UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
ESCOLA DE EDUCAÇÃO FÍSICA, FISIOTERAPIA E DANÇA
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DO MOVIMENTO HUMANO

DESENVOLVIMENTO LONGITUDINAL DA APTIDÃO FÍSICA DE JOVENS ATLETAS DE FUTEBOL: INTERAÇÕES ENTRE MATURAÇÃO BIOLÓGICA, EXPOSIÇÃO COMPETITIVA E TREINAMENTO ESPORTIVO

Artur Goulart Berger

2025

Artur Goulart Berger

DESENVOLVIMENTO LONGITUDINAL DA APTIDÃO FÍSICA DE JOVENS ATLETAS DE FUTEBOL: INTERAÇÕES ENTRE MATURAÇÃO BIOLÓGICA, EXPOSIÇÃO COMPETITIVA E TREINAMENTO ESPORTIVO

Tese apresentada ao Programa de Pós-Graduação em Ciências do Movimento Humano da Universidade Federal do Rio Grande do Sul, como requisito parcial para a obtenção do título de Doutor em Ciências do Movimento Humano.

Orientador: Prof. Dr. Thiago José Leonardi

Porto Alegre,

2025

CIP - Catalogação na Publicação

Berger, Artur Goulart
DESENVOLVIMENTO LONGITUDINAL DA APTIDÃO FÍSICA DE JOVENS ATLETAS DE FUTEBOL: INTERAÇÕES ENTRE MATURAÇÃO BIOLÓGICA, EXPOSIÇÃO COMPETITIVA E TREINAMENTO ESPORTIVO / Artur Goulart Berger. -- 2025.
162 f.
Orientador: Thiago José Leonardi.

Tese (Doutorado) -- Universidade Federal do Rio Grande do Sul, Escola de Educação Física, Programa de Pós-Graduação em Ciências do Movimento Humano, Porto Alegre, BR-RS, 2025.

1. Futebol. 2. Desenvolvimento físico. 3. Treinamento esportivo. 4. Maturação biológica. I. José Leonardi, Thiago, orient. II. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

Artur Goulart Berger

DESENVOLVIMENTO LONGITUDINAL DA APTIDÃO FÍSICA DE JOVENS ATLETAS DE FUTEBOL: INTERAÇÕES ENTRE MATURAÇÃO BIOLÓGICA, EXPOSIÇÃO COMPETITIVA E TREINAMENTO ESPORTIVO

Defesa Aprovada em 24 de outubro de 2025

BANCA EXAMINADORA

Prof. Dr. Ronei Silveira Pinto

Universidade Federal do Rio Grande do Sul

Prof. Dr. Humberto Jorge Gonçalves Moreira de Carvalho

Universidade Federal de Santa Catarina

Prof. Dr. Fábio Yuzo Nakamura

Universidade da Maia

Orientador:

Prof. Dr. Thiago José Leonardi

Universidade Federal do Rio Grande do Sul

AGRADECIMENTOS

Aos meus amigos e à minha família, obrigado.

Agradeço ao Prof. Dr. Thiago José Leonardi pela orientação sempre próxima e paciente, com contribuições fundamentais para o desenvolvimento deste trabalho, bem como aos colegas do Laboratório de Estudos Multidisciplinares em Esporte (LEME), pelo convívio, apoio e auxílio ao longo de todo o processo.

Agradeço aos colegas do Grupo de Pesquisa em Treinamento de Força (GPTF) e do Grupo de Pesquisa em Biomecânica e Cinesiologia (GPBIC) pelas importantes contribuições e colaborações durante a realização desta pesquisa.

Agradeço também à Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) e ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, 405316/2021-6) pelo apoio e incentivo à pesquisa.

RESUMO

Introdução: O desenvolvimento físico de jovens jogadores de futebol resulta da interação de múltiplos fatores, como crescimento, maturação biológica e estímulos de treino, sendo determinante para o desempenho a longo prazo. Diante da elevada variabilidade individual e das distintas trajetórias de desenvolvimento desde idades precoces, compreender a evolução longitudinal dessas variáveis é essencial para orientar o planejamento do treinamento e a tomada de decisão na formação de atletas. Contudo, estudos longitudinais que investiguem conjuntamente as variações maturacionais e as exposições às cargas e metodologias de treino ainda são escassos no contexto do futebol brasileiro. **Objetivos**: (I) investigar as mudanças no tamanho corporal e nos parâmetros de aptidão física ao longo do tempo, considerando o desenvolvimento em função da idade cronológica e da idade estimada no pico de velocidade de crescimento; (II) analisar as diferenças nas taxas de evolução física entre atletas com distintos níveis de exposição ao treino e ao jogo; (III) avaliar os efeitos de um programa de treinamento baseado em jogos reduzidos sobre o desenvolvimento neuromuscular de jovens jogadores de futebol; (IV) verificar a correlação entre desempenho neuromuscular e diversos indicadores de fadiga. **Metodologia**: Participaram do estudo 76 jovens jogadores de futebol (12,22 ± 1,20 anos; IC: 10,59–15,04 anos) de um clube brasileiro, acompanhados ao longo de 20 meses. Um subgrupo de 35 jogadores (16,05 ± 2,03 anos) foi avaliado antes e após 12 semanas de treinamento com jogos reduzidos. Foram avaliados composição corporal, salto, agilidade, resistência intermitente, velocidade, pico de torque e fadiga muscular. Os atletas foram classificados pelos treinadores de acordo com o nível de exposição ao treino e às partidas. A análise do desempenho em relação à idade cronológica e à idade no pico de velocidade de crescimento, bem como para avaliação do desenvolvimento neuromuscular, utilizou a modelagem de regressão multinível bayesiana. **Resultados**: A estatura e a massa corporal aumentaram de forma não linear, enquanto o somatório de dobras cutâneas permaneceu estável. O desempenho físico apresentou maior consistência em relação à idade no pico de velocidade de crescimento do que à idade cronológica. Atletas com maior exposição ao treino e à competição apresentaram ganhos mais significativos em velocidade, agilidade e potência, enquanto aqueles com menor participação mostraram progressos reduzidos. O treinamento baseado exclusivamente em jogos reduzidos resultou em menor desenvolvimento do pico de torque, maior fadiga muscular e incremento limitado de massa magra, embora com alta variabilidade individual. **Conclusão**: Identificamos que

analisar o desenvolvimento com base na maturação fornece informações mais precisas sobre o estágio de cada atleta e contribui para reduzir as diferenças individuais, assim como a exposição à competição exerce influência significativa na taxa de desenvolvimento da aptidão física, com impacto especialmente relevante em atletas com experiência limitada. Destacamos também que o treinamento baseado em jogos reduzidos promove adaptações heterogêneas dentro do grupo de atletas. Por fim, percebemos que a avaliação da aptidão física por meio de testes máximos não apresenta correlação com as capacidades de resistência à fadiga. Esses achados reforçam que o desenvolvimento longitudinal da aptidão física deve ser interpretado a partir de trajetórias e características individuais, uma vez que a maturação, a exposição à competição e o treinamento são vivenciados de formas distintas por cada atleta, gerando respostas específicas.

Palavras-chave: Jogos reduzidos; Fadiga; Velocidade; Potência; Pico de torque; Titulares.

ABSTRACT

Introduction: The physical development of young soccer players results from the interaction of multiple factors, such as growth, biological maturation, and training stimuli, and is a key determinant of long-term performance. Given the high inter-individual variability and distinct developmental trajectories from early ages, understanding the longitudinal evolution of these variables is essential to inform training planning and decision-making in athlete development. However, longitudinal studies that jointly examine maturational variations and exposure to training loads and methodologies remain scarce in the Brazilian soccer context. **Objectives**: (I) to investigate changes in body size and physical fitness parameters over time, considering development in relation to chronological age and the estimated age at peak velocity of growth; (II) to analyses differences in the rates of physical development between athletes with different levels of exposure to training and; (III) to evaluate the effects of a training programme based on small-sided games on the neuromuscular development of young football players; (IV) to examine the correlation between neuromuscular performance tests and various indicators of fatigue. **Methodology**: The study involved 76 young football players (12.22 ± 1.20 years; CI: 10.59–15.04 years) from a Brazilian club, monitored over 20 months. A sub-group of 35 players (16.05 ± 2.03 years) was assessed before and after 12 weeks of training with small-sided games. Body composition, jumping, agility, intermittent endurance, speed, peak torque, and muscular fatigue were evaluated. The athletes were classified by coaches according to their level of exposure to training and matches. The analysis of performance in relation to chronological age and the age at peak velocity of growth, as well as for neuromuscular development assessment, utilized Bayesian multilevel regression modeling. **Results**: Height and body mass increased in a non-linear manner, while skinfold measurements remained stable. Physical performance showed greater consistency concerning the age at peak velocity of growth than chronological age. Athletes with higher exposure to training and competition demonstrated more significant gains in speed, agility, and power, whereas those with less participation showed reduced progress. Training based solely on small-sided games resulted in less development of peak torque, increased muscular fatigue, and limited gains in lean mass, although with high individual variability. **Conclusion**: We identified that analyzing development based on maturation provides more accurate information about each athlete's stage and helps to reduce individual differences, just as exposure to competition exerts a significant influence on the rate of physical fitness development, with a particularly relevant impact

on athletes with limited experience. We also highlight that training based on small-sided games promotes heterogeneous adaptations within the group of athletes. Finally, we observe that assessing physical fitness through maximum tests does not correlate with fatigue resistance capabilities. These findings reinforce that the longitudinal development of physical fitness should be interpreted from individual trajectories and characteristics, since maturation, exposure to competition, and training are experienced differently by each athlete, generating specific responses.

Keywords: Soccer; Small-sided games; Fatigue; Speed; Power; Peak torque; Starters.

SUMÁRIO

1. **INTRODUÇÃO** 13
1.1 OBJETIVOS 23
1.1.1 Objetivo Geral: **23**
1.1.2 Objetivos Específicos **23**
2. ARTIGO 1 ..... **32**
3. ARTIGO 2 ..... **54**
4. ARTIGO 3 ..... **75**
5. ARTIGO 4 ..... **103**
6. CONSIDERAÇÕES FINAIS **125**
REFÊRENCIAS **130**
APÊNDICE A – TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE) **144**
APÊNDICE B – TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE) – PAIS E/OU RESPONSÁVEIS **147**
APÊNDICE C – TERMO DE ASSENTIMENTO LIVRE E ESCLARECIDO (TALE) **150**
APÊNDICE D - ANAMNESE **152**
APÊNDICE E - SUPPLEMENTARY FILES **162**

ESTRUTURA DA TESE

Este documento está organizado em conformidade com as normas estabelecidas para dissertações e teses do Programa de Pós-Graduação em Ciências do Movimento Humano da Universidade Federal do Rio Grande do Sul. O trabalho está estruturado no modelo escandinavo, composto por quatro artigos científicos originais relacionados ao tema central da pesquisa. Esse formato possibilita a apresentação dos artigos de maneira lógica e sequencial, refletindo o desenvolvimento do processo investigativo e contribuindo para a discussão e compreensão integrada do problema de pesquisa.

A estrutura da tese compreende uma introdução, que contempla os conceitos fundamentais, o problema de pesquisa, a justificativa e a relevância do tema, bem como os objetivos do estudo. Em seguida, o corpo principal da tese está organizado em quatro artigos. Cada artigo inclui seções próprias: resumo, introdução, metodologia, resultados, discussão e conclusões. Os artigos que compõem a tese são:

- **Artigo 1** - *Longitudinal development of physical fitness in young football players: a Bayesian analysis* (Estudo publicado, *Research Quarterly for Exercise and Sport*; doi:10.1080/02701367.2025.2558190)
- **Artigo 2** - *Longitudinal effects of competition exposure on physical fitness development in youth football: a Bayesian analysis*
- **Artigo 3** - *Effects of a 12-week in-season small-sided games training on properties in young football players*
- **Artigo 4** - *Are neuromuscular performance tests related to the fatigue index in young football players?*

Por fim, o fechamento da tese se dá com a seção de considerações finais, na qual é apresentada uma síntese dos resultados obtidos, são destacadas as principais contribuições dos quatro artigos para as questões centrais da pesquisa, bem como as formas que se complementam para responder ao problema central do estudo. Por fim, são apresentadas aplicações práticas e perspectivas futuras para contribuir com o campo investigado.

