA; º) values equal to or greater than 7.7º of Futsal players.

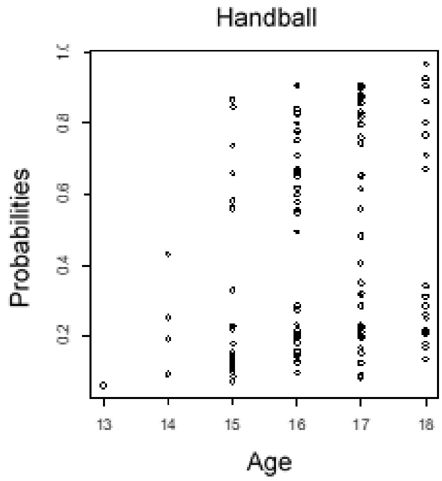

Figure 5. Representation of the probabilities presented by the phase angle (PhA; º) values equal to or greater than 7.7º of Handball players.

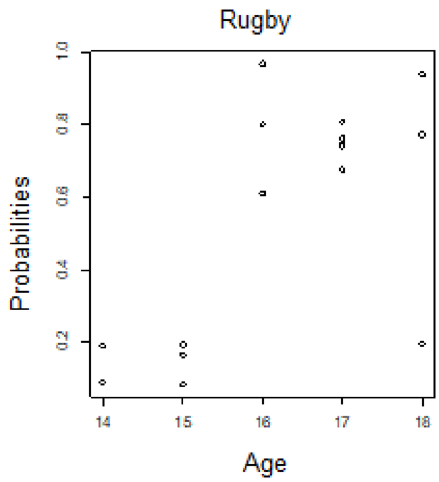

Figure 6. Representation of the probabilities presented by the phase angle (PhA; º) values equal to or greater than 7.7º of Rugby players.

Considering all the variables formulated in our equation of the logistic model, we calculated the exponential referring to each team invasion sport from the values of p (Table 5), where the Intercept parameters β_0 are confused with Basketball, m_2 ($\beta 1a = 2$) represents Soccer, m_3 ($\beta 1a = 3$) Futsal, m_4 ($\beta 1a = 4$) Handball and m_5 ($\beta 1a = 5$) Rugby, aiming verify the odds ratio (i.e., probability) of an athlete obtaining a PhA value higher or lower than the median of the presented study.

Table 6. Odds Ratio (probability) of an athlete developing a phase angle (PhA: º) higher than the cut-off point stablished (median = 7.7º), Sport Exponential (Probability or Odds Ratio).

Sport	Exponential (Probability or Odds Ratio)
Basketball (Confused with intercept parameter)	Could not be calculate
Soccer - m_2 ($\beta_{1a=2}$)	2.20
Futsal - m_3 ($\beta_{1a=3}$)	2.13
Handball - m_4 ($\beta_{1a=4}$)	1.78
Rugby - m_5 ($\beta_{1a=5}$)	2.01

The results obtained for the odds ratio of an athlete developing a PhA higher than the cut-off point stablished (7.7º), our findings showed that Soccer, Futsal, Rugby and Handball players had 2.2, 2.13, 2.01, and 1.78 more chances to reach a higher PhA, respectively.

2.5 DISCUSSION

The aim of the present study was to verify which invasion team sport (i.e., Basketball, Soccer, Futsal, Handball and Rugby) presents a greater probability to obtain a higher PhA value, considering the age, time of practice (t), vertical jump tests (SJ and CMJ) and handgrip strength (HGS) of young players. As predicted the athletes who practice sports with more contact obtained higher PhA value than others who practice sports with less physical contact.

Some researchers have invested some efforts to study the PhA of players from several sports, for example Bongiovanni et al. [8] in Soccer, Koury et al. [24] in Basketball, and Cattem et al. [4], Cirillo et al. [9] and Campa et al. [30] in multi-sports. Moreover, our testing variables were stablished by the results obtained from the relationship confirmed between PhA and CMJ ($r = 0.930$) [31] and HGS ($r = 0.696$) [32]. All the PhA values obtained from the studies abovementioned were similar to the present study, which appears that PhA is a reliable measure to assess the strength performance of athletes.

Considering the Basketball modality (Figure 2), it was noted through the probabilities that this sport did not show discrimination in relation to the measured PhA when considering the age range, since the R software used perform a confounding variable between the Intercept parameter and the first categorical variable (in the present study it was Basketball). That is why it was not possible to calculate the odds ratio for Basketball.

According to practice similarities of Soccer and Futsal, our findings showed that Soccer and futsal players presented 2.20 and 2.13 more chances of presenting a PhA above 7.7º, mainly in the age ranges starting from 16 years (Figures 3 and 4). It appears that a subject who becomes a Soccer player has more probability of having a higher PhA value, and a better functional muscle structure.

In fact, we found some studies where young soccer players presented results close to our predetermined PhA cut-off point, particularly PhA mean values of 7.12º ± 0.7 [33], 7.08º ± 0.7 [8], and 7.4º ± 0.6 [34], respectively. In a study with Portuguese male futsal athletes (age = 23.8 ± 5.3 years), participants were divided into tertiles, starting from the level of VO2max, since those with lower VO2max (tertile 1) presented higher absolute (kg) and relative (%) body mass and fat mass than the other groups (tertiles 2 and 3). In addition, the athletes included in tertile 1 had a lower percentage of muscle mass (tertile 1 = 41.6% ± 6.8; tertile 2 = 43.8% ± 3.9; tertile 3 = 48.3% ± 7.5) and PhA (tertile 1 = 6.9º ± 0.4; tertile 2 = 7.2º ± 0.4; tertile 3 = 7.5º ± 0.5) than the tertile 3 group. These findings may also suggest that individuals who practice futsal may have a higher PhA when they have a greater amount of muscle mass (favorable to better performance in CMJ and SJ, HGS) and also a higher VO_2max [35].

With respect to the handball modality (Figure 5), it can be seen through the probabilities that this sport does not show a clear discrimination in relation to the PhA measured, when considering the age range. Although it presented a characteristic of relevant physical contact during practice and also high mean values in strength tests (when compared to other modalities), we observed the existence of practitioners throughout the age group with low and high probabilities of occurrence. Thus, handball practitioners have a probability of 1.78 of presenting a PhA higher than the median of the present study. PhA values of 7.5º ± 0.5 were found for the sample in a study with 19 male handball athletes (age = 16.5 ± 0.6) for the U17 level [36], where the authors suggested sex, chronological age, and selection of an intense routine based on physical training may determine the specificity of BIA properties in handball players.

When considering the rugby modality, it was observed that most players have a probability of 2.01 to generate a PhA greater than 7.7º, mainly for the age group above 16 years, which can be explained by the average results of the strength tests (i.e., CMJ, SJ, and HGS), which are superior to those of the other modalities. In addition, this sport has greater attention to strength training since it is characterized by intense physical contact.

In the study conducted by Campa et al. [30] reference PhA percentiles were created for players from different sports, including team sports (i.e., basketball, soccer, handball, and rugby). The mean PhA value proposed was 7.7º ± 0.8, and were organized by modalities and percentiles, namely: basketball (50th: 7.6º; 95th: 9.0º), handball (50th: 7.7º; 95th: 9.0º), soccer (50th: 7.6º; 95th: 9.0º), and rugby (50th: 7.6º; 95th: 9.0º). These results may suggest that team invasion players had more chances to develop a higher PhA.

Our findings, strongly suggest that higher PhA values obtained through the logistic regression equation developed will reflect in a better cellular integrity and greater muscle mass, predisposing the athletes to express greater strength during jumping and handgrip tests.

2.6 CONCLUSIONS

The present study showed that higher PhA values predisposed the Soccer, Futsal and Rugby players to express greater strength performance during jumping or handgrip tests, mostly explained by the probability of PhA values higher than the cut-off point determined as a function of other variables (i.e., age, time of practice and strength). Therefore, and considering the advantage of using PhA as a marker of a healthy body composition profile, the magnitude of these probabilities to reach PhA higher values of strength performance in young athletes may depend on the sport modality practiced and their exposure to specific training.

2.7 REFERENCES

1) Lord, F., Pyne, D. B., Welvaert, M., & Mara, J. K. (2020). Methods of performance analysis in team invasion sports: A systematic review. *Journal of Sports Science*, 38(20), 2338-2349.

2) Roschel, H., Tricoli, V., & Ugrinowitsch, C. (2011). Treinamento físico: considerações práticas e científicas. *Revista Brasileira de Educação Física Esporte*, 25, 53-65.

3) Braz, T. V., Spigolon, L. M. P., & Borin, J. P. (2012). Caracterização dos meios e métodos de influência prática no treinamento em futebolistas profissionais. *Revista Brasileira de Ciência do Esporte*, 34, 495-511.

4) Cattem, M. V. O., Sinforoso, B. T., Campa, F., & Koury, J. C. (2021). Bioimpedance vector patterns according to age and handgrip strength in adolescent male and female athletes. *International Journal Environmental Research Public Health*, 18(11), Article 6069. https://doi.org/10.3390/ijerph18116069

5) Silva Neto, M., Simões, R., Grangeiro Neto, J. A., Cardone, C. P. (2010). Avaliação isocinética da força muscular em atletas profissionais de futebol feminino. *Revista*

Brasileira de Medicina do Esporte. 16 (1). https://doi.org/10.1590/S1517-86922010000100006

6) Oliveira, S. D., Oliveira, S. L., Menezes, R. K. et al., (2016). Análise da força de preensão manual e risco cardiovascular de adolescentes com Diabetes Melitos tipo 1. *Revista Brasileira de Ciência e Movimento*, 24(2), 5-14.

7) Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal Obesety*, 32(1), 1-11.

8) Bongiovanni, T., Rossi, A., Trecroci, A., et al. (2022). Regional Bioelectrical Phase Angle Is More Informative than Whole-Body Phase Angle for Monitoring Neuromuscular Performance: A Pilot Study in Elite Young Soccer Players. *Sports*, 10(5), Article 66. https://doi.org/10.3390/sports10050066

9) Cirillo, E. L. R., Pompeo, A., Cirillo, F. T. et al. (2023). As relações entre a composição corporal, ângulo de fase da bioimpedância e força em adolescentes atletas paranaenses. *Motricidade*. Vol. 19 No. 1. https://doi.org/10.6063/motricidade.27834

10) Souza, M. F., Tomeleri, C. M., Ribeiro, A. S. et al. (2017). Effect of resistance training on phase angle in older women: A randomized controlled trial. *Scandinavian Journal of Medicine & Science in Sports*, 27(11), 1308-1316.

11) Hetherington-Rauth, M., Leu, C. G., Júdice, P. B. et al. (2021). Whole body and regional phase angle as indicators of muscular performance in athletes. *European Journal Sport Science*, 1-9. https://doi.org/10.1080/17461391.2020.1858971

12) Ribeiro, A. S., Avelar, A., dos Santos, L. et al. (2017). Hypertrophy-type resistance training improves phase angle in young adult men and women. *International Journal Sports Medicine*, 38(01), 35-40.

13) Kołodziej, M., Koźlenia, D., Kochan-Jacheć, K., & Domaradzki, J. (2020). Bioelectrical impedance components and the mass and strength of upper limb skeletal muscles in young adults. *Human Movement Science*, 21(4), 111-117. https://doi.org/10.5114/hm.2020.95989

14) Bosy-Westphal, A., Danielzik, S., Dörhöfer, R. P. et al. (2006). Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. *Journal of Parenteral and Enteral Nutrition*., 30(4), 309-316.

15) Gonzalez, M. C., Barbosa-Silva, T. G., Bielemann, R. M., Gallagher, D., & Heymsfield, S. B. (2016). Phase angle and its determinants in healthy subjects: influence of body composition. *The American Journal of Clinical Nutrition*, 103(3), 712-716.

16) Barbosa-Silva, M. C. G., Barros, A. J. D., Wang, J., Heymsfield, S. B., & Pierson Jr, R. N. (2005). Bioelectrical impedance analysis: population reference values for phase angle by age and sex. *The American Journal of Clinical Nutrition*, 82(1), 49-52.

17) Kyle, U. G., Genton, L., Slosman, D. O, & Pichard, C. (2001). Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. *Nutrition*, 17(7-8), 534-541.

18) Marra, M., Da Prat, B., Montagnese, C. et al., (2016). Segmental bioimpedance analysis in professional cyclists during a three-week stage race. *Physiological Measurement*, 37(7), 1035-1040.

19) Bongiovanni, T., Rossi, A., Iaia, F. M. et al. (2021). Association of phase angle and appendicular upper and lower body lean soft tissue with physical performance in young elite soccer players: a pilot study. *The Journal of Sports Medicine and Physical Fitness*. Aug;62(8):1015-1022. https://doi.org/10.23736/S0022-4707.21.12911-1

20) Bongiovanni, T., Trecroci, A., Rossi, A. et al. (2021). Association between change in regional phase angle and jump performance: a pilot study in serie a soccer players. *European Journal of Investigation in Health, Psychology and Education*, 11(3), 860-865. https://doi.org/10.3390/ejihpe11030063

21) Cesanelli, L., Ammar, A., Arede, J., Calleja-González, J., & Leite, N. (2022). Performance indicators and functional adaptive windows in competitive cyclists: effect of one-year strength and conditioning training programme. *Biology of Sport*, 39(2), 329-340.

22) Honorato, R. C., Soares Marreiros Ferraz, A., Kassiano, W. et al. (2022). Regional phase angle, not whole-body, is augmented in response to pre-season in professional soccer players. *Research in Sports Medicine*, 1-15.

23) Di Vincenzo, O., Marra, M., & Scalfi, L. (2019). Bioelectrical impedance phase angle in sport: a systematic review. *Journal of the International Society of Sports Nutrition*, 16(1), Article 49. https://doi.org/10.1186/s12970-019-0319-2

24) Koury, J. C., Trugo, N. M. F., & Torres, A. G. (2014). Phase angle and bioelectrical impedance vectors in adolescent and adult male athletes. *The International Journal of Sports Physiology and Performance*, 9(5), 798-804.

25) Verma, J. P., & Verma, P. (2020). Determining sample size and power in research studies. *Springer*.

26) Moura, P. M. d. L. S., Moreira, D., & Caixeta, A. P. L. (2008). Força de preensão palmar em crianças e adolescentes saudáveis. *Revista Paulista de Pediatria*, 26, 290-294.

27) Bosco, C., Montanari, G., Ribacchi, R. et al., M. (1987). Relationship between the efficiency of muscular work during jumping and the energetics of running. *European Journal of Applied Physiology*, 56, 138-143.

28) Field, A. (2009). Descobrindo a estatística usando o SPSS-5. *Penso Editora*, (Chapter 6, p. 221 - 264).

29) Maroco, J. (2007). Regressão Categorial/Regressão Logística. *In Sílabo ed., Análise estatística com utilização do SPSS* (3ª ed., pp. 684-740). Portugal.

30) Campa, F., Thomas, D. M., Watts, K. et al., (2022). Reference Percentiles for Bioelectrical Phase Angle in Athletes. *Biology-Basel*, 11(2), Article 264.

31) Di Vincenzo, O., Marra, M., Sammarco, R. et al. (2020). Body composition, segmental bioimpedance phase angle and muscular strength in professional volleyball players compared to a control group. *The Journal of Sports Medicine and Physical Fitness*, 60(6), 870-874. https://doi.org/10.23736/S0022-4707.20.10548-6

32) Obayashi, H., Ikuta, Y., Fujishita, H. et al. (2021). The relevance of whole or segmental body bioelectrical impedance phase angle and physical performance in adolescent athletes. *Physiological Measurement*, 42(3), Article 035011. https://doi.org/10.1088/1361-6579/abed35

33) Koury, J. C., de Oliveira-Junior, A. V., Portugal, M. R. C., de Oliveira, K. d. J. F., & Donangelo, C. M. (2018). Bioimpedance parameters in adolescent athletes in relation to bone maturity and biochemical zinc indices. *Journal of Trace Elements in Medicine and Biology*, 46, 26-31.

34) Campa, F., Silva, A. M., Iannuzzi, V. et al. (2019). The role of somatic maturation on bioimpedance patterns and body composition in male elite youth soccer players. *International Journal of Environmental Research and Public Health*, 16(23), Article 4711. https://doi.org/10.3390/ijerph16234711

35) Matias, C. N., Campa, F., Cerullo, G. et al. (2022). Bioelectrical Impedance Vector Analysis Discriminates Aerobic Power in Futsal Players: The Role of Body Composition. *Biology-Basel*, 11(4), Article 505. https://doi.org/10.3390/biology11040505

36) Di Credico, A., Gaggi, G., Vamvakis, A. et al. (2021) Bioelectrical impedance vector analysis of young elite team handball players. *International Journal of Environmental Research and Public Health*, 18(24), Article 2972. https://doi.org/10.3390/ijerph182412972

CAPÍTULO III

ESTUDO III

Bioimpedance Phase Angle and Muscle Strength Performance in Young Male Volleyball Athletes **(*Accepted; Motricidade*)**

Estudo III

Bioimpedance Phase Angle and Muscle Strength Performance in Young Male Volleyball Athletes (*accepted; Motricidade*)

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3.1 ABSTRACT

Introduction: Volleyball performance depends partially on lower limbs strength. The phase angle (PhA) is a marker of functional muscle mass, and also a surrogate measure of athletic muscle performance. The aim of this study was to verify the correlation between PhA (bioimpedance) and lower limbs muscle strength in young volleyball athletes.