LISTA DE FIGURAS

ARTIGO 1:

Figura 1 - Growth curves in stature, body mass, and sum of skinfolds

Figura 2 - Physical performance in sprint test

Figura 3 - Physical performance in long jump test

Figura 3 - Physical performance in CMJ test

Figura 5 - Physical performance in agility test

Figura 6 - Physical performance in intermittent endurance test

ARTIGO 2:

Figura 1 – Countermovement jump aligned by CA (a), and by PHV (b)

Figura 2 - Long jump aligned by CA (a), and by PHV (b)

Figura 3 - 20 meters sprint aligned by CA (a), and by PHV (b)

Figura 4 - Agility aligned by CA (a), and by PHV (b)

ARTIGO 3:

Figura 1 – Leg lean mass

Figura 2 – Knee extensor concentric peak torque

Figura 3 - Knee flexor concentric peak torque

Figura 4 - Knee flexor eccentric peak torque

Figura 5 - Knee extensor concentric fatigue

Figura 6 - Knee flexor concentric fatigue

Figura 7 – Differences between legs in knee extensor concentric peak torque

Figura 8 - Differences between legs in knee flexor concentric peak torque

Figura 9 - Differences between legs in knee flexor eccentric peak torque

Figura 10 – Fat mass (supplementary files)

ARTIGO 4:

Figura 1 – Running anaerobic sprint test

Figura 2 – Countermovement jump assessments

Figura 3 - Isokinetic peak torque and fatigue assessment

1. INTRODUÇÃO

O futebol é um esporte de grande exigência física, no qual atletas de elite percorrem entre 10 e 12 km em uma partida (Bangsbo, 1994; Reilly *et al*., 2000; Oliva-Lozano *et al*., 2020), predominando a contribuição do sistema metabólico aeróbio para sustentar o nível de desempenho ao longo do jogo (Mohr *et al*., 2005; Stolen *et al*., 2005). No entanto, o êxito em momentos decisivos, como disputas pela posse de bola e ações que resultam em gols, está associado a esforços de curta duração e elevada intensidade (e.g. acelerações, mudanças de direção, saltos e ações de bola) (Barnes *et al*., 2014; Faude *et al*., 2012; Reilly *et al*., 2000). Dessa forma, apesar da predominância aeróbia, o sistema anaeróbio é repetidamente recrutado, uma vez que os jogadores realizam, em média, esforços de alta intensidade a cada 30 segundos e um sprint máximo a cada 90 segundos (Reilly; Bangsbo; Franks, 2000; Haugen, 2014). Assim, o futebol caracteriza-se pela alternância irregular entre intensidades físicas, evidenciando a complexidade metabólica e funcional exigida (Bangsbo *et al*., 2006; Vigne *et al*., 2010; Oliva-Lozano *et al*., 2020; Stolen *et al*., 2005).

Análises recentes observando as principais ligas de futebol do mundo indicam que a frequência de movimentos intensos nos jogos aumentou, enquanto a distância total percorrida permaneceu relativamente estável (Barnes *et al*., 2014; Pons *et al*., 2019). Além disso, foi identificado que sprints máximos, atingindo velocidades superiores a 30 km/h, costumam ocorrer tanto no início da partida quanto durante os últimos 15 minutos do jogo (Oliva-Lozano *et al*., 2023). Neste contexto, espera-se que um atleta de elite seja capaz de gerar força, velocidade e potência durante movimentos complexos de jogo, além de manter esses esforços ao longo de toda a partida (Reilly & Bangsbo, 2000; Vigne *et al*., 2010; Hammami *et al*., 2017; Barnes *et al*., 2014). Portanto, a aptidão física, entendida como o conjunto de capacidades motoras que sustentam o desempenho esportivo, incluindo força, velocidade, agilidade, potência e resistência, representa um componente essencial para a prática e o rendimento no futebol (Stolen *et al*., 2005; Reilly *et al*., 2000).

Uma carreira de sucesso no futebol é resultado da interação entre fatores físicos, técnicos, psicológicos, sociológicos, motivacionais e contextuais ao longo do tempo (Huijgen *et al*., 2014; Kelly & Williams, 2020; Reilly *et al*., 2000; Williams *et al*., 2020). Entretanto, tem-se observado que os processos de identificação de talentos estão ocorrendo cada vez mais em idades mais jovens, e o desempenho físico tem sido frequentemente utilizado como principal critério na avaliação e seleção de jovens atletas (Albadadejo-Saura *et al*., 2021;

Meylan *et al*., 2010). Em contextos de formação esportiva, as competições de diversas modalidades são organizadas utilizando o ano de nascimento dos atletas como referência (Cumming *et al*., 2023). No entanto, em uma mesma faixa etária, podem ser observadas variações substanciais nos níveis hormonais, idade esquelética, massa corporal e estatura entre os jovens, realidade que resulta em uma vantagem temporária na aptidão física (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022). Assim, muitos jovens, em diferentes fases do processo de maturação, são submetidos a programas de treinamento intensivo e competições, enfrentando-se em disputas nas quais o componente físico exerce forte influência no sucesso (Albadadejo-Saura *et al*., 2021).

As diferenças no crescimento e nos níveis de aptidão física de jovens atletas de uma mesma categoria etária decorrem da complexidade do processo maturacional que, embora siga um padrão biológico comum, não ocorre de forma linear entre indivíduos (Malina *et al*., 2009. A maturação é regida pelo aumento da atividade hormonal durante a puberdade, influenciando diretamente o crescimento, o desenvolvimento muscular e as adaptações fisiológicas associadas ao desempenho físico (Beunen e Malina, 2008; Malina; Bouchard; Bar-Or, 2009). As variações no tempo e ritmo desse processo são amplas e resultam em diferenças significativas na estatura, massa e composição corporal de indivíduos da mesma idade cronológica (Carvalho *et al*., 2017; 2019; Leonardi *et al*., 2018; Malina *et al*., 2009).

O efeito dessa realidade, junto a um processo seletivo prematuro, resulta em equipes de base nas quais prevalecem os atletas nascidos nos primeiros meses do ano e/ou aqueles que atingem o pico de velocidade de crescimento (PVC) mais cedo (Albadadejo-Saura *et al*., 2021; Albuquerque *et al*., 2024; Bidaurrazaga-Letona *et al*., 2017; Carvalho *et al*., 2017; Malina *et al*., 2000; Meylan *et al*., 2010; Peña-González *et al*., 2018; 2022; Reilly *et al*., 2000; Vaeyens *et al*., 2006; Valente-dos-Santos *et al*., 2012). A meta-análise de Lima *et al*. (2023) evidencia a influência da seleção esportiva ao mostrar que jovens futebolistas atingem o PVC mais precocemente (13,15 anos) do que não atletas (13,8–14,2 anos), indicando um favorecimento de indivíduos com maturação biológica antecipada.

Antes do PVC, o aumento da estatura e da massa corporal ocorre de forma gradual. Com o início da puberdade, há um aumento significativo na produção de hormônios anabólicos, como a testosterona, o hormônio do crescimento (GH) e o fator de crescimento semelhante à insulina (IGF-1), que aceleram o crescimento ósseo e muscular (Malina; Bouchard; Bar-Or, 2009). Esse aumento da atividade hormonal promove o ganho de massa

magra, que está diretamente relacionado ao aumento da força e resistência muscular e, consequentemente, marca uma fase de rápido avanço no desempenho físico dos jovens atletas (Beunen e Malina, 2008; Malina; Bouchard; Bar-Or, 2009; Valente-dos-Santos *et al*., 2012).

Estudos têm utilizado a idade estimada do PVC como um marcador biológico para avaliar e interpretar o desenvolvimento físico de jovens atletas, permitindo compreender com maior precisão as fases de aceleração e desaceleração do crescimento e suas repercussões sobre o desempenho esportivo (Carvalho *et al*., 2017; Deprez *et al*., 2015; Philliparets *et al*., 2006; Malina *et al*., 2021). No entanto, não há relação direta entre a idade em que se atinge o PVC e a estatura adulta (Malina *et al*., 2009). Além disso, a maturação precoce não prevê inerentemente um desempenho adulto superior, tendo em vista que as curvas de desenvolvimento físico normalmente se alinham com o PVC (Carvalho *et al*., 2017; Philippaerts *et al*., 2006). Em função disso, embora as características antropométricas e a aptidão física de jovens atletas sejam aparentemente atraentes para a identificação e seleção de talentos esportivos, sua capacidade de prever com sucesso uma carreira profissional subsequente é contestável (Carling *et al*., 2012; Figueiredo, Coelho e Silva, 2009). As vantagens físicas precoces podem não persistir ao longo do tempo e levar à identificação prematura ou enviesada de talentos, caso o potencial de longo prazo seja negligenciado (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022). Segundo o estudo de Phillippaerts *et al*. (2006), os melhores desempenhos físicos na idade adulta não correspondem necessariamente aos jovens que maturaram precocemente. Tal descoberta evidencia que o desenvolvimento esportivo é um processo longo e complexo, cujas relações nem sempre podem ser compreendidas a partir de avaliações transversais.

Neste sentido, enquanto estudos transversais fornecem informações limitados sobre as trajetórias de desenvolvimento a longo prazo (Carvalho *et al*., 2017), os estudos longitudinais permitem monitorar mudanças nas características físicas ao longo do tempo, tanto em nível de grupo quanto individual. Esse tipo de delineamento contribui com informações valiosas sobre a influência da maturação biológica no desempenho físico e nas variações na resposta ao treino ao longo do tempo, contribuindo para que estratégias de treinamento mais eficazes sejam projetadas (Abarghoueinejad *et al*., 2021; Malina *et al*., 2009). No entanto, apesar da reconhecida importância de identificar trajetórias individuais de crescimento e desempenho, avaliações longitudinais da aptidão física permanecem relativamente escassas na literatura (Armstrong, 2019; Bidaurrazaga-Letona *et al*., 2015; Huijgen *et al*., 2010, 2014).

Os estudos longitudinais desenvolvidos junto a ambientes de treinamento estruturados se concentram predominantemente em amostras europeias (Abarghoueinejad *et al*., 2021; Lima *et al*., 2023), frequentemente envolvendo populações relativamente homogêneas. Isso levanta questões sobre a generalização de seus achados para contextos mais diversos, como o futebol juvenil brasileiro, onde os atletas são expostos a condições culturais, socioeconômicas e de treinamento distintas. Até o momento, faltam estudos longitudinais que descrevam o desenvolvimento da aptidão física de jovens atletas de futebol brasileiros. Além disso, estudos raramente consideram a maturação biológica por meio de abordagens longitudinais, apesar de sua influência bem documentada no desempenho e nos processos de seleção esportiva.

É nesse contexto seletivo e complexo que o presente estudo se insere, buscando melhor compreender como o crescimento e a maturação biológica influenciam o desenvolvimento da aptidão física de jovens atletas de futebol brasileiros. Entende-se que melhor compreender este processo pode contribuir para que avaliações mais justas e eficientes sejam realizadas no contexto dos clubes de formação, bem como para oferecer subsídios às comissões técnicas, potencializando o desenvolvimento de estratégias de treinamento mais individualizadas e eficientes.