Methods: The sample included 38 young male volleyball athletes (Age: 16.7 ± 1.3 years; Weight: 73.7 ± 9.7 kg; Height: 179.3 ± 6.9 cm). We performed a cross-sectional observational study and evaluated the volleyball athletes for vertical jump tests (Counter-Movement Jump: CMJ, and Squat Jump: SJ) and whole-body bioimpedance.

Results: The Pearson test verified the correlation between the PhA and CMJ and SJ, which showed positive and moderate significant correlations ($r = 0.550$, $r = 0.559$; respectively). **Conclusion**: Our findings demonstrated that assessing the PhA through bioimpedance provides relevant measures of muscle strength and power in young volleyball athletes.

Keywords: Non-invasion team sports; body composition; muscle power; sports training.

3.2 RESUMO

Introdução: O voleibol depende em grande parte das habilidades motoras, particularmente na força máxima e potência muscular, para membros inferiores. O ângulo de fase (PhA) é considerado um parâmetro importante, sendo usado como marcador de massa muscular funcional e quando se trata de avaliar o desempenho muscular de atletas. O objetivo do presente estudo foi verificar a correlação entre o PhA (bioimpedância) e a força muscular de membros inferiores em jovens atletas de voleibol.

Métodos: A amostra incluiu 38 jovens atletas de voleibol masculino (Idade: 16.7 ± 1.3 anos; Peso: 73.7 ± 9.7 kg; Altura: 179.3 ± 6.9 cm). Adotamos um estudo observacional transversal para realizar o teste de bioimpedância de corpo inteiro e testes de salto vertical (Contra-Movimento: CMJ e Squat Jump: SJ).

Resultados: O teste de Pearson verificou a correlação entre o PhA e os CMJ e SJ, onde apresentaram uma correlação significativamente moderada e positiva (r = 0.550, r = 0.559; respetivamente).

Conclusão: Os nossos resultados confirmam a importância da utilização do PhA no monitoramento de programas de treinamento de Voleibol.

Palavras-chave: Desportos Coletivos de não invasão; composição corporal; potência muscular; treinamento desportivo.

3.3 INTRODUCTION

Success in volleyball depends largely on motor skills, particularly maximum strength, power, and speed, in lower limbs (Pawlik, Dziubek, Rogowski, Struzik, & Rokita, 2022), on an individual's ability to jump and land (Tillman, Hass, Brunt, & Bennett, 2004). These motor skills are required during rallies, which involve explosive movements, such as spiking, blocking, and diving. Moreover, in volleyball is important to simultaneously develop overall strength, power, and speed to help support sport-specific training, performance, and injury reduction of the athletes (Hedrick, 2007).

Training the lower limbs, in particular by using plyometric methods, is essential for volleyball athletes, since this training methodology may able to develop players performance in vertical and horizontal jumps, strength, speed, and agility (Silva, Clemente, Lima, Nikolaidis, Rosemann, & Knechtle, 2019).

Among the physical abilities necessary for success in volleyball, vertical jump height is pointed out as the most important characteristic (Crivelin et al., 2018), as it is estimated that attackers perform an average of 40 to 70 jumps per game (Tillman, Hass, Brunt, & Bennett, 2004). Moreover, attacking and blocking skills characterized approximately 45% of the players' total movements and approximately 80% of the points during a match are dependent on performing a vertical jump (Crivelin et al., 2018). In addition, the work-rest ratio for top-level adult male volleyball players is approximately 1:6 (4.99 sec of work to 29.02 sec of rest), and it is considered a high-intensity anaerobic sport (Weldon, Mak, Wong, Duncan, Clarke, & Bishop, 2021).

In this sense, it is important to carry out the assessment of muscle strength in athletes, particularly through a vertical jump (lower limbs), which will make it possible to monitor athletes' strength performance (Bongiovanni et al., 2022; Cattem, Sinforoso, Campa, & Koury, 2021; Cirillo et al., 2023b; Crivelin et al., 2018), including young volleyball players. Several performances tests to estimate the strength and power of leg extensor muscles have been used by research community for many years (e.g., vertical jump tests). For example, Carvalho et al. (2007) assessed the low limb strength of 10 Portuguese male volleyball athletes by using the counter-movement jump (CMJ) and squat jump (SJ). The results obtained (CMJ: 44.0 ± 3.7 cm; SJ: 42.6 ± 3.6 cm) exhibited the importance of assessing the lower limbs performance.

Body composition also seems to affect athletes' performance (González-Ravé, Arija, & Clemente-Suarez, 2011), as the athletes require a higher amount of lean mass, a lower amount of body fat (Zapolska, Witczak, Manczuk, & Ostrowska, 2014), greater height, and longer lower and upper limbs (Gabbett & Georgieff, 2007). The practice of exercises has also been associated with the development of bone and muscle tissue, where fat-free mass (FFM) is considered a predictor of muscle strength and physical abilities (Cattem et al., 2021).

In addition, knowledge of body composition variables, parameters of bioelectrical impedance (BIA), and strength tests can help to verify the effects of physical activity and sports practice over time (Cattem et al., 2021). Through the BIA test, we obtained the Phase Angle (PhA), which is considered an important parameter, that is calculated directly from the primary values of resistance (R) and reactance (Xc). In clinical use, the PhA seems to reflect the cellular health, body cell mass, and cell wall integrity (Norman, Stobäus, Pirlich, & Bosy-Westphal, 2012). The PhA is calculated using the equation $PhA = \arctan Xc / R \times 180o\pi$ (Baumgartner et al., 1988).

Therefore, the PhA corresponds to a direct measure of stability at the cellular level (Souza et al., 2017) and can be influenced by factors such as sex, age, and the body mass index (Bosy-Westphal et al., 2006; Gonzalez, Barbosa-Silva, Bielemann, Gallagher, & Heymsfield, 2016). In healthy individuals, values can reach between 5º and 7.5º (Barbosa-Silva, Barros, Wang, Heymsfield, & Pierson Jr, 2005; Bosy-Westphal et al., 2006; Kyle, Genton, Slosman, & Pichard, 2001), while in trained athletes (including young athletes) it can reach 8.5º (Cirillo et al., 2023b; Marra et al., 2016). In volleyball athletes, PhA values have been reported of 6.8º ± 0.43 (Di Vincenzo et al., 2020), 7.5º ± 0.6 (Campa et al., 2020), and 6.91º ± 0.48 (Mala et al., 2015). Moreover, the PhA values is also proposed to be a strong predictor of the total participation of skeletal muscle and limb muscle mass (Hetherington-Rauth et al., 2021; Kołodziej, Koźlenia, Kochan-Jacheć, & Domaradzki, 2020).

Scientific evidence elucidated the existence of a relationship between PhA lower limb strength tests (CMJ and SJ) (Bongiovanni et al., 2021; Cirillo et al., 2023a). Although some studies report that there is a vast field to better understand the state of the art considering these variables, in which several studies demonstrated a consensus that PhA can also be used to monitor physical condition and sports performance in adolescent athletes, and may be crucial to assess the body composition of athletes, providing useful data on the percentage of body cell mass and fat-free mass (Cirillo et al., 2023b; Di Vincenzo et al., 2019).

To the best of our knowledge, there are no studies that verified the relationship between PhA and muscle strength of lower limbs in young volleyball athletes. In this sense, the aim of the present study was to verify the correlation between PhA (whole body) and the muscle strength of lower limbs in young male volleyball athletes. It is expected that we observed a positive correlation between PhA lower limb strength of young male volleyball players.

3.4 METHODS

3.4.1 Study design

We performed a cross-sectional observational study. The evaluations were carried out during the final phase of the Paraná Youth Games, ensuring that the best athletes from Paraná participated in the research. The sample underwent whole-body BIA analysis (in a fasted state for 4-hours) for PhA verification, in addition to vertical jump tests (CMJ and SJ).

3.4.2 Sample

We performed the sample calculation using G*Power, version 3.1.9.7 (Dusseldorf, Germany), which resulted in the appropriate sample size for carrying (suggesting a sample size of 38) out this study ($\alpha = 0.05$; $\beta = 0.95$) (Verma & Verma, 2020). Study participants included thirty-eight young sub-elite Brazilian male volleyball athletes (Age: 16.7 ± 1.3 years; Weight: 73.7 ± 9.7 kg; Height: 179.3 ± 6.9 cm). The athletes had been training for at least 4.7 ± 2.1 years, with a weekly workload of 9.6 hours/week, at sub-elite level. The inclusion criterion was: (i) being an active and semi-professional participant in the included competition, in the volleyball sport modality. The exclusion criteria were: (i) lack of authorization from those responsible; (ii) lack of interest in performing the tests; and (iii) any physical problem that prevented the athlete from performing any of the tests proposed in the research. The sample characteristics are presented in Table 1.

Table 1 – Mean values and standard deviation of anthropometric characteristics of volleyball athletes.

Variables	m ± SD
Age (year)	16.7 ± 1.3
Height (cm)	179.3 ± 6.9
Weight (kg)	73.7 ± 9.7
BMI (kg/m^2)	22.9 ± 2.5
Fat Mass (%)	10.1 ± 3.7

3.4.3 Procedures

Athletes and guardians were fully informed about the procedures of this research, as well as the aims and potential risks, where all participants and their parents/guardians provided written consent prior to their participation. As the sample included athletes under 18 years of age, this term was signed by the coach of the team. This study was performed according to the Declaration of Helsinki, and was approved by the Ethics Committee of the lead university (protocol number S2121). Also, we were authorized by the Secretary of State for Sport and Tourism of the State of Paraná (Brazil) to collect data from the athletes, through a consent form.

We carried out the sequence of tests so that the effort of one test would not influence the result of the subsequent test: i) Questionnaire (sample characterization only); ii) Weight and height; iii) Bioimpedance; iv) Vertical Jump.

3.4.4 Instruments (testers were blind)

3.4.4.1 Assessment of body composition and BIA

A questionnaire was used to verify the number of years that athletes had practiced volleyball, as well as the weekly training hours. Also, we measured height and body mass, which were recorded using a stadiometer, with a precision of 0.01 cm (Cardiomed Model Avanutri, Ref. 5130332, Rio de Janeiro, Brazil,) and a digital scale, with a precision of 0.1 kg (Cristal Seven Plenna /Model, Ref. SIM00530, São Paulo, Brazil), respectively.

The body composition variables (fat mass, lean mass, intra and extracellular mass, total body water, intra and extracellular water and basal energy metabolism), and whole-body BIA parameters (R, Xc, PhA), were obtained by using a BIA (biodynamics model 450, version 5.1, BiodynamicsR, Corp. Seattle, WA, USA) and Resting Tab ECG electrodes (Conmed R Corporation, Utica, NY, USA). The equipment provides body parameters through the flow of an alternating current of low frequency and high voltage (800 mA and 50 kHz), with accuracy values of 0.1% in R, 0.2% in Xc, and 0.2% in PhA (Biodinamics Corporation, 2007).

The athletes were positioned in a comfortable dorsal decubitus position, without using metallic objects (e.g., watches, bracelets, and earrings), barefoot, with their legs apart at 45º in relation to the midline of the body and with the upper limbs positioned 30º from the trunk. The skin was initially cleaned with pads soaked in alcohol, and then four adhesive electrodes were positioned as recommended: one electrode on the dorsal surface of the right wrist, another on the third metacarpal, one on the anterior surface of the right ankle between the prominent portions of the bones, and the last electrode on the dorsal surface of the third metatarsal. To minimize possible interference in the results, we previously advised the athletes not to ingest alcohol drinks, or take diuretics, and also to fast for at least four hours before the test.

To obtain a greater precision of the results, this equipment enables the addition of information on age, sex, height, weight of the individual, and weekly hours of training, and provides results in a short time.

3.4.4.2 Muscle strength of lower limbs - Vertical jump tests

The vertical jump tests carried out were the CMJ and SJ (Bosco et al., 1987), using a system for measuring and analyzing vertical jumps through optoelectronic sensors, from the Sys Jump brand (Sys Jump, Systware, Miami, Florida, USA). From the half-flexion of the knees, in the SJ the athlete remained in the jump area, in a half-squat position for 5 seconds, with hands on the waist and knees at 90º. The evaluator gave a verbal signal for the athlete to perform the jump as high as possible without removing the hands from the waist, and without retracting the feet or throwing them forward. In the CMJ, the athlete was positioned in the standing jump area, with hands resting on the waist and legs extended. After the evaluator's verbal command, the athlete performed a quick squat and then jumped as high as possible, without removing the hands from the waist and without retracting the feet or throwing them forward. The athletes performed three attempts in both tests, with an interval of 30 seconds between executions. We recorded the best result, in cm (Rodrigues & Marins, 2011).

3.4.4.3 Statistical Analysis

To verify the normality of the data, the Shapiro-Wilk test was applied, demonstrating normal distribution. Descriptive statistics (mean ± standard deviation) were calculated for all measurements. A Pearson correlation test (r) was used to assess the correlation between PhA and CMJ and SJ, which was considered a very weak correlation between 0.00 and 0.19, weak between 0.20 and 0.39, moderate between 0.40 and 0.69, strong between 0.70 and 0.89, and very strong between 0.90 and 1.00 (Maroco, 2007). Data were analyzed with IBM SPSS Statistics, version 23.0 (IBM Corp., Armonk, NY, USA). The alpha level for significance was set at $p < 0.05$.

3.5 RESULTS

The PhA, CMJ and SJ variables, expressed in mean and standard deviation, are presented in Table 2.

Table 2 – Mean and standard deviation values of the phase angle (PhA; º) and counter movement jump (CMJ; cm) and squat jump (SJ; cm).

Variables	m ± SD
PhA (º)	8.1 ± 0.56
CMJ (cm)	50,9 ± 8.3
SJ (cm)	42.2 ± 5.9

The correlation values obtained between the PhA and the CMJ and SJ, evidenced a moderate significant correlation (r = 0.550, r = 0.559; respectively) (Table 3).

Table 3 – Pearson correlation values (r) between the phase angle (PhA; º) and counter movement jump (CMJ; cm) and squat jump (SJ; cm).

		CMJ (cm)	SJ (cm)
PhA	Pearson correlation	.550**	.559**
	p	.000	.001

** The correlation is significant at 0.01 level (bilateral).

Moreover, both vertical jump tests: CMJ ($r = 0.587$, $p = 0.000$) and SJ ($r = 0.526$, $p = 0.001$), evidenced a positive correlation with PhA.

3.6 DISCUSSION

The aim of the present study was to verify the relationship between the PhA (whole body) and the performance variables for lower limb strength in young volleyball athletes. Our hypothesis was confirmed, since the PhA were positive and moderately correlated with strength values for all applied tests.

Accordingly to the existing literature, and to the best of our knowledge, we observed that any study analysed the correlation between PhA with muscle strength in young male volleyball players.

Hetherington-Rauth et al. (2021) evaluated 117 adult athletes from different sports, including volleyball (21.0 ± 3.8 years), which they found that PhA measurements (whole body) were also highly correlated with the lower limbs (CMJ) ($r = 0.86$, $p < 0.05$). Accordingly to their results, the authors suggested that PhA may also be a relevant marker of athletes' muscle performance, particularly in the strength. Albeit in our study we found a moderate correlation, we strongly believed that these results were due to the age of our athletes (16.7 ± 1.3 years) because the athletes are still in the maturation phase with consequent muscle formation. In support of our results, an investigation found significant and positive correlations, when controlling chronological age, between maturity and handgrip strength and various medicine ball throw tasks in young tennis players aged between 8 and 16 years old (Myburgh, Cumming, Silva, Cooke, Malina, 2016).

We confirm our hypothesis, based on the positive and moderate correlation between PhA and lower limb strength, whether for CMJ or SJ. Incidentally, we did not find studies that aimed to verify the correlation between PhA and SJ in young volleyball players. The PhA can also be used to analyze only the concentric phase of the vertical jump movement.

Moreover, some studies have suggested the use of PhA and CMJ to monitor the strength performance of athletes (Bongiovanni et al., 2021; Cirillo et al., 2023b), this premise was also confirmed in our study by using young volleyball players, which now should be included in the sample categories.

Finally, and according to Di Vincenzo et al. (2020), PhA has the potential to be applied by athletic trainers to facilitate and rapidly assess muscle performance, which can help in the determination of competition readiness, training progress, and tracking the return of muscle performance during rehabilitation phase. Therefore, for training monitoring, we reinforce the use of the PhA due to its practicality, which was mentioned in the present study, together with CMJ and the SJ, where at least fact the sports team's need evaluation and monitoring procedures to be quick, agile and easy to interpret throughout a sports season, including volleyball.

As a limitation, we emphasized that the need of carry out these same tests during different moments of a season, in order to verify how the correlation between PhA and strength tests of lower limbs behave in this sample.

3.7 CONCLUSION

The present study confirmed the relationship between PhA and lower limb strength (CMJ and SJ) in young volleyball athletes. In addition, the results underlined that evaluations based on the BIA test can be useful in an assessment focused on monitoring training programs. Furthermore, the findings add information about the clear relationship between PhA and muscle strength in young volleyball athletes.