No entanto, não é apenas o crescimento e a maturação que influenciam o desenvolvimento da aptidão física de um atleta. Em clubes de formação esportiva, os jovens são expostos a muitas horas de treino semanal, e a interação entre a maturação biológica e as experiências de treinamento pode moldar significativamente as trajetórias de desenvolvimento físico dos atletas (Phillipaerts *et al*., 2006). Estudos destacam que, em uma mesma equipe, há diferentes padrões nas cargas de treinamento e jogo experimentadas por atletas com diferentes graus de exposição (e.g., titulares, reservas e aqueles que apenas participam dos treinamentos) (Anderson *et al*., 2016; Barreira *et al*., 2022; Clemente *et al*., 2024). Em jogos, atletas titulares geralmente recebem maior tempo de exposição, percorrem maiores distâncias, realizam mais ações de intensidade em relação aos reservas (Anderson *et al*., 2016; Barreira *et al*., 2022; Clemente *et al*., 2024; Castillo-Rodriguez *et al*., 2023). Por outro lado, estudos que analisaram os minutos finais do jogo não encontraram diferenças nas cargas externas desempenhadas por titulares e reservas (Janusiak *et al*., 2023), enquanto análises que ajustam as cargas com base no tempo de jogo de cada atleta, indicam que as reservas experimentam distâncias maiores e intensidades mais altas (Clemente *et al*., 2024; Castillo-Rodriguez *et al*., 2023).

A literatura não apresenta um consenso quanto às cargas experienciadas por atletas com diferentes status de exposição, o que pode ser interpretado com base nas particularidades de cada equipe (e.g. número de atletas, características individuais e estratégias de jogo, pelas diferenças significativas entre a movimentação de atletas de variadas posições e funções, e pela influência do contexto do jogo) (Dellal *et al*., 2012; Gonçalves *et al*., 2024; Oliva-Lozano *et al*., 2022; Gimenez *et al*., 2019). Apesar disso, entende-se que diferentes intensidades e volumes de estímulos podem resultar em variações significativas na carga total acumulada ao longo da semana e impactar diretamente o desenvolvimento da aptidão física a longo prazo (Clemente *et al*., 2024; Varjan *et al*., 2023; Valente-dos-Santos *et al*., 2012). Portanto, a análise dos diferentes níveis de exposição à competição se torna essencial para compreender plenamente os determinantes do crescimento e da evolução física dos atletas, contribuindo para a interpretação dos resultados centrais deste estudo.

Para o nosso conhecimento, nenhum estudo examinou os padrões de crescimento longitudinal em jovens atletas de futebol com diferentes níveis de exposição à competição, o que restringe a compreensão sobre como o tempo de jogo influencia o desenvolvimento físico, técnico e tático ao longo do tempo. Adicionalmente, não identificamos estudos que considerem os atletas que, embora integrem o grupo e participam dos treinamentos, não recebem oportunidades de disputar jogos nas competições. Diante destas lacunas, questionamos se existem diferenças no padrão de evolução da aptidão física entre atletas de futebol masculino com distintos níveis de exposição ao treino e ao jogo? Explorar os efeitos cumulativos da maturação e da exposição à competição sobre o desenvolvimento da aptidão física pode contribuir para a identificação de distintos padrões de crescimento e desempenho, favorecendo uma melhor compreensão das variadas trajetórias de desenvolvimento e subsidiando a definição de abordagens mais adequadas às necessidades individuais de cada atleta.

Além do crescimento, da maturação e das experiências competitivas, outro fator que influencia significativamente o desenvolvimento de um atleta são os treinamentos. Atualmente, o calendário competitivo impõe uma carga de trabalho elevada, com atletas participando de inúmeras partidas ao longo da temporada, tanto em níveis profissionais quanto de base. Essa combinação de maior intensidade de jogo (Barnes *et al*., 2014; Pons *et al*., 2019), alta frequência de competições e curtos períodos de recuperação tem contribuído para o aumento da fadiga acumulada entre os atletas (Altarriba-Bartes *et al*., 2020; Nédélec *et al*., 2012). Como consequência, a sobrecarga competitiva tem sido apontada como um fator determinante para o aumento da incidência de lesões musculoesqueléticas (Cezarino *et al*., 2020; Dupont, 2010).

Diante desse cenário, treinadores e comissões técnicas enfrentam o desafio de elaborar estratégias eficazes para minimizar o acúmulo de fadiga, equilibrando as demandas de desempenho e recuperação (Otero-Esquina *et al*., 2017; Gabbet *et al*., 2014).

O desempenho de tarefas motoras complexas e variadas durante uma partida (por exemplo, saltos, sprints, mudanças de direção, desafios físicos e chutes) depende muito da força e da potência dos atletas, que são fundamentais para proteger a força explosiva muscular, manter a estabilidade postural sob altas demandas físicas e otimizar o desempenho técnico (Aktug *et al*., 2015; Stølen *et al*., 2005; Mohr *et al*., 2003; Cometti *et al*., 2001; Wing *et al*., 2020; Lehance *et al*., 2009; Morin *et al*., 2015; Dowson *et al*., 1998). Os músculos do quadríceps femoral estão envolvidos em diferentes tarefas, como corrida, salto e chute de bola, enquanto os músculos isquiotibiais desempenham funções importantes envolvendo extensão de quadril e flexão do joelho em uma contração concêntrica, que também afeta significativamente a força da passada, enquanto atua excentricamente para controlar, desacelerar e estabilizar o joelho (Lehance *et al*., 2009; Ruas *et al*., 2015).

Diferentes metodologias voltadas para o aprimoramento da força têm sido aplicadas a jogadores de futebol e se mostraram eficazes, incluindo treinamento de força por meio de métodos convencionais (Stern *et al*., 2020; de Hoyo *et al*., 2016) ou com ênfase em exercícios excêntricos (Grazioli *et al*., 2023; de Hoyo *et al*., 2015), pliometria (Bedoya *et al*., 2015; Michailidis *et al*., 2013) e métodos alternativos. Embora a literatura aponte para resultados encorajadores, a aplicação prática desses métodos é limitada pela curta pré-temporada, pelo tempo reduzido para recuperação entre as partidas e pelos efeitos de interferência observados quando altas cargas físicas são aplicadas em múltiplas capacidades físicas ao longo da temporada (Branquinho *et al*., 2024; Balagué *et al*., 2024). Além disso, atletas de futebol precisam não apenas melhorar seu desempenho físico, mas também aprimorar suas habilidades técnicas e táticas, tanto individualmente quanto em equipe (Hill-Hass *et al*., 2011). Portanto, otimizar o tempo, as estratégias e a metodologia de treinamento são fatores essenciais para alcançar um alto desempenho, manter o equilíbrio da carga de trabalho e reduzir as taxas de lesões (Otero-Esquina *et al*., 2017; Iacono *et al*., 2017; 2019).

Neste contexto, os jogos reduzidos (JR) representam uma estratégia que pode promover o desenvolvimento integrado de diferentes demandas específicas inerentes às partidas de futebol (Hill-Hass *et al*., 2011; Iacono *et al*., 2017; 2019). Os JR envolvem configurações de jogo modificadas, incluindo alterações do tamanho do campo, no número de jogadores, na

presença do goleiro, no limite de toques na bola e outras restrições, podendo organizar equipes equilibradas ou com vantagens e desvantagens (Hill-Hass *et al*., 2011; Clemente *et al*., 2014). Com essas diversas possibilidades, os JR permitem reproduzir as demandas de movimento do jogo real, incluindo intensidade de esforço e habilidades técnicas, melhorar a tomada de decisão durante situações de fadiga, além de aumentar a motivação e a aceitação entre os atletas em comparação com os métodos tradicionais de treinamento (Clemente *et al*., 2024; Hill-Hass *et al*., 2011; Gabbett *et al*., 2008).

Diversos estudos sugerem que os jogos reduzidos (JR) são eficazes no aprimoramento da aptidão física de jogadores de futebol (Bujalance-Moreno *et al*., 2019; Hill-Hass *et al*., 2011; Iacono *et al*., 2017; 2019; Clemente *et al*., 2024). Por meio dos JR, é possível provocar um estímulo fisiológico significativo nos atletas, desencadear respostas relevantes no sistema cardiovascular e no metabolismo energético (Jeffreys *et al*., 2004), além de promover alterações em marcadores inflamatórios associados ao dano muscular, reforçando assim seu potencial para produzir adaptações nas propriedades neuromusculares (Bekris *et al*., 2022). Enquanto os JR em espaços pequenos aumentam os requisitos de intensidade e o engajamento com a bola, campos maiores aumentam a carga externa, amplificando distâncias de sprint e corrida em velocidades mais altas (Hill-Hass *et al*., 2011; Iacono *et al*., 2017; 2019; Clemente *et al*., 2024). Assim, os JR demonstraram ser eficazes no aumento da capacidade aeróbica e anaeróbica, como o aumento do tempo até a exaustão, da capacidade de sprints repetidos e das habilidades de mudança de direção (Bujalance-Moreno *et al*., 2019; 2020; Dellal *et al*., 2012; Rodríguez-Fernández *et al*., 2016; Jastrzebski *et al*., 2014). No entanto, Otero-Esquina *et al.* (2017) identificaram que atletas que participaram de duas sessões semanais de treinamento de força, pliometria e arrasto de trenó apresentaram melhorias no desempenho de potência, velocidade e agilidade durante tarefas de salto e corrida, em relação ao grupo que realizou apenas os treinamentos específicos do futebol. Esses achados indicam a necessidade de compreender o efeito dos JR no desenvolvimento da aptidão física, uma vez que os JR podem oferecer um contexto prático para integrar diferentes metodologias de treinamento.

A literatura também destaca diversas limitações, desafios e lacunas relacionadas aos JR. A variedade de formatos dificulta o gerenciamento das cargas individuais dos atletas (Hill-hass *et al*., 2011; Iacono *et al*., 2019). Além disso, as diferentes respostas individuais, influenciadas pela posição do jogador, funções, habilidade técnica, níveis de condicionamento físico e motivação, podem alterar significativamente o estímulo fisiológico entre os jogadores

e afetar negativamente o desenvolvimento físico individual (Hůlka & Strniště, 2021; Makar *et al*., 2023; Iacono *et al*., 2019). Apesar do crescente corpo de pesquisas examinando os efeitos fisiológicos e de desempenho dos JR, pouca atenção tem sido dedicada à variabilidade interindividual. Além disso, existem lacunas na literatura sobre as respostas ao treinamento baseado em JR no desenvolvimento das propriedades neuromusculares, como estímulo ao aumento de massa magra, força e resistência muscular (Feng *et al*., 2025), bem como sobre seus efeitos no equilíbrio e no risco de lesões (Cezarino *et al*., 2021). Para o nosso conhecimento, não há evidências sobre os efeitos do treinamento de futebol baseado em JR nas adaptações de força e resistência muscular dos membros inferiores, particularmente no que diz respeito às adaptações entre os membros (dominante e não-dominante) e às mudanças na composição corporal. Compreender os efeitos do treinamento sobre as propriedades neuromusculares baseado exclusivamente nos JR pode contribuir para treinadores e preparadores físicos ajustarem de forma mais precisa as rotinas de treinamento, visando otimizar o desempenho, promover equilíbrio muscular e reduzir a incidência de lesões.