3.8 REFERENCES

Barbosa-Silva, M. C. G., Barros, A. J. D., Wang, J., Heymsfield, S. B., Pierson Jr, R. N. (2005). Bioelectrical impedance analysis: population reference values for phase angle by age and sex. *The American Journal of Clinical Nutrition*, 82(1), 49-52.

Baumgartner, R. N., Chumlea, W. C., Roche, A. F. (1988). Bioelectric impedance phase angle and body composition. *The American Journal of Clinical Nutrition*, 48(1), 16-23.

Biodinamics Corporation. (2007). Manual de Instrução. 1ª Edição: Copyright © *Biodynamics Corporation*; TBW Importadora Ltda.

Bongiovanni, T., Rossi, A., Iaia, F. M., Alberti, G., Pasta, G., Trecroci, A. (2021). Association of phase angle and appendicular upper and lower body lean soft tissue with physical performance in young elite soccer players: a pilot study. *The Journal of Sports Medicine and Physical Fitness*. 62(8):1015-1022. https://doi.org/10.23736/S0022-4707.21.12911-1

Bongiovanni, T., Rossi, A., Trecroci, A., Martera, G., Iaia, F. M., Alberti, G., Pasta, G., Lacome, M. (2022). Regional bioelectrical phase angle is more informative than whole-body phase angle for monitoring neuromuscular performance: A pilot study in elite young soccer players. *Sports*, 10(5), Article 66. https://doi.org/10.3390/sports10050066

Bongiovanni, T., Trecroci, A., Rossi, A., Iaia, F. M., Pasta, G., Campa, F. (2021). Association between change in regional phase angle and jump performance: a pilot study in serie a soccer players. *European Journal of Investigation in Health, Psychology and Education*, 11(3), 860-865. https://doi.org/10.3390/ejihpe11030063

Bosco, C., Montanari, G., Ribacchi, R., Giovenali, P., Latteri, F., Iachelli, G., Faina, M., Colli, R., Dal Monte, A., La Rosa, M., Cortili, G., Saibene, F. (1987). Relationship between the efficiency of muscular work during jumping and the energetics of running. *European Journal of Applied Physiology and Occupational Physiology*, 56, 138-143. https://doi.org/10.1007/BF00640636

Bosy-Westphal, A., Danielzik, S., Dörhöfer, R. P., Later, W., Wiese, S., Müller, M. J. (2006). Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. *Journal of Parenteral and Enteral Nutrition*, 30(4), 309-316.

Campa, F., Silva, A. M., Matias, C. N., Monteiro, C. P., Paoli, A., Nunes, J. P., Talluri, J., Lukaski, H., Toselli, S. (2020). Body water content and morphological characteristics modify bioimpedance vector patterns in volleyball, soccer, and rugby players. *International Journal of Environmental Research and Public Health*, 17(18), 6604, https://doi.org/10.3390/ijerph17186604

Carvalho, C., Vieira, L., Carvalho, A. (2007). Avaliação, controlo e monitorização da condição física da selecção portuguesa de voleibol sénior masculina–época de 2004. *Revista Portuguesa de Ciências do Desporto*, 7(1), 68-79.

Cattem, M. V. O., Sinforoso, B. T., Campa, F., Koury, J. C. (2021). Bioimpedance vector patterns according to age and handgrip strength in adolescent male and female athletes. *International Journal of Environmental Research and Public Health*, 18(11), Article 6069. https://doi.org/10.3390/ijerph18116069

Cirillo, E., Pompeo, A., Cirillo, F. T., Vilaça-Alves, J., Costa, P., Ramirez, R., Dourado, A. C, Afonso, J., Casanova, F. (2023a). Relationship between bioelectrical impedance phase angle and upper and lower limb muscle strength in athletes from several sports: a systematic review with meta-analysis. *Sports*. 11(5), 107. https://doi.org/10.3390/sports11050107

Cirillo, E. L. R., Pompeo, A., Cirillo, F. T., Osiecky, R., Avelar, A., Casanova, F., Dourado, A. C. (2023b). As relações entre a composição corporal, ângulo de fase da bioimpedância e força em adolescentes atletas paranaenses. *Motricidade*, Vol. 19(1), https://doi.org/10.6063/motricidade.27834

Crivelin, V. X., Moreira, A., Finotti, R. L., Lopes, C. R., Ramos, M., Aoki, M. S., Capitani, C. D. (2018). Correlação entre altura do salto e composição corporal em atletas profissionais de voleibol. *Arquivos de Ciências do Esporte*, 6(1), 24-27, https://doi.org/10.17648/aces.v6n1.2362.

Di Vincenzo, O., Marra, M., Sammarco, R., Speranza, E., Cioffi, I., Scalfi, L. (2020). Body composition, segmental bioimpedance phase angle and muscular strength in professional volleyball players compared to a control group. *Journal of Sports Medicine and Physical Fitness*, 60(6), 870-874. https://doi.org/10.23736/S0022-4707.20.10548-6

Di Vincenzo, O., Marra, M., Scalfi, L. (2019). Bioelectrical impedance phase angle in sport: a systematic review. *Journal of the International Society of Sports Nutrition*, 16(1), Article 49. https://doi.org/10.1186/s12970-019-0319-2

Gabbett, T., Georgieff, B. (2007). Physiological and anthropometric characteristics of Australian junior national, state, and novice volleyball players. *The Journal of Strength & Conditioning Research*, 21(3), 902-908.

Gonzalez, M. C., Barbosa-Silva, T. G., Bielemann, R. M., Gallagher, D., Heymsfield, S. B. (2016). Phase angle and its determinants in healthy subjects: influence of body composition. *The American Journal of Clinical Nutrition*, 103(3), 712-716.

González-Ravé, J. M., Arija, A., Clemente-Suarez, V. (2011). Seasonal changes in jump performance and body composition in women volleyball players. *The Journal of Strength & Conditioning Research*, 25(6), 1492-1501.

Hedrick, A. (2007). Training for high level performance in women's collegiate volleyball: Part I training requirements. *Strength & Conditioning Journal*, 29(6), 50-53.

Hetherington-Rauth, M., Leu, C. G., Júdice, P. B., Correia, I. R., Magalhães, J. P., Sardinha, L. B. (2021). Whole body and regional phase angle as indicators of muscular performance in athletes. *European Journal of Sport Science*. 21(12):1684-1692. https://doi.org/10.1080/17461391.2020.1858971

Kołodziej, M., Koźlenia, D., Kochan-Jacheć, K., Domaradzki, J. (2020). Bioelectrical impedance components and the mass and strength of upper limb skeletal muscles in young adults. *Human Movement*, 21(4), 111-117. https://doi.org/10.5114/hm.2020.95989

Kyle, U. G., Genton, L., Slosman, D. O., Pichard, C. (2001). Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. *Nutrition*, 17(7-8), 534-541.

Mala, L., Maly, T., Zahalka, F., Bunc, V., Kaplan, A., Jebavy, R., Tuma, M. (2015). Body composition of elite female players in five different sports games. *Journal of Human Kinetics*, 45(1), 207-215. https://doi.org/10.1515/hukin-2015-0021

Maroco, J. (2007). Regressão Categorial/Regressão Logística. In Sílabo ed., Análise estatística com utilização do SPSS. *Silabo* (3ª ed., pp. 684-740). Portugal.

Marra, M., Da Prat, B., Montagnese, C., Caldara, A., Sammarco, R., Pasanisi, F., Corsetti, R. (2016). Segmental bioimpedance analysis in professional cyclists during a three-week stage race. *Physiological Measurement*, 37(7), 1035-1040. https://doi.org/10.1088/0967-3334/37/7/1035

Myburgh, G. K., Cumming, S. P., Silva, M. C. E., Cooke, K., Malina, R. M. (2016). Maturity-associated variation in functional characteristics of elite youth tennis players. *Pediatric Exercise Science*, 28(4), 542-552.

Norman, K., Stobäus, N., Pirlich, M., Bosy-Westphal, A. (2012). Bioelectrical phase angle and impedance vector analysis - Clinical relevance and applicability of impedance parameters. *Clinical Nutrition*, 31(6), 854-861. https://doi.org/10.1016/j.clnu.2012.05.008

Pawlik, D., Dziubek, W., Rogowski, Ł., Struzik, A., Rokita, A. (2022). Strength Abilities and Serve Reception Efficiency of Youth Female Volleyball Players. *Applied Bionics and Biomechanics*, 1-7, https://doi.org/10.1155/2022/4328761.

Rodrigues, M. E., Marins, J. C. B. (2011). Counter movement e squat jump: análise metodológica e dados normativos em atletas. *Revista Brasileira de Ciência e Movimento*, 19(4), 108-119.

Silva, A. F., Clemente, F. M., Lima, R., Nikolaidis, P. T., Rosemann, T., Knechtle, B. (2019). The effect of plyometric training in volleyball players: A systematic review. *International Journal of Environmental Research and Public Health*, 16(16), 2960.

Souza, M. F., Tomeleri, C. M., Ribeiro, A. S., Schoenfeld, B. J., Silva, A. M., Sardinha, L. B., Cyrino, E. S. (2017). Effect of resistance training on phase angle in older women: A randomized controlled trial. *Scandinavian Journal of Medicine & Science in Sports*, 27(11), 1308-1316.

Tillman, M. D., Hass, C. J., Brunt, D., Bennett, G. R. (2004). Jumping and landing techniques in elite women's volleyball. *Journal of Sports Science & Medicine*, 3(1), 30.

Verma, J. P., Verma, P. (2020). Determining sample size and power in research studies. *Springer*. https://doi.org/10.1007/978-981-15-5204-5

Weldon, A., Mak, J. T. S., Wong, S. T., Duncan, M. J., Clarke, N. D., Bishop, C. (2021). Strength and conditioning practices and perspectives of volleyball coaches and players. *Sports*, 9(2), 28.

Zapolska, J., Witczak, K., Manczuk, A., Ostrowska, L. (2014). Assessment of nutrition, supplementation and body composition parameters on the example of professional volleyball players. *Roczniki Państwowego Zakładu Higieny*, 65(3).

CAPÍTULO IV

DISCUSSÃO GERAL

4.1 DISCUSSÃO GERAL

Conforme mencionado anteriormente, o objetivo geral da presente Tese de Doutoramento foi estudar a relação entre o PhA da bioimpedância elétrica e a força muscular em atletas de diversos esportes, sabendo que para tal, foram realizados três estudos que se definiram: (i) rever sistematicamente a literatura, com metanálise; (ii) verificar qual esporte de invasão em equipe que tem maior probabilidade de apresentar um PhA mais elevado a partir de variáveis de força, idade e tempo de prática esportiva; (iii) verificar se existe correlação entre PhA e as variáveis de força muscular em testes de salto vertical (CMJ e SJ) em jovens atletas de voleibol. Os resultados encontrados na presente Tese de Doutoramento, nos permitiu confirmar nossas hipóteses a respeito de: (i) existir uma relação entre o PhA e a força muscular, inclusíve a metanálise confirmou esta relação com o CMJ em atletas; (ii) esportes com mais contato físico favorecem obter um valor maior do PhA do que aqueles com menos contato, considerando variáveis CMJ, HGS, idade, tempo de prática esportiva e SJ; (iii) verificar uma correlação positiva entre o PhA e força de membros inferiores em jovens atletas de voleibol.

No intuito de fornecer uma base científica para os estudos 2 e 3, inicialmente foi realizado uma revisão sistemática com metanálise, visando melhor entender quais eram as linhas investigacionais a respeito da temática científica abordada.

Assim, em nossa revisão sistemática com metanálise, foi possível verificar que diversos estudos demostraram uma correlação positiva entre PhA e força muscular, porém dentre os 13 estudos elegíveis, somente foi possível realizar a metanálise em 4 estudos (Bongiovani et al., 2021; Bongiovani et al., 2022; Martins et al., 2021; Honorato et al., 2022), apenas para o teste CMJ. Os resultados mostraram uma correlação positiva entre PhA e força de membros inferiores ($r = 0,691$ [IC 95% 0,249 a 0,895]; $p = 0,005$), enquanto nenhuma metanálise foi possível para as relações entre PhA e força de membros superiores. Além disso, o GRADE mostrou uma certeza de evidência baixa.

Não obstante, Mundstock et al. (2018) realizaram uma revisão sistemática com metanálise, onde objetivaram verificar a relação entre o PhA e o nível de atividade física. Nesta pesquisa não limitaram a busca por publicação seja no período, por idioma, idade, tipo de dieta e tipo ou nível de exercício realizado. Os resultados em estudos transversais demonstraram que o PhA foi maior entre os indivíduos ativos (Média da Diferença = 0,70; 95% CI: 0,48, 0,92, $P < 0,001$), com baixa heterogeneidade ($I2 = 0\%$; $P = 0,619$). Em estudos longitudinais, o PhA foi significativamente maior para o grupo de indivíduos ativos do que nos grupos controle (Média da Diferença = 0,30; IC 95%: 0,11, 0,49, P = 0,001), com baixa heterogeneidade (I2 = 13%, P = 0,331). Assim, os autores concluiram que a associação positiva do nível de atividade física com o PhA reforça a importância de incluir rotina de exercícios nos cuidados de saúde, onde também identificaram a necessidade de se realizarem mais estudos para se definir diferentes tipos, intensidades e frequências de exercícios de forma a encontrar a melhor relação dose-efeito.

Não obstante, e de acordo com o assinalado no nosso estudo de revisão sistemática com meta-análise, sugerimos que a prática de atividades físicas contribui para o aumento da massa muscular, visto que, talvez isso possa justificar que as pessoas ativas apresentem maior PhA do que os não ativos.

Ademais, em outra revisão sistemática realizada por Di Vincenzo et al. (2019), objetivaram avaliar a variabilidade do PhA entre atletas e sua relação com o desempenho esportivo, além de investigar se o PhA difere entre os atletas de diferentes esportes. Nas buscas iniciais, foram achados 196 estudos, dos quais 35 foram incluídos (21 estudos transversais e 14 longitudinais). Dentre várias observações nesta pesquisa, os autores verificaram que o PhA aumenta com a idade, em ambos os sexos, até o final da idade adulta e depois diminuem em idosos, com diferença entre os sexos que se torna maior durante a adolescência, além de encontrarem valores médios do PhA na idade adulta consistentemente maiores em homens do que mulheres. Também, assinalaram que diferenças em anos de prática e programas de treinamento pode influenciar mudanças do PhA com o tempo, além das relações entre PhA e nível de desempenho poderem variar em diferentes esportes, onde possivelmente são influenciados por critérios usados para avaliar o nível de desempenho, reforçando, uma vez mais, os achados em nossa revisão sistemática com meta-análise.

Considerando os achados nas pesquisas citadas acima, também, em nosso estudo com atletas de voleibol encontramos uma correlação moderada e positiva na relação entre o PhA e os testes de salto vertical, a saber: CMJ ($r = 0.587$, $p = 0.000$) e SJ ($r = 0.526$, $p = 0.001$). Também, Hetherington-Rauth et al. (2021), que avaliaram 117 atletas adultos de diferentes esportes, incluindo voleibol (21,0 ± 3,8 anos), descobriram que as medidas de PhA (corpo inteiro) estavam altamente correlacionadas com os membros inferiores (CMJ) ($r = 0{,}86$, $p < 0{,}05$). Embora em nosso estudo tenhamos encontrado uma correlação moderada, acreditamos fortemente que esses resultados se devem à idade de nossos atletas (16,7 ± 1,3 anos), pois os atletas ainda estão em fase de maturação com consequente formação muscular. Corroborando os nossos resultados, uma investigação encontrou correlações significativas e positivas, ao controlar a idade cronológica, entre maturidade e força de preensão manual e várias tarefas de arremesso de bola medicinal em jovens tenistas com idades entre 8 e 16 anos (Myburgh, Cumming, Silva, Cooke, Malina, 2016).

Subsequentemente, dentre a busca de conhecer com mais profundidade este tema, bem como contribuir com a construção do saber da relação do PhA e força muscular de membros superiores e inferiores, curiosamente buscamos entender como esse panorama se comporta quando tratamos dos esportes de invasão em equipes (e.g., basquetebol, futebol, futsal, handebol e rugby). Ou seja, procuramos identificar qual destes esportes tem mais probabilidade de atingir um valor de PhA superior, a partir de uma equação de regressão logística, com variáveis categóricas (esporte e sexo) e covariáveis (idade, tempo de prática - t, CMJ, SJ e força de preensão manual esquerda- HGSl, e direita- HGSr, respectivamente). A partir do ponto de corte estabelecido na mediana do grupo (7,7º) e as variáveis selecionadas, nosso modelo de regressão logística apresentou o futebol como a modalidade que apresenta uma maior probabilidade de obter um PhA superior, sendo esta chance estimada em 2.2 vezes superior, seguido de futsal (2.13), rugby (2.01) e handebol (1.78).

Curiosamente, no estudo de Campa et al. (2022), que objetivou criar uma tabela de referência em percentis para a variável PhA em atletas, contando com uma amostra de 2224 atletas, sendo 1658 masculinos (idade 26.2 ± 8.9 anos) e 566 femininos (idade 26.9 ± 6.6 anos), a média para PhA foi semelhante ao ponto de corte estabelecido em nosso estudo dos esportes de invasão em equipes, ou seja, 7.7º ± 0.8. Também, foi apresentado os valores de PhA por modalidade e sexo, onde relatamos aqui os valores do percentil 50 e intervalo de confiança (95%), dos esportes relatados (Tabela 1).