Até este ponto, contextualizamos os elementos que influenciam diretamente o processo complexo de desenvolvimento da aptidão física de jovens atletas. As referências utilizadas para fundamentar a proposta desta tese, especialmente em estudos longitudinais sobre trajetórias de desenvolvimento, têm se baseado, tradicionalmente, em testes máximos de capacidades físicas, tais como força, velocidade, agilidade, potência e resistência, como ferramentas de avaliação (Carvalho *et al*., 2017; 2019; Phillipaerts *et al*., 2006). Avaliações de sprint e de salto são amplamente utilizadas para avaliar as capacidades explosivas e o potencial de aceleração dos jogadores, servindo como indicadores confiáveis das capacidades neuromusculares. Entre os testes de salto, o salto contramovimento (CMJ) é particularmente valioso para avaliar a força dos membros inferiores e a eficiência do ciclo alongamento-encurtamento, que são essenciais para mudanças rápidas de direção, saltos verticais e o desempenho geral durante a partida (Markovic *et al*., 2004; Slimani *et al*., 2016). Testes de sprint em distâncias de 10, 15, 20 e 30 metros são comumente utilizados para quantificar a aceleração e a velocidade máxima, oferecendo insights sobre a capacidade do jogador de realizar ações de alta intensidade e sprints repetidos durante o jogo (Haugen *et al*., 2014; Abargoueinejad *et al*., 2021). Adicionalmente, para avaliar essas qualidades neuromusculares, déficits de força, assimetrias entre membros, relação isquiotibiais-quadríceps e índice de fadiga, vários estudos têm utilizado testes isocinéticos, focando especialmente nos músculos isquiotibiais e quadríceps. Essa abordagem mede o pico de torque (PT) nos flexores e extensores do joelho e é amplamente reconhecida

por sua utilidade na identificação de desequilíbrios musculares, no monitoramento de adaptações ao treinamento e no suporte a decisões de retorno ao jogo após lesão (Grazioli *et al*., 2023; Baroni *et al*., 2020; Asimakidis *et al*., 2024; Sangnier, Tourney-Chollet, 2007).

No entanto, conforme mencionado, a capacidade de sustentar altos níveis de desempenho ao longo do jogo é tão importante quanto a produção de força, velocidade e potência para um atleta de elite (Stolen *et al*., 2005; Reilly & Bangsbo, 2000; Vigne *et al*., 2010; Hammami *et al*., 2017; Barnes *et al*., 2014). Fadiga é o termo utilizado para definir a redução do desempenho desejado, a partir das limitações nas funções físicas e cognitivas (Gandevia, 2001; Enoka e Duchateau, 2016). No futebol, a fadiga afeta não apenas o desempenho físico, mas também compromete a execução técnica e a tomada de decisões (Allen *et al*., 2008; Mohr *et al*., 2003). Essa diminuição das capacidades do atleta é resultado de uma complexa interação entre centrais e periféricos, incluindo redução do impulso neural e alterações nas propriedades contráteis musculares, desequilíbrios iônicos e depleção de substratos energéticos (Allen *et al*., 2008; Glaister *et al*., 2005; Gaitanos *et al*., 1993).

Como mencionado, testes máximos de sprint e salto são amplamente utilizados para avaliar as capacidades explosivas e o potencial de aceleração dos jogadores, como indicadores confiáveis das capacidades neuromusculares. A partir destas avaliações, protocolos de avaliação de específicos para o futebol foram desenvolvidos para melhor simular o contexto do jogo (Buchheit *et al*., 2010). Testes de sprints repetidos são amplamente utilizados para avaliar a capacidade anaeróbica e monitorar o decréscimo na velocidade máxima ao longo de esforços repetidos (Jiménez-Reyes *et al*., 2016, 2018). Já os testes utilizando o CMJ fornecem informações valiosas sobre a produção de potência dos membros inferiores e permitem o monitoramento da fadiga em contextos de esportes coletivos (Armada-Cortés *et al*., 2022). A sensibilidade do CMJ para detectar fadiga favorece a implementação de protocolos envolvendo saltos após séries de sprints máximos ou após sessões de treinamento e partidas, possibilitando quantificar o declínio no desempenho explosivo ao longo dos esforços (Jiménez-Reyes *et al*., 2018). Em contraste, avaliações laboratoriais, como a dinamometria isocinética, são consideradas o padrão-ouro para mensurar tanto a força quanto a fadiga muscular em condições específicas e controladas, especialmente nos extensores e flexores do joelho (Ekstrand *et al*., 2016; Baroni *et al*., 2020). Portanto, enquanto os testes máximos avaliam o potencial neuromuscular máximo do atleta, os testes de resistência à fadiga avaliam a capacidade de sustentar o desempenho sob esforços repetidos ou prolongados de alta intensidade.

Depender exclusivamente de avaliações máximas pode negligenciar elementos críticos do desempenho da partida, ressaltando a importância de avaliações suplementares que combinem avaliações de capacidades máximas com tolerância à fadiga. Apesar das correlações entre capacidades neuromusculares serem amplamente discutidas na literatura sobre futebol (Newmann *et al*., 2004; Keiner *et al*., 2014; Morel *et al*., 2015; Dowson *et al*., 1998), até onde sabemos, nenhum estudo examinou a relação entre avaliações de desempenho neuromuscular máximo (incluindo velocidade, potência e força) com avaliações de resistência à fadiga em jogadores de futebol, representando uma lacuna crítica na literatura.

Questionamos, portanto, a correlação entre os níveis máximos de velocidade de corrida, de altura de salto e de pico de torque e a capacidade de sustentar os altos níveis de desempenho em situações de fadiga. Refletir sobre essa temática pode contribuir para interpretações mais precisas acerca das limitações da avaliação por testes máximos, além de indicar caminhos para futuras pesquisas, na intenção de ampliar o entendimento sobre questões complexas como o desenvolvimento longitudinal da aptidão física de jovens atletas de futebol.

Portanto, a presente tese, ao se inserir neste contexto de desenvolvimento longo, complexo e altamente seletivo, objetiva olhar para diferentes elementos de maneira longitudinal e individualizada, para ser capaz de contribuir com informações relevantes tanto para o contexto prático de treinamento e formação de atletas quanto para o contexto metodológico, apontando possíveis caminhos para próximos estudos.

1.1 OBJETIVOS

1.1.1 Objetivo Geral:

Descrever, de forma longitudinal, o desenvolvimento da aptidão física de jovens atletas de futebol brasileiros, considerando a influência da idade cronológica, a maturação biológica, a exposição competitiva e a metodologia de treinamento.

1.1.2 Objetivos Específicos

- Descrever o desenvolvimento longitudinal dos parâmetros de crescimento e aptidão física em atletas masculinos de futebol de um clube brasileiro, considerando tanto a idade cronológica quanto a idade biológica;
- Analisar os efeitos longitudinais do status de exposição de atletas aos jogos no desenvolvimento da aptidão física de jogadores de futebol masculinos de um clube brasileiro, considerando tanto a idade cronológica quanto a idade biológica;
- Descrever as adaptações no desempenho neuromuscular e na composição corporal de jovens jogadores de futebol ao longo de 12 semanas durante uma fase de competição, considerando exclusivamente treinamentos baseados em jogos reduzidos;
- Avaliar as respostas individuais dos atletas às intervenções de treinamento, identificando variações entre os jogadores;
- Investigar diferenças bilaterais no desempenho neuromuscular, comparando perna dominante e não dominante;
- Analisar fatores relacionados à composição corporal que possam influenciar as respostas individuais ao treinamento;
- Verificar a correlação entre os níveis máximos obtidos em testes de desempenho neuromuscular e diversos indicadores de fadiga;
- Verificar a correlação entre diferentes protocolos de avaliação da fadiga.

REFERÊNCIAS

ABARGHOUEINEJAD, M. *et al*. Motor performance in male youth soccer players: a systematic review of longitudinal studies. Sports, v. 9, n. 4, p. 1–16, 2021.

AKTUĞ, Z. B.; HARBILI, E.; HARBILI, S. Comparison of isokinetic knee strength between the dominant and non-dominant legs and relationships among isokinetic strength, vertical jump, and speed performance in soccer players. Turkiye Klinikleri Journal of Sports Sciences, v. 8, n. 1, p. 8-14, jan. 2016.

ALBALADEJO-SAURA, M. *et al*. Relationship between biological maturation, physical fitness, and kinanthropometric variables of young athletes: a systematic review and meta-analysis. International Journal of Environmental Research and Public Health, v. 18, n. 1, p. 1–20, 2021.

ALBUQUERQUE, M. R. *et al*. Relative age effect and ACTN3 R577X and ACE I/D polymorphisms in Brazilian football players: an association genetic study. Research Quarterly for Exercise and Sport, p. 1-11, 2024.

ALLEN, D. G.; LAMB, G. D.; WESTERBLAD, H. Skeletal muscle fatigue: cellular mechanisms. Physiological Reviews, v. 88, n. 1, p. 287-332, jan. 2008.

ALTARRIBA-BARTES, A.; PEÑA, J.; VICENS-BORDAS, J.; MILÀ-VILLAROEL, R.; CALLEJA-GONZÁLEZ, J. Post-competition recovery strategies in elite male soccer players. Effects on performance: a systematic review and meta-analysis. PLoS One, v. 15, n. 10, e0240135, 2 out. 2020.

ANDERSON, L.; ORME, P.; DI MICHELE, R.; CLOSE, G. L.; MILSOM, J.; MORGANS, R.; DRUST, B.; MORTON, J. P. Quantification of seasonal-long physical load in soccer players with different starting status from the English Premier League: implications for maintaining squad physical fitness. International Journal of Sports Physiology and Performance, v. 11, p. 1038–1046, 2016.

ARMADA-CORTÉS, E.; BENÍTEZ-MUÑOZ, J. A.; SAN JUAN, A. F.; SÁNCHEZ-SÁNCHEZ, J. Evaluation of neuromuscular fatigue in a repeat sprint ability, countermovement jump and hamstring test in elite female soccer players. International Journal of Environmental Research and Public Health, v. 19, n. 22, p. 15069, 16 nov. 2022.

BANGSBO, J. Fitness training in football – a scientific approach. Bangsvaerd: HO Storm, 1994.

BANGSBO, J.; MOHR, M.; KRUSTRUP, P. Physical and metabolic demands of training and match-play in the elite football player. Journal of Sports Sciences, v. 24, p. 665–674, 2006.

BARNES, C. *et al*. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BARONI, B. M.; RUAS, C. V.; RIBEIRO-ALVARES, J. B.; PINTO, R. S. Hamstring-to-quadriceps torque ratios of professional male soccer players: A systematic review. *The Journal of Strength & Conditioning Research*, v. 34, n. 1, p. 281–293, 2020.

BARREIRA, J.; NAKAMURA, F. Y.; FERREIRA, R.; PEREIRA, J.; AQUINO, R.; FIGUEIREDO, P. Season match loads of a Portuguese under-23 soccer team: differences

between different starting statuses throughout the season and specific periods within the season using global positioning systems. Sensors (Basel), v. 22, n. 17, p. 6379, 24 ago. 2022.

BEDOYA, A. A.; MILTENBERGER, M. R.; LOPEZ, R. M. Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. Journal of Strength & Conditioning Research, v. 29, n. 8, p. 2351–2360, 2015.

BEKRIS, E.; BOURDAS, D. I.; MYLONIS, E.; ISPIRLIDIS, I.; ZACHARAKIS, E. D.; KATIS, A. Effect of 3 vs. 3 soccer small-sided game on various performance, inflammatory, muscle damage and hormonal indicators in semi-professional players. *Sports*, v. 10, n. 7, p. 102, 2022.

BEUNEN, G.; MALINA, R. M. Growth and biologic maturation: relevance to athletic performance. *The Young Athlete*, v. 1, p. 3–17, 2008.

BIDAURRAZAGA-LETONA, I. *et al*. Longitudinal field test assessment in a Basque football youth academy: a multilevel modeling framework to partition effects of maturation. International Journal of Sports Medicine, v. 36, n. 3, p. 234–240, 2015.

BIDAURRAZAGA-LETONA, I. *et al*. Progression in youth football: selection and identification in youth football players aged 13–15 years. Journal of Strength & Conditioning Research, v. 33, n. 9, p. 2548–2558, 2017.

BRANQUINHO, L.; DE FRANÇA, E.; TEIXEIRA, J. E.; TITTON, A.; LEITE DE BARROS, L. F.; CAMPOS, P.; MARINHO, D. A.; FORTE, P.; CAPERUTO, E. C.; THOMATIELI DOS SANTOS, R. V.; FERRAZ, R. Identifying the ideal weekly training load for in-game performance in an elite Brazilian soccer team. Frontiers in Physiology, v. 15, p. 1341791, 2024.