Tabela 1- Valores de Ângulo de Fase (PhA) expressos em percentil 50 (95%CI), conforme estudo de Campa et al. (2022).

Esporte	Masculino		Feminino	
	n	**Percentil 50 (95%CI) – PhA (º)**	**n**	**Percentil 50 (95%CI) – PhA (º)**
Basquetebol	85	7.6º (7.6º-7.7º)	55	6.9º (6.8º-6.9º)
Handebol	40	7.7º (7.6º-7.7º)	4	6.8º (6.7º-6.9º)
Futebol	490	7.6º (7.6º-7.7º)	55	6.8º (6.8º-6.9º)
Rugby	147	7.6º (7.6º-7.7º)	-	-
Voleibol	174	7.6º (7.6º-7.7º)	94	6.8º (6.7º-6.9º)

Também, parece ser interessante observar que na pesquisa de Campa et al. (2022), as mulheres apresentaram um valor de PhA semelhante ao ponto de corte do nosso estudo dos esportes de invasão, somente no percentil 85 [7.7º (7.6º-7.8º)], o que sugere a diferença entre os sexos. Além disso, os autores também apresentaram os valores referenciais de PhA conforme o tipo de prática da modalidade esportiva, onde se verifica que nos jogos desportivos coletivos os atletas possuem uma média de 7.7º ± 0.8 (masculino) e 6.8º ± 0.8 (feminino).

Em suma, nossos achados sugerem fortemente que maiores valores de PhA obtidos através da equação de regressão logística desenvolvida irão refletir em uma melhor integridade celular e maior massa muscular, predispondo os atletas a expressarem maior força durante os testes de salto e preensão manual.

Embora a modalidade voleibol (PhA: 8,1º) não tenha sido incluída no estudo 2, por ser considerado um esporte coletivo, porém de não invasão, não obstante, obteve valores de PhA semelhantes aos esportes futebol (8,1º) e futsal (8,3º) para idades semelhantes, visto que, nos faz levantar uma outra hipótese para futuros estudos, que seria de saber qual probabilidade o voleibol teria de atingir um PhA maior que o ponto de corte estabelecido.

Assim, torna-se evidente que os dados apresentados nesta Tese de Doutoramento fornecem um suporte sólido aos objetivos da pesquisa, pois contribuem para o conhecimento existente na área e podem estimular a discussão acadêmica, oferecendo possibilidades para o avanço neste domínio, bem como à comunidade das ciências do esporte.

De tal forma, se recomenda novas pesquisas a respeito da relação do PhA e a força muscular em outras modalidades esportivas, quer seja coletiva ou individual, inclusive considerando jovens atletas e, também, em contexto de pesquisa longitudinal, visando conhecer como se comportam estas variáveis ao longo do desenvolvimento esportivo até a profissionalização.

5. CONCLUSÃO

Considerando o entendimento da relação do PhA e a força muscular de membros superiores e inferiores em atletas de esportes coletivos e de acordo com os resultados relatados nos diferentes estudos apresentados nesta tese, foi possível concluir:

1. A relação do PhA com a força muscular de membros inferiores e superiores em atletas de diversos esportes, bem como seu uso como estratégia para o avaliação de atletas em uma temporada esportiva;

2. Maiores valores de PhA predispõem os atletas de futebol, futsal e rugby a expressarem maior desempenho de força durante testes de salto ou preensão manual, explicado principalmente pela probabilidade de valores de PhA superiores ao ponto de corte determinado em função de outras variáveis (ou seja, idade, tempo de prática e força). Portanto, e considerando a vantagem de utilizar o PhA como marcador de um perfil de composição corporal saudável, a magnitude dessas probabilidades de atingir valores de PhA maiores de desempenho de força em atletas jovens pode depender da modalidade esportiva praticada e de sua exposição a treinamentos específicos. Assim, dos esportes de invasão analisados, o futebol se mostrou como o esporte que proporciona maiores probabilidades de desenvolver um PhA superior a partir de variáveis de força de membros superiores e inferiores, além da idade e tempo de prática esportiva;

3. A relação entre PhA e força de membros inferiores (CMJ e SJ) em jovens atletas de voleibol. Além disso, os resultados evidenciaram que avaliações baseadas no teste BIA podem ser úteis em uma avaliação focada no monitoramento de programas de treinamento.

Assim, torna-se evidente que os achados nesta Tese de Doutoramento fornecem um suporte sólido aos objetivos da pesquisa, pois contribuem para o conhecimento existente na área e podem estimular a discussão académica, oferecendo possibilidades para o avanço neste domínio, bem como à comunidade das ciências do esporte.

De tal forma, se recomenda novas pesquisas a respeito da relação do PhA e a força muscular em outras modalidades esportivas, quer seja coletiva ou individual, inclusive considerando jovens atletas e, também, em contexto de pesquisa longitudinal, visando conhecer como se comportam estas variáveis ao longo do desenvolvimento esportivo até a profissionalização.

Como limitação, não tivemos condições adequadas para se controlar as variáveis relacionadas a maturação e puberdade dos atletas nos estudos 2 e 3.

6. REFERÊNCIAS

Afonso, J., Garganta, J., McRobert, A., Williams, M., & Mesquita, I. (2014). Visual search behaviours and verbal reports during film-based and in situ representative tasks in volleyball. *European Journal of Sport Science*, *14*(2), 177-184.

Baumgartner, R. N., Chumlea, W. C., & Roche, A. F. (1988). Bioelectric impedance phase angle and body composition. *The American Journal of Clinical Nutrition*, *48*(1), 16-23.

Bongiovanni, T., Rossi, A., Trecroci, A., Martera, G., Iaia, F. M., Alberti, G., Pasta, G., Lacome, M. (2022). Regional Bioelectrical Phase Angle Is More Informative than Whole-Body Phase Angle for Monitoring Neuromuscular Performance: A Pilot Study in Elite Young Soccer Players. *Sports*, *10*(5), Article 66. https://doi.org/10.3390/sports10050066

Bongiovanni, T., Trecroci, A., Rossi, A., Iaia, F. M., Pasta, G., & Campa, F. (2021). Association between change in regional phase angle and jump performance: a pilot study in serie a soccer players. *European Journal of Investigation in Health, Psychology and Education*, *11*(3), 860-865. https://doi.org/10.3390/ejihpe11030063

Bosy-Westphal, A., Danielzik, S., Dörhöfer, R. P., Later, W., Wiese, S., & Müller, M. J. (2006). Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. *Journal of Parenteral and Enteral Nutrition*, *30*(4), 309-316.

Braz, T. V., Spigolon, L. M. P., & Borin, J. P. (2012). Caracterização dos meios e métodos de influência prática no treinamento em futebolistas profissionais. *Revista Brasileira de Ciência do Esporte*, 34, 495-511.

Campa, F., Thomas, D. M., Watts, K., Clark, N., Baller, D., Morin, T., Toselli, S., Koury, J. C., Melchiorri, G., Andreoli, A., Mascherini, G., Petri, C., Sardinha, L. B., Silva, A. M. (2022). Reference Percentiles for Bioelectrical Phase Angle in Athletes. *Biology-Basel*, *11*(2), Article 264. https://doi.org/10.3390/biology11020264

Cesanelli, L., Ammar, A., Arede, J., Calleja-González, J., & Leite, N. (2022). Performance indicators and functional adaptive windows in competitive cyclists: Effect of one-year strength and conditioning training programme. *Biology of Sport*, *39*(2), 329-340. https://doi.org/10.5114/biolsport.2022.105334

Cirillo, E., Pompeo, A., Cirillo, F. T., Vilaça-Alves, J., Costa, P., Ramirez, R., Dourado, A. C., Afonso, J., Casanova, F. (2023b). Relationship between bioelectrical impedance phase angle and upper and lower limb muscle strength in athletes from several sports: a systematic review with meta-analysis. *Sports.* 2023, 11, 107. https://doi.org/10.3390/sports11050107

Cirillo, E. L. R., Pompeo, A., Cirillo, F. T., Osiecky, R., Avelar, A., Casanova, F., Dourado, A. C. (2023a). As relações entre a composição corporal, ângulo de fase da bioimpedância e força em adolescentes atletas paranaenses. *Motricidade.* Vol. 19 No. 1. https://doi.org/10.6063/motricidade.27834

Coelho, D. B., Coelho, L. G. M., Braga, M. L., Paolucci, A., Cabido, C. E. T., Ferreira Junior, J. B., ... & Garcia, E. S. (2011). Correlação entre o desempenho de jogadores de futebol no teste de sprint de 30m e no teste de salto vertical. Motriz: Revista de Educação Física, 17, 63-70.

Colín-Ramírez, E., Castillo-Martínez, L., Orea-Tejeda, A., Vázquez-Durán, M., Rodríguez, A. E., & Keirns-Davis, C. (2012). Bioelectrical impedance phase angle as a prognostic marker in chronic heart failure. *Nutrition*, *28*(9), 901-905.

Cronin, J., Lawton, T., Harris, N., Kilding, A., & McMaster, D. T. (2017). A brief review of handgrip strength and sport performance. *The Journal of Strength & Conditioning Research*, *31*(11), 3187-3217.

Di Vincenzo, O., Marra, M., Sammarco, R., Speranza, E., & Scalfi, L. (2019). Body Composition and Segmental Bioimpedance Phase Angle in Elite Volleyball Players. [Icsports: proceedings of the 7th international conference on sport sciences research and technology support]. *7th International Conference on Sport Sciences Research and Technology Support (icSPORTS)*, Vienna, AUSTRIA. https://doi.org/10.5220/0007945701130116

Gonzalez, M. C., Barbosa-Silva, T. G., Bielemann, R. M., Gallagher, D., & Heymsfield, S. B. (2016). Phase angle and its determinants in healthy subjects: influence of body composition. *The American Journal of Clinical Nutrition*, *103*(3), 712-716.

Hansen, L., Bangsbo, J., Twisk, J., & Klausen, K. (1999). Development of muscle strength in relation to training level and testosterone in young male soccer players. *Journal of Applied Physiology*, *87*(3), 1141-1147.

Hetherington-Rauth, M., Leu, C. G., Judice, P. B., Correia, I. R., Magalhães, J. P., & Sardinha, L. B. (2021). Whole body and regional phase angle as indicators of muscular performance in athletes. *European Journal of Sport Science*, 1-9. https://doi.org/10.1080/17461391.2020.1858971

Honorato, R. C., Soares, M. F. A., Kassiano, W., Martins, P. C., Silva, D. A. S., & Ceccatto, V. M. Regional phase angle, not whole-body, is augmented in response to pre-season in professional soccer players. *Research in Sports Medicine*. (2022), 1-15. https://doi.org/10.1080/15438627.2022.2052069

Horie, L. M., Barbosa-Silva, M. C. G., Torrinhas, R. S., de Mello, M. T., Cecconello, I., & Waitzberg, D. L. (2008). New body fat prediction equations for severely obese patients. *Clinical Nutrition*, *27*(3), 350-356. https://doi.org/10.1016/j.clnu.2008.03.011

Kyle, U. G., Bosaeus, I., De Lorenzo, A. D., Deurenberg, P., Elia, M., Gómez, J. M., Heitmann, B. L., Kent-Smith, L., Melchior, J. C., Pirlich, M., Scharfetter, H., Schols, A. M. W., Pichard, C. (2004). Bioelectrical impedance analysis - Part I: Review of principles and methods [Article]. *Clinical Nutrition*, *23*(5), 1226-1243. https://doi.org/10.1016/j.clnu.2004.06.004

Komi, P. V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. Medicine and science in sports, 10(4), 261-265.

Lord, F., Pyne, D. B., Welvaert, M., & Mara, J. K. (2020). Methods of performance analysis in team invasion sports: A systematic review. *Journal of Sports Science*, 38(20), 2338-2349.

Lukaski, H. C., Kyle, U. G., & Kondrup, J. (2017). Assessment of adult malnutrition and prognosis with bioelectrical impedance analysis: Phase angle and impedance ratio. *Current Opinion in Clinical Nutrition and Metabolic Care*, *20*(5), 330-339. https://doi.org/10.1097/MCO.0000000000000387

Martins, P. C., Teixeira, A. S., Guglielmo, A. L. G., Francisco, J. S., Silva, D. A. S., Nakamura, F. Y., & de Lima, L. R. A. Phase angle is related to 10 m and 30 m sprint time and repeated-sprint ability in young male soccer players. (2021) *International Journal Environmental Research Public Health.*, 18(9), 4405. https://doi.org/10.3390/ijerph18094405

Moura, P. M. d. L. S., Moreira, D., & Caixeta, A. P. L. Força de preensão palmar em crianças e adolescentes saudáveis. *Revista Paulista de Pediatria.* (2008), 26, 290-294.

Mundstock, E., Amaral, M. A., Baptista, R. R., Sarria, E. E., dos Santos, R. R. G., Filho, A. D., Rodrigues, C. A. S., Forte, G. C., Castro, L., Padoin, A. V. Stein, R., Perez, L. M., Ziegelmann, P. K., Mattiello, R. (2018). Association between phase angle from bioelectrical impedance analysis and level of physical activity: Systematic review and meta-analysis. *Clinical Nutrition*, *38*(4), 1504-1510. https://doi.org/10.1016/j.clnu.2018.08.031

Myburgh, G. K., Sean P. C., Silva, M. C. E., Cooke, K., Malina, R. M. Maturity-associated variation in functional characteristics of elite youth tennis players. *Pediatric Exercise Science*, v. 28, n. 4, p. 542-552, 2016. https://doi.org/10.1123/pes.2016-0035

Nescolarde, L., Yanguas, J., Lukaski, H., Alomar, X., Rosell-Ferrer, J., & Rodas, G. (2015). Effects of muscle injury severity on localized bioimpedance measurements. *Physiological Measurement*, *36*(1), 27-42. https://doi.org/10.1088/0967-3334/36/1/27

Norman, K., Stobäus, N., Pirlich, M., & Bosy-Westphal, A. (2012). Bioelectrical phase angle and impedance vector analysis - Clinical relevance and applicability of impedance parameters. *Clinical Nutrition*, *31*(6), 854-861. https://doi.org/10.1016/j.clnu.2012.05.008

Ott, M., Fischer, H., Polat, H., Helm, E. B., Frenz, M., Caspary, W. F., & Lembcke, B. (1995). Bioelectrical impedance analysis as a predictor of survival in patients with human immunodeficiency virus infection. *Journal of Acquired Immune Deficiency Syndromes and Human Retrovirology: Official Publication of the International Retrovirology Association*, *9*(1), 20-25.

Ribeiro, A. S., Avelar, A., Dos Santos, L., Silva, A. M., Gobbo, L. A., Schoenfeld, B. J., Sardinha, L; B., Cyrino, E. S. (2017). Hypertrophy-type resistance training improves phase angle in young adult men and women. *International Journal of Sports Medicine*, 38(1), 35-40. https://doi.org/10.1055/s-0042-102788

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*, 1419-1449.

Tanaka, S., Ando, K., Kobayashi, K., Hida, T., Ito, K., Tsushima, M., Morozumi, M., Machimo, M., Ota. K., Seki, T., Ishiguro, N., Hasegawa, Y., Imagama, S. (2018). A low phase angle measured with bioelectrical impedance analysis is associated with osteoporosis and is a risk factor for osteoporosis in community-dwelling people: the Yakumo study. *Archives of Osteoporosis*, *13*, 1-6.

Tavares, F., & Casanova, F. (2017). A tomada de decisão nos jogos desportivos coletivos: Do laboratório ao terreno de jogo. *Porto: Faculdade do Desporto da Universidade do Porto*. Portugal.

Tomeleri, C. M., Ribeiro, A. S., Cavaglieri, C. R., Deminice, R., Schoenfeld, B. J., Schiavoni, D., Santos, L., Souza, M. F., Antunes, M., Venturini, D., Barbosa, D. S., Sardinha, L. B., Cyrino, E. S. (2018). Correlations between resistance training-induced changes on phase angle and biochemical markers in older women. *Scandinavian Journal of Medicine & Science in Sports, 28*(10), 2173-2182. https://doi.org/10.1111/sms.13232

7. ANEXOS

Supplementary Table S1. PRISMA Checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Pages 1-2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Pages 2-3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 3
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 3
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 4
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 4
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio,	Page 4

Section and Topic	Item #	Checklist item	Location where item is reported
		mean difference) used in the synthesis or presentation of results.	
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 4
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 4
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 4
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 4
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Pages 4-5
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Pages 4-5
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Page 5
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Page 5
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 5-6
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 5-6
Study characteristics	17	Cite each included study and present its characteristics.	Pages 6-10
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 10
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Pages 11-13
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pages 13-15
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Pages 14-15
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Pages 14-15

Section and Topic	Item #	Checklist item	Location where item is reported
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Pages 14-15
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not applicable: less than 10 studies per comparison
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Page 15
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pages 16
	23b	Discuss any limitations of the evidence included in the review.	Pages 16
	23c	Discuss any limitations of the review processes used.	Pages 16
	23d	Discuss implications of the results for practice, policy, and future research.	Pages 16
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 16
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 16
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Pages 17
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 17
Competing interests	26	Declare any competing interests of review authors.	Page 17
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Pages 3 and 17

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