BUCHHEIT, M.; SAMOZINO, P.; GLYNN, J. A.; SIMPSON, B.; AL HADDAD, H.; MENDEZ-VILLANUEVA, A.; MORIN, J. B. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. Journal of Sports Sciences, v. 32, n. 20, p. 1906–1913, 2014.

BUJALANCE-MORENO, P.; LATORRE-ROMÁN, P. Á.; GARCÍA-PINILLOS, F. A systematic review on small-sided games in football players: acute and chronic adaptations. Journal of Sports Sciences, v. 37, n. 8, p. 921–949, 2019.

CARLING, C.; LE GALL, F.; MALINA, R. M. Body size, skeletal maturity, and functional characteristics of elite academy football players on entry between 1992 and 2003. Journal of Sports Sciences, v. 30, p. 1683–1693, 2012.

CARVALHO, H. M. *et al*. Growth, functional capacities and motivation for achievement and competitiveness in youth basketball: an interdisciplinary approach. Journal of Sports Science, p. 1–7, 2017a.

CARVALHO, H. M. *et al*. Influence of coaches on sources of enjoyment in youth basketball. Revista de Psicologia del Deporte, v. 26, p. 143–148, 2017b.

CARVALHO, H. M. *et al*. Longitudinal changes of functional capacities among adolescent female basketball players. Frontiers in Physiology, v. 10, p. 339, 2019.

CASTILLO-RODRÍGUEZ, A.; GONZÁLEZ-TÉLLEZ, J. L.; FIGUEIREDO, A.; CHINCHILLA-MINGUET, J. L.; ONETTI-ONETTI, W. Starters and non-starters soccer players in competition: is physical performance increased by the substitutions? BMC Sports Science, Medicine and Rehabilitation, v. 15, n. 1, p. 33, 2023.

CEZARINO, L. G.; DA SILVA GRÜNINGER, B. L.; SILVA, R. S. Injury profile in a Brazilian first-division youth soccer team: a prospective study. Journal of Athletic Training, v. 55, n. 3, p. 295–302, 2020.

CLEMENTE, F.; PILLITTERI, G.; VIEIRA, L. H. P.; RABBANI, A.; ZMIJEWSKI, P.; BEATO, M. Balancing the load: a narrative review with methodological implications of compensatory training strategies for non-starting soccer players. Biology of Sport, v. 41, n. 4, p. 173–185, 2024.

COELHO E SILVA, M. J. *et al*. Growth, maturation, functional capacities and sport-specific skills in 12–13 year-old basketball players. Journal of Sports Medicine and Physical Fitness, v. 50, n. 2, p. 174–181, 2010.

COMETTI, G.; MAFFIULETTI, N. A.; POUSSON, M.; CHATARD, J. C.; MAFFULLI, N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. International Journal of Sports Medicine, v. 22, n. 1, p. 45–51, 2001.

CUMMING, S. P.; HILL, M.; JOHNSON, D.; PARR, J.; TEUNNISEN, J. W.; MALINA, R. M. Growth and maturation. In: *Science and Soccer*. Abingdon: Routledge, 2023. p. 329–345.

DE HOYO, M.; GONZALO-SKOK, O.; SAÑUDO, B.; CARRASCAL, C.; PLAZA-ARMAS, J. R.; CAMACHO-CANDIL, F.; OTERO-ESQUINA, C. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. Journal of Strength & Conditioning Research, v. 30, n. 2, p. 368–377, 2016.

DE HOYO, M.; POZZO, M.; SAÑUDO, B.; CARRASCO, L.; GONZALO-SKOK, O.; DOMÍNGUEZ-COBO, S.; MORÁN-CAMACHO, E. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. *International Journal of Sports Physiology and Performance*, v. 10, n. 1, p. 46–52, 2015.

DELLAL, A.; OWEN, A.; WONG, D. P.; KRUSTRUP, P.; VAN EXSEL, M.; MALLO, J. Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science*, v. 31, n. 4, p. 957–969, 2012.

DOWSON, M. N.; NEVILL, M. E.; LAKOMY, H. K.; NEVILL, A. M.; HAZELDINE, R. J. Modelling the relationship between isokinetic muscle strength and sprint running performance. Journal of Sports Sciences, v. 16, n. 3, p. 257–265, 1998.

DUPONT, G.; NEDELEC, M.; MCCALL, A.; MCCORMACK, D.; BERTHOIN, S.; WISLØFF, U. Effect of 2 soccer matches in a week on physical performance and injury rate. American Journal of Sports Medicine, v. 38, n. 9, p. 1752–1758, 2010.

EKSTRAND, J.; WALDÉN, M.; HÄGGLUND, M. Hamstring injuries have increased 4% annually in men's professional football since 2001: A 13-year longitudinal analysis of the UEFA elite club injury study. *British Journal of Sports Medicine*, v. 50, n. 12, p. 731–737, 2016.

ENOKA, R. M.; DUCHATEAU, J. Translating fatigue to human performance. *Medicine and Science in Sports and Exercise*, v. 48, n. 11, p. 2228, 2016.

ESKANDARIFARD, E.; SILVA, R.; NOBARI, H.; CLEMENTE, F. M.; PÉREZ-GÓMEZ, J.; FIGUEIREDO, A. J. Maturational effect on physical capacities and anabolic hormones in under-16 elite footballers: a cross-sectional study. Sport Sciences for Health, v. 18, n. 2, p. 297–305, 2022.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. Journal of Sports Sciences, v. 30, n. 7, p. 625–631, 2012.

FIGUEIREDO, A. J. *et al*. Characteristics of youth soccer players who drop out, persist or move up. Journal of Sports Sciences, v. 27, n. 9, p. 883–891, 2009a.

FIGUEIREDO, A. J. *et al*. Youth soccer players, 11–14 years: maturity, size, function, skill and goal orientation. Annals of Human Biology, v. 36, n. 1, p. 60–73, 2009b.

GABBETT, T. J.; MULVEY, M. J. Time-motion analysis of small-sided training games and competition in elite women soccer players. Journal of Strength & Conditioning Research, v. 22, n. 2, p. 543–552, mar. 2008.

GABBETT, T. J.; WHYTE, D. G.; HARTWIG, T. B.; WESCOMBE, H.; NAUGHTON, G. A. The relationship between workloads, physical performance, injury and illness in adolescent male football players. Sports Medicine, v. 44, n. 7, p. 989–1003, 2014.

GAITANOS, G. C.; WILLIAMS, C.; BOOBIS, L. H.; BROOKS, S. Human muscle metabolism during intermittent maximal exercise. Journal of Applied Physiology, v. 75, n. 2, p. 712–719, 1993.

GANDEVIA, S. C. Spinal and supraspinal factors in human muscle fatigue. Physiological Reviews, v. 81, n. 4, p. 1725–1789, 2001.

GIMÉNEZ, J. V.; LEICHT, A. S.; GOMEZ, M. A. Physical performance differences between starter and non-starter players during professional soccer friendly matches. Journal of Human Kinetics, v. 69, p. 283–291, 2019.

GLAISTER, M. Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. Sports Medicine, v. 35, n. 9, p. 757–777, 2005.

GONÇALVES, L. G.; NOBARI, H.; RITES, A. A.; NAKAMURA, F. Y.; GARCIA, G. R.; AQUINO, R. Influence of contextual factors on match running performance of starters and non-starters in elite youth male soccer players. Science Progress, v. 107, n. 2, Art. 368504241239187, 2024.

GRAZIOLI, R.; INÁCIO, M.; LOPEZ, P.; FREITAS, S. R.; CUNHA, G. D. S.; MACHADO, C. L. F.; VEECK, F.; BARONI, B. M.; CADORE, E. L.; PINTO, R. S. Effects of eccentric-emphasized leg curl intervention on muscle strength imbalance markers in professional soccer players during pre-season. Journal of Bodywork and Movement Therapies, v. 35, p. 28–32, 2023.

HAMMAMI, A. *et al*. Blood pressure, heart rate and perceived enjoyment after small-sided soccer games and repeated sprint in untrained healthy adolescents. Biology of Sport, v. 34, n. 3, p. 219, 2017.

HAUGEN, T. A.; TØNNESSEN, E.; SEILER, S. Anaerobic performance testing of professional soccer players 1995–2010. *International Journal of Sports Physiology and Performance*, v. 8, n. 2, p. 148–156, 2013.

HILL-HAAS, S. V.; DAWSON, B.; IMPELLIZZERI, F. M.; COUTTS, A. J. Physiology of small-sided games training in football: a systematic review. Sports Medicine, v. 41, n. 3, p. 199–220, 2011.

HUIJGEN, B. C. H. *et al*. Development of dribbling in talented youth football players aged 12–19 years: a longitudinal study. Journal of Sports Sciences, v. 28, n. 7, p. 689–698, 2010.

HUIJGEN, B. C. H. *et al*. Multidimensional performance characteristics in selected and deselected talented football players. European Journal of Sport Science, v. 14, n. 1, p. 2–10, 2014.

HŮLKA, K.; STRNIŠTĚ, M. Fitness improvements of young soccer players after high volume or small sided games interventions. Biology of Sport, v. 38, n. 4, p. 573–578, 2021.

IACONO, A. D.; BEATO, M.; UNNITHAN, V. Effects of game profile–based training and small-sided games on physical performance of elite young soccer players. *The Journal of Strength & Conditioning Research*, [s. l.], 2019.

IACONO, A. D.; MARTONE, D.; CULAR, D.; MILIC, M.; PADULO, J. Game profile–based training in soccer: A new field approach. *The Journal of Strength & Conditioning Research*, v. 31, n. 12, p. 3333–3342, 2017.

JANUSIAK, M.; SILVA, A. F.; SILVA, R.; KOSENDIAK, A.; BOGDAŃSKI, B.; SMOTER, M.; PRAÇA, G.; CLEMENTE, F. M. Testing variations between starters and substitute players in terms of total distance, high-speed running, and sprinting distance: a descriptive study on professional male soccer players. Biology of Sport, v. 41, n. 2, p. 95–103, 2024.

JASTRZEBSKI, Z.; BARNAT, W.; DARGIEWICZ, R.; JASKULSKA, E.; SZWARC, A.; RADZIMIŃSKI, Ł. Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. *International Journal of Sports Science & Coaching*, v. 9, n. 5, p. 1169–1179, 2014.

JEFFREYS, I. The use of small-sided games in the metabolic training of high school soccer players. Strength and Conditioning Journal, v. 26, n. 5, p. 77–78, 2004.

JIMÉNEZ-REYES, P.; PAREJA-BLANCO, F.; CUADRADO-PEÑAFIEL, V.; MORCILLO, J. A.; PÁRRAGA, J. A.; GONZÁLEZ-BADILLO, J. J. Mechanical, metabolic and perceptual response during sprint training. International Journal of Sports Medicine, v. 37, n. 10, p. 807–812, 2016.

JIMÉNEZ-REYES, P.; PAREJA-BLANCO, F.; CUADRADO-PEÑAFIEL, V.; ORTEGA-BECERRA, M.; PÁRRAGA, J.; GONZÁLEZ-BADILLO, J. J. Jump height loss as an indicator of fatigue during sprint training. Journal of Sports Sciences, v. 37, n. 9, p. 1029–1037, 2019.

JULLIEN, H.; BISCH, C.; LARGOUËT, N.; MANOUVRIER, C.; CARLING, C. J.; AMIARD, V. Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players? Journal of Strength & Conditioning Research, v. 22, n. 2, p. 404–411, 2008.

KEINER, M.; SANDER, A.; WIRTH, K.; HARTMANN, H.; YAGHOBI, D. Correlations between maximal strength tests at different squat depths and sprint performance in adolescent soccer players. American Journal of Sports Science, v. 2, n. 1, p. 1–7, 2014.

KELLY, A. L.; WILLIAMS, C. A. Physical characteristics and the talent identification and development processes in male youth football: A narrative review. Strength & Conditioning Journal, v. 42, n. 6, p. 15–34, 2020

LEHANCE, C.; BINET, J.; BURY, T.; CROISIER, J. L. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scandinavian Journal of Medicine & Science in Sports, v. 19, n. 2, p. 243–251, 2009.

LEONARDI, T. J. *et al*. Biological maturation, training experience, body size and functional capacity of adolescent female basketball players: A Bayesian analysis. International Journal of Sports Science and Coaching, v. 13, n. 5, p. 713–722, 2018.

LIMA, A. B.; QUINAUD, R. T.; GONÇALVES, C. E.; CARVALHO, H. M. Peak height velocity in young athletes: A longitudinal meta-analysis. Journal of Sports Sciences, v. 41, n. 2, p. 151–163, 2023.

MAKAR, P.; SILVA, A.; KAWCZYŃSKI, A.; AKYILDIZ, Z.; YILDIZ, M.; PRAÇA, G.; CLEMENTE, F. Variability of peak speed and sprinting actions during the same small-sided games: within- and between-player variations inspected over four consecutive weeks. *Biology of Sport*, v. 40, n. 4, p. 959–965, 2023.

MALINA, R. M. *et al*. Height, mass and skeletal maturity of elite Portuguese football players aged 11–16 years. Journal of Sports Sciences, v. 18, n. 9, p. 685–693, 2000.

MALINA, R. M.; BOUCHARD, C.; BAR-OR, O. Growth, maturation, and physical activity. Champaign: Human Kinetics, 2009.

MARKOVIC, G.; DIZDAR, D.; JUKIC, I.; CARDINALE, M. Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research*, v. 18, n. 3, p. 551–555, 2004.

MEYLAN, C. *et al*. Talent identification in football: The role of maturity status on physical, physiological and technical characteristics. International Journal of Sports Science & Coaching, v. 5, n. 4, p. 571–592, 2010.

MICHAILIDIS, Y.; FATOURES, I. G.; PRIMPA, E.; MICHAILIDIS, C.; AVLONITI, A.; CHATZINIKOLAOU, A.; KAMBAS, A. Plyometrics' trainability in preadolescent soccer athletes. Journal of Strength & Conditioning Research, v. 27, n. 1, p. 38–49, 2013.

MOHR, M.; KRUSTRUP, P.; BANGSBO, J. Fatigue in soccer: a brief review. *Journal of Sports Sciences*, v. 23, n. 6, p. 593–599, 2005.

MOHR, M.; KRUSTRUP, P.; BANGSBO, J. Match performance of high-standard soccer players with special reference to development of fatigue. Journal of Sports Sciences, v. 21, n. 7, p. 519–528, 2003.

MORIN, J. B.; GIMENEZ, P.; EDOUARD, P.; ARNAL, P.; JIMENEZ-REYES, P.; SAMOZINO, P.; MENDIGUCHIA, J. Sprint acceleration mechanics: The major role of hamstrings in horizontal force production. *Frontiers in Physiology*, v. 6, n. DEC, 2015

NÉDÉLEC, M.; MCCALL, A.; CARLING, C.; LEGALL, F.; BERTHOIN, S.; DUPONT, G. Recovery in soccer: Part I – post-match fatigue and time course of recovery. Sports Medicine, v. 42, n. 12, p. 997–1015, 2012.

NEWMAN, M. A.; TARPENNING, K. M.; MARINO, F. E. Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players. Journal of Strength and Conditioning Research, v. 18, n. 4, p. 867–872, 2004.

OLIVA-LOZANO, J. M. *et al*. Acceleration and sprint profiles of professional male football players in relation to playing position. PloS One, v. 15, n. 8, e0236959, 2020.

OLIVA-LOZANO, J. M.; FORTES, V.; LÓPEZ-DEL CAMPO, R.; RESTA, R.; MUYOR, J. M. When and how do professional soccer players experience maximal intensity sprints in LaLiga? Science and Medicine in Football, v. 7, n. 3, p. 288–296, 2023.

OTERO-ESQUINA, C.; DE HOYO LORA, M.; GONZALO-SKOK, Ó.; DOMÍNGUEZ-COBO, S.; SÁNCHEZ, H. Is strength-training frequency a key factor to develop performance adaptations in young elite soccer players? European Journal of Sport Science, v. 17, n. 10, p. 1241–1251, 2017.

PEÑA-GONZÁLEZ, I.; FERNÁNDEZ-FERNÁNDEZ, J.; MOYA-RAMÓN, M.; CERVELLÓ, E. Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. Research Quarterly for Exercise and Sport, v. 89, n. 3, p. 373–379, 2018.

PEÑA-GONZÁLEZ, I.; JAVALOYES, A.; CERVELLÓ, E.; MOYA-RAMÓN, M. The maturity status but not the relative age influences elite young football players' physical performance. Science and Medicine in Football, v. 6, n. 3, p. 309–316, 2022.

PHILIPPAERTS, R. M. *et al*. The relationship between peak height velocity and physical performance in youth football players. Journal of Sports Sciences, v. 24, n. 3, p. 221–230, 2006.

PONS, E. *et al*. A comparison of a GPS device and a multi-camera video technology during official football matches: Agreement between systems. PloS One, v. 14, n. 8, e0220729, 2019.

REILLY, T. *et al*. A multidisciplinary approach to talent identification in football. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

REILLY, T.; BANGSBO, J.; FRANKS, A. Anthropometric and physiological predispositions for elite football. Journal of Sports Sciences, v. 18, n. 9, p. 669–683, 2000.

RMSTRONG, N. *Development of the youth athlete*. Abingdon: Routledge, 2019.

RODRÍGUEZ-FERNÁNDEZ, A.; RODRÍGUEZ-MARROYO, J. A.; CASAMICHANA, D.; VILLA, J. G. Effects of 5-week pre-season small-sided-game-based training on repeat sprint ability. *The Journal of Sports Medicine and Physical Fitness*, v. 57, n. 5, p. 529–536, 2016.

RUAS, C. V.; MINOZZO, F.; PINTO, M. D.; BROWN, L. E.; PINTO, R. S. Lower-extremity strength ratios of professional soccer players according to field position. Journal of Strength and Conditioning Research, v. 29, n. 5, p. 1220–1226, 2015.

SANGNIER, S.; TOURNY-CHOLLET, C. Study of the fatigue curve in quadriceps and hamstrings of soccer players during isokinetic endurance testing. Journal of Strength and Conditioning Research, v. 22, n. 5, p. 1458–1467, 2008.

SLIMANI, M.; CHAMARI, K.; MIARKA, B.; DEL VECCHIO, F. B.; CHEOUR, F. Effects of plyometric training on physical fitness in team sport athletes: a systematic review. *Journal of Human Kinetics*, v. 53, p. 231, 2016.

STERN, D.; GONZALO-SKOK, O.; LOTURCO, I.; TURNER, A.; BISHOP, C. A comparison of bilateral vs. unilateral-biased strength and power training interventions on measures of physical performance in elite youth soccer players. *The Journal of Strength & Conditioning Research*, v. 34, n. 8, p. 2105–2111, 2020.

STØLEN, T.; CHAMARI, K.; CASTAGNA, C.; WISLØFF, U. Physiology of soccer: an update. *Sports Medicine*, v. 35, n. 6, p. 501–536, 2005.

SUAREZ-ARRONES, L.; LARA-LOPEZ, P.; TORRENO, N.; SAEZ DE VILLARREAL, E.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Effects of strength training on body composition in young male professional soccer players. *Sports*, v. 7, n. 5, p. 104, 2019.

SUAREZ-ARRONES, L.; PETRI, C.; MALDONADO, R. A.; TORRENO, N.; MUNGUÍA-IZQUIERDO, D.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Body fat assessment in elite soccer players: cross-validation of different field methods. *Science and Medicine in Football*, v. 2, n. 3, p. 203–208, 2018.

VAEYENS, R. *et al*. A multidisciplinary selection model for youth football: The Ghent Youth Football Project. British Journal of Sports Medicine, v. 40, n. 11, p. 928–934, 2006.

VAEYENS, R.; LENOIR, M.; WILLIAMS, A. M.; PHILIPPAERTS, R. M. Talent identification and development programmes in sport: current models and future directions. Sports Medicine, v. 38, n. 9, p. 703–714, 2008.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. Pediatric Exercise Science, v. 24, p. 603–621, 2012.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. Pediatric Exercise Science, v. 24, p. 603–621, 2012.

VARJAN, M.; HANK, M.; KALATA, M.; CHMURA, P.; MALA, L.; ZAHALKA, F. Weekly training load differences between starting and non-starting soccer players. *Journal of Human Kinetics*, v. 90, p. 125, 2023.

VIGNE, G. *et al*. Activity profile in elite Italian football team. International Journal of Sports Medicine, v. 31, n. 5, p. 304–310, 2010.

WILLIAMS, M.; FORD, P.; DRUST, B. Talent identification and development in soccer since the millennium. Journal of Sports Sciences, v. 38, n. 11–12, p. 1199–1210, 2020.

WING, C. E.; TURNER, A. N.; BISHOP, C. J. Importance of strength and power on key performance indicators in elite youth soccer. Journal of Strength and Conditioning Research, v. 34, n. 7, p. 2006–2014, 2020.

2. ARTIGO 1

LONGITUDINAL DEVELOPMENT OF PHYSICAL FITNESS IN YOUNG FOOTBALL PLAYERS: A BAYESIAN ANALYSIS

Artur G. Berger; Humberto M. Carvalho; Marcelo F. S. Cardoso; Jonatan Oliveira; Vitor A. Delavald; Ronei S. Pinto; Thiago J. Leonardi

Research Quarterly for Exercise and Sport, https://www.tandfonline.com/doi/abs/10.1080/02701367.2025.2558190.
Publicado em 18/09/2025.

ABSTRACT

Purpose: This study investigated developmental changes in body size and physical fitness parameters in 76 young football players (12.22 ± 1.20 years; CI: 10.59–15.04 years) from a Brazilian club across 20 months. **Methods:** Players performed jumping, agility, intermittent endurance, and sprint tests. A Bayesian multilevel regression modeling approach was used to analyze performance relative to both chronological age (CA) and age at peak height velocity (PHV). **Results:** The results indicate that stature and body mass increased non-linearly, while skinfold measurements remained stable across the period investigated. Physical fitness performance aligned more consistently with age at PHV than CA, and Bayesian models accounting for age at PHV exhibit greater homogeneity. **Conclusion:** These findings emphasize the importance of considering biological maturation when interpreting body size and performance changes in young football players. Considering both CA and age at PHV helps select more suitable training strategies throughout the long-term development process and enhances fairness while reducing the risk of overlooking potential talents in the athlete selection process.

Keywords: Growth; Multilevel regression; Jump; Sprint.

INTRODUCTION

Football is an intermittent sport characterized by alternating periods of high-intensity efforts and recovery (Bangsbo *et al*., 2006; Vigne *et al*., 2010; Oliva-Lozano *et al*., 2020). During a match, high-level adult athletes typically cover 10 to 12 km, with 5% to 15% of that distance performed at high intensity (Bangsbo, 1994; Reilly *et al*., 2000; Oliva-Lozano *et al*., 2020). Young football players also face high physical demands, usually covering about 10 km per game, with 24.5% of their activity at high intensities (Sánchez-Sánchez *et al*, 2021). Recent analyses of major football leagues worldwide indicate that while total distance covered has remained relatively stable, the frequency of intense movements has increased (Barnes *et al*., 2014; Pons *et al*., 2019). Furthermore, the demands of the final minutes of matches have also intensified (Oliva-Lozano *et al*., 2023). Short-duration activities, such as accelerations, changes of direction, jumps, and ball-related actions, are closely associated with critical moments of the game (Barnes *et al*., 2014; Faude *et al*., 2012; Reilly *et al.*, 2000; Bangsbo, 1994). Consequently, developing the ability to generate force and speed in complex game situations and movements, and to sustain these efforts throughout the match, is crucial for competitive football performance (Reilly & Bangsbo, 2000; Vigne *et al*., 2010).

A successful football career is determined by interaction among physical, technical, psychological, sociological, motivational, and contextual factors over time (Huijgen *et al*., 2014; Kelly & Williams, 2020; Reilly *et al*., 2000; Williams *et al*., 2020). However, talent identification processes are increasingly occurring at younger ages, often favoring individuals born in the early months of the year and/or those who experience early peak growth velocity (Albaladejo-Saura *et al*., 2021; Albuquerque *et al*., 2024; Bidaurrazaga-Letona *et al*., 2017; Carvalho *et al*., 2017; Malina *et al*., 2000; Meylan *et al*., 2010; Peña-Gonzales *et al*., 2018; 2022; Reilly *et al*., 2000; Vaeyens *et al*., 2006; Valente-dos-Santos *et al*., 2012). While biological maturation follows a common pattern, it is not linear, and its timing and tempo vary significantly between individuals (Carvalho *et al*., 2017; 2019; Leonardi *et al*., 2018; Malina *et al*., 2009). Within the same age group, substantial variations in hormonal levels, skeletal age, body mass, and stature can be observed. Therefore, young athletes who mature early often show temporarily increased physical abilities, such as strength, power, and aerobic endurance (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022).

Studies indicate that there is no direct relationship between the age at peak height velocity (PHV) and adult stature (Malina *et al*., 2009), and early maturation does not inherently predict superior adult performance, as functional development curves typically align with the timing of PHV (Carvalho *et al*., 2017; Philippaerts *et al*., 2006). That is, early physical advantages may not persist over time and can lead to biased talent identification if long-term potential is overlooked (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022). Therefore, although anthropometric and physical characteristics are still frequently used for talent identification and selection in youth football, their ability to predict professional career success remains uncertain (Carling *et al*., 2012; Figueiredo *et al*., 2009).

To guide longitudinal development, models such as the Youth Physical Development Model (YPDM) have been proposed. The YPDM focuses on biological maturity instead of CA as the foundation for training strategies, thereby improving adaptations and lowering injury risk (Lloyd & Oliver, 2012). Nonetheless, the model's assumptions are mostly theoretical and require empirical validation through longitudinal data that reflect the complexity and individual differences in athlete development. Despite the recognized importance of identifying individual growth and performance trajectories, longitudinal assessments of physical fitness remain relatively scarce in the literature (Armstrong, 2019; Bidaurrazaga-Letona *et al*., 2015; Huijgen *et al*., 2010, 2014). These assessments allow researchers to monitor changes in physical characteristics over time at both group and individual levels, providing valuable insights into the influence of biological maturation on physical performance and variations in training response over time, thereby enabling training strategies to be more effective (Abarghoueinejad *et al*., 2021; Malina *et al*., 2009).

However, research on physical fitness development in young athletes has mostly relied on cross-sectional designs, which provide limited insight into long-term developmental pathways (Carvalho *et al*., 2017). Although a few longitudinal studies exist, they are typically conducted in structured training environments and predominantly focus on European samples (Abarghoueinejad *et al*., 2021; Lima *et al*., 2023), often involving relatively homogeneous populations. This raises questions about the generalizability of their findings to more diverse contexts, such as Brazilian youth football, where athletes are exposed to distinct cultural, socioeconomic, and training conditions. To date, longitudinal studies describing the physical development of young Brazilian football athletes are lacking. Furthermore, studies rarely account for biological maturation using longitudinal approaches, despite its well-documented

influence on performance and selection processes. Therefore, this study aims to describe developmental changes in growth and physical fitness parameters in male football athletes from a Brazilian club, using both CA and an estimated mean age at PHV to approximate maturational timing.

METHODOLOGY

Sample and design

This study used a mixed longitudinal design, with six measurement time points spanning three competitive seasons from August of 2022 to March of 2024, totalizing 20 months of follow-up. Assessments were conducted at three distinct phases within each competitive year: pre-competition (assessments 3 and 6), competition (assessments 1 and 4), and post-competition (assessments 2 and 5).

The sample comprised 76 young male football athletes, aged between 10.6 and 15.0 years (mean age 12.2 years), from under-11, under-12, under-13, under-14, under-15, and under-17 categories of a football club located in Vale do Taquari, Rio Grande do Sul, Brazil. Athletes were included if they completed a minimum of three assessments. The observations distribution was as follows: 13 athletes completed all six assessments (17.11% of the total sample), 21 completed five (27,63%), 17 completed four (22,37%), and 25 completed three (32,89%). The club participating in this study competed in regional and state-level competitions organized by the Rio Grande do Sul Football Federation. Athletes in the under-12, under-13, and under-14 categories engaged in three weekly two-hour training sessions. Athletes in the under-15 and under-17 categories participated in four weekly two-hour training sessions, in addition to weekend competitive or friendly matches.

Ethical approval for this study was granted by the research ethics committee at the local University. All athletes and their parents or legal guardians signed the informed consent and assent (Apêndices A, B e C). This study adhered to the ethical principles outlined in the Declaration of Helsinki (World Medical Association, 2013).

Procedures

Age and anthropometry

CA was calculated as the number of days between the date of birth and the assessment, expressed to the nearest 0.1 years, using the formula:

$$Age = (((year_{observation} - Year_{birth})x365.2 + ((Month_{observation} - Month_{birth})x30.5) + (Day_{observation} - Day_{birth})/365.2$$

Stature and body mass were measured using standardized procedures (Lohman, Roche, & Martorell, 1988). Stature was recorded to the nearest 0.1 cm using a portable stadiometer (Seca model 206, Hanover, MD), and body mass was measured to the nearest 0.1 kg using a calibrated portable balance (Seca model 770, Hanover, MD). Skinfold thicknesses (triceps, subscapular, abdominal, pectoral, anterior thigh, and calf) were measured using a Cescorf® scientific caliper (85 mm capacity, 0.1 mm accuracy), following the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Marfell-Jones, Stewart, & De Ridder, 2012). The sum of these skinfolds served to evaluate subcutaneous fat, not the fat percentage. The pattern of variation in repeated measurements was used to determine the typical error of measurement (Hopkins, 2000). The typical measurement error was 4.7% for skinfold analysis and 0.1% for stature measurement.

Physical fitness parameters

Countermovement Jump (CMJ)

Lower limb vertical jump performance was assessed using the countermovement jump (CMJ) (Bosco *et al.*, 1983; Saéz *et al*., 2008), employing an electronic contact mat (Jump System Pro, Cefise, Nova Odessa, Brazil). Each athlete performed three attempts, with 10 seconds of rest between jumps (Pereira *et al*., 2009). A maximum variation of 3% was allowed between valid attempts, and the highest jump height was recorded for analysis. All jumps were performed bilaterally, with athletes instructed to jump "as strongly, quickly, and powerfully as possible," while keeping their hands on their hips and self-selected knee and ankle flexion.

Long Jump

Lower limb horizontal jump performance was assessed by horizontal jump distance, measured with a tape measure fixed to the floor. Athletes started with feet parallel, behind the

starting line (zero mark), and were instructed to jump as far as possible, using lower limb strength and arm swing. In case of imbalance, the attempt was invalidated, and the athlete repeated the jump after a 1-minute rest. Two valid jumps were performed, with a 1-minute interval between them, and the distance from the starting line to the first landing contact point was recorded to the nearest 0.01 cm.

Sprints

Speed performance was assessed using four pairs of photocells (Cefise, Nova Odessa, Brazil) positioned at 0, 5, 10, and 20 meters. Athletes performed two trials, starting from a standing position 0.3 meters behind the starting line, with a 5-minute rest interval. For analysis, the fastest times recorded at 5, 10, and 20 meters from the best sprint trial were used, rounded to the nearest 0.01 seconds.

Zig-Zag Test (Agility)

Agility was evaluated using the Zig-zag test (Loturco *et al*., 2019). Two photocells (Cefise, Nova Odessa, Brazil) were placed at the start and finish (0 and 20 meters, respectively). The test involved four 5-meter sections, marked by cones at 100° angles, requiring rapid deceleration and acceleration around each cone. Athletes started 0.3 meters behind the first photocell and performed two maximum attempts, with a 5-minute rest between trials. The best time, recorded to the nearest 0.01 second, was used for analysis.

Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1)

Intermittent endurance performance was assessed using the Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) (Bangsbo, 1994). The protocol consisted of repeated 20-meter shuttle runs with a 5-second active recovery period within a 5-meter zone. Audio cues dictated the running pace, which starts at 10km/h and rapidly increases during the initial stages (e.g., from 10 to 13.5 km/h in the first four stages). After that, it progresses in more gradual increments (e.g., 0.5km/h every eight shuttle bouts beyond stage five). The test concluded when an athlete failed to reach the starting line before the audio cue on two consecutive

occasions. The total distance covered (meters) corresponds to the last stage reached and was recorded for further analysis. All the athletes were familiar with this protocol.

Statistical Analysis

To examine developmental changes in physical fitness indicators in young football athletes, we fitted a two-level Bayesian hierarchical growth model (Goldstein, 1986). This model extends previous work from our group (Carvalho *et al*., 2019; Soares *et al*., 2023, Miguel *et al*., 2025), describing variation at two levels: (1) within-athlete changes over time (Level 1), and (2) between-athlete variation in developmental trajectories (Level 2).

Given the mixed longitudinal design with a 20-month observation period (August 2022 to March 2024), CA was included as a time-varying predictor with both linear and quadratic terms to capture potential nonlinearity. Each athlete's repeated measures $y_{athlete_t}$ at age (*t)* were modeled as:

$$y_{athlete_t} \sim Normal(\mu_{athlete_t}, \sigma)$$
$$\mu_{athlete_t} = \alpha_{athlete_t} + \beta^{age}_{athlete_t} + \beta^{age^2}_{athlete_t} + \beta^{age^3}_{athlete_t}$$

Where, $\alpha_{athlete_t}$ is the athlete-specific intercept (baseline level), $\beta^{age}_{athlete_t}$ is the linear slope (rate of change per year), $\beta^{age^2}_{athlete_t}$ is the quadratic slope (acceleration/deceleration), and σ is the residual error. For each athlete, the varying intercept $\alpha_{athlete_t}$ and varying slopes $\beta^{age}_{athlete_t}$ and $\beta^{age^2}_{athlete_t}$ were modeled with a multivariate normal distribution with zero correlations between intercepts and slopes. For computational convenience, the off-diagonal elements were set to zero, indicating zero correlation between the varying intercept α_i and the varying slopes β^{age} and β^{age^2}. This implies that the intercepts and slopes varied independently across athletes:

$$\left[\alpha_{athlete_t}\, \beta^{age}_{athlete_t}\, \beta^{age^2}_{athlete_t}\right] \sim MVNormal(0\ 0\ 0\ , S)$$
$$S = \left[\sigma_\alpha\ 0\ 0\ 0\ \sigma_{\beta^{age}}\ 0\ 0\ 0\ \sigma_{\beta^{age^2}}\right]$$

The variance–covariance matrix S describes between-athlete variability in intercepts and slopes. In our primary models, we assumed no correlation between the intercept and slope parameters. This assumption was based on two considerations: (i) empirical exploration of

initial models did not indicate substantial correlation between intercept and slope estimates across outcomes; (ii) given the imbalanced structure of the mixed-longitudinal design and the limited number of repeated observations per athlete, estimating correlations could introduce identifiability issues and impair convergence.

We acknowledge that with a complete longitudinal observation, intercept–slope dependencies may be expected; however, such effects were not evident in our dataset and were therefore not estimated.

All outcome variables were standardized before modeling by subtracting the sample mean and dividing by two standard deviations (Gelman & Hill, 2007). This procedure improves convergence, allows for interpretation of coefficients as approximate effect sizes, and enhances stability in regularized models by placing predictors on comparable scales, facilitating prior specification and reducing sensitivity to the units of measurement. For selected models, body mass was added as a fixed predictor, also standardized and centered for comparability, to adjust for potential influence of between-athlete variations in body dimensions on maximal short-term power outputs (Carvalho *et al*., 2019; Dore *et al*., 2005; Praagh & Dore, 2002).

Given the inherent noise in physiological outcomes and the imbalanced repeated measures data, we adopted a conservative approach. Weakly informative priors were used to regularize estimates:

$$\alpha = Normal(0,2)$$
$$\beta^{age}, \beta^{age^2} \sim Normal(0,2)$$
$$\alpha = student - t(3,0,2.5)$$
$$\sigma_{\alpha}, \sigma_{\beta^{age}}, \sigma_{\beta^{age^2}} \sim Exponential(1)$$

To enable a biologically informed interpretation of changes in physical fitness, we transformed CA into a centered variable representing years from the population mean age at PHV. Specifically, we subtracted 12.95 years, the estimated average age at PHV in youth sports based on a recent meta-analysis (Lima *et al*., 2023), from each athlete's CA at each measurement. This transformation provides a maturity-related timescale, expressing how many years before or after the estimated population-level PHV each measurement occurred. Although individual-level estimates of age at PHV are preferable, our data lacked the longitudinal resolution needed to support such modeling. Furthermore, widely used anthropometric prediction equations are known to have limited validity in athletic populations

(Carvalho & Gonçalves, 2023). Accordingly, we adopted this conservative, population-level alignment strategy while acknowledging interindividual variability in maturational timing (Carvalho *et al*., 2017; Malina, 1994).

For each model, we ran four chains for 2000 iterations, with a 1000-iteration warm-up, which proved sufficient for convergence and adequate effective sample size. Convergence was assessed using the $\hat{R}$ statistic (Vehtari *et al*., 2021), comparing between-chain and within-chain variances. Convergence was confirmed when $\hat{R}$ was below 1.01 for all parameters and quantities of interest (Vehtari *et al*., 2021).

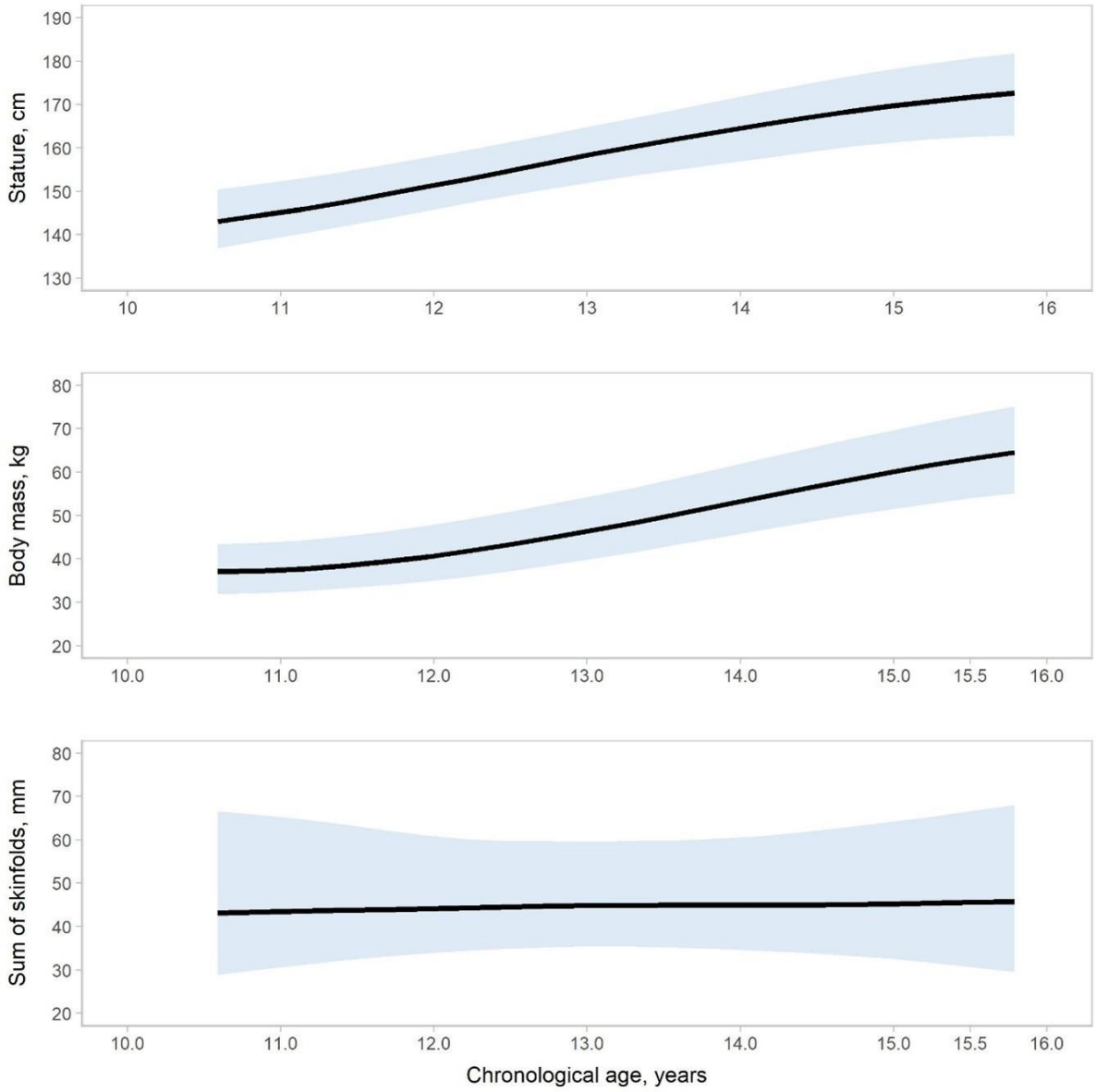
Model adequacy was evaluated through posterior predictive checks (Gabry *et al*., 2019; Vehtari *et al*., 2017) and residual plots, examining whether models produced size-free outcomes when body mass-associated variation was significant.

Models were fitted using R (R Core Team, 2018) with the "brms" package (Bürkner, 2017), which utilizes Stan (Stan Development Team, 2020). Model predictions were extracted with the "tidybayes" package (Kay, 2023) and visualized with the "ggplot2" package (Wickham, 2016).

RESULTS

Table 1 presents the descriptive characteristics of the study sample. Longitudinal changes in stature, body mass, and the sum of skinfolds are depicted in Figure 1. Stature exhibited an initial linear increase from age 10, with a notable acceleration in growth between ages 12 and 13, continuing until age 16. Body mass showed a gradual increase until age 12, followed by a substantial linear increase until approximately age 16. Considerable inter-individual variation was observed for stature and body mass with increasing age. The sum of skinfolds displayed a linear trend throughout the observation period, with greater variability observed in athletes under 11 years and higher values around age 15.

Figure 1 - Growth curves in stature, body mass, and sum of skinfolds



Figures 2, 3, 4, 5, and 6 illustrate the longitudinal changes in physical performance parameters. The long jump, agility, and Yo-Yo IR1 tests demonstrated linear trends, indicating consistent development across the analyzed period. When the data were aligned based on PHV, a notable decrease in the slope was observed for the long jump and agility tests, suggesting a stabilization of development. In contrast, the Yo-Yo IR1 test showed minimal differences.

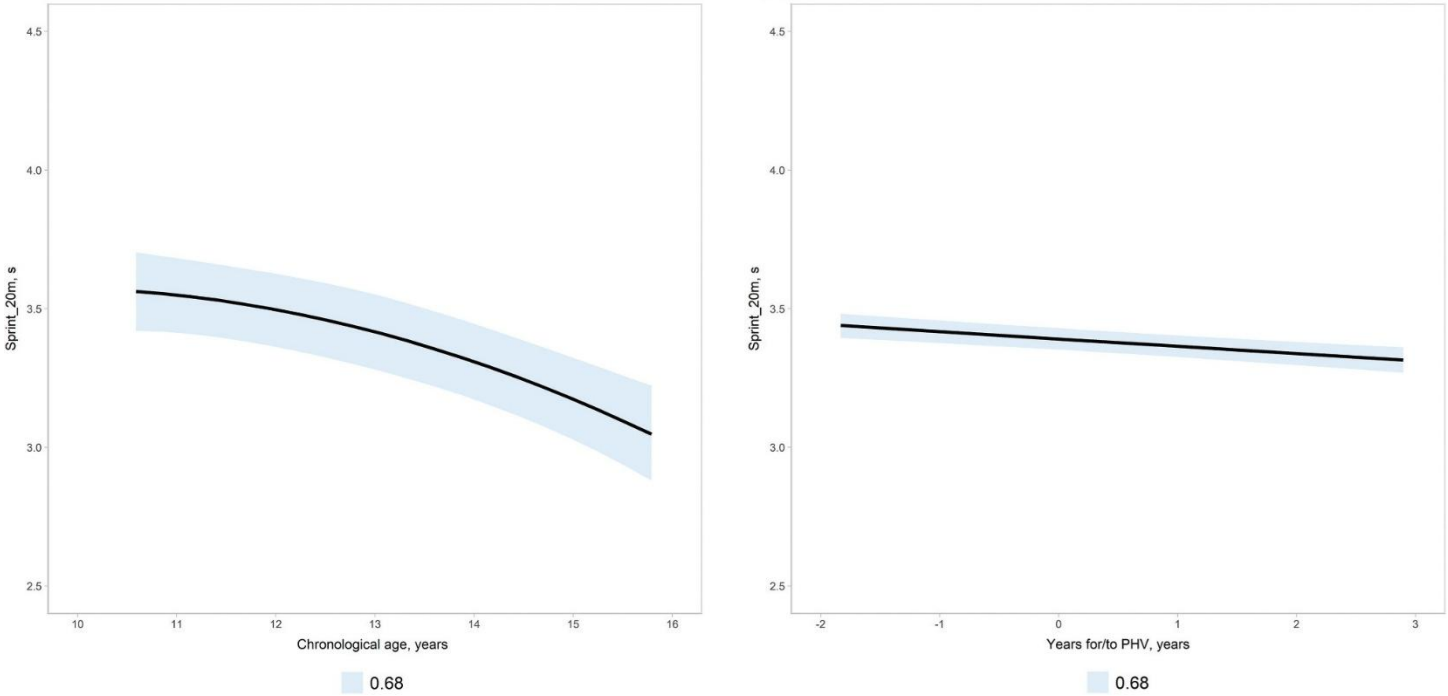
Table 1 - Sample characteristics in alignment by chronological age at baseline

	U-11 (n=14)	U-12 (n=22)	U-13 (n=17)	U-14 (n=16)	U-15 (n=7)	Total (n=76)
Chronological age	10,76 (0,1)	11,43 (0,32)	12,35 (0,43)	13,5 (0,18)	14,4 (0,34)	12,23 (1,20)
Stature (cm)	143,71 (8,36)	146,34 (4,24)	154,22 (6,13)	164,78 (6,71)	169,03 (7,01)	153,65 (10,99)
Body mass (kg)	38,42 (6,47)	40,1 (4,48)	43,81 (7,94)	52,1 (8,30)	61,4 (9,90)	45,28 (10,07)
Sum of skinfold (mm)	45,5 (12,7)	48,33 (11,68)	46,23 (15,01)	51,48 (17,33)	42,12 (10,33)	47,27 (21,71)
CMJ (cm)	27,31 (4,13)	27,84 (3,88)	29,6 (3,74)	31,79 (5,42)	34,44 (7,79)	29,67 (5,11)
Long jump (m)	1,59 (0,15)	1,52 (0,16)	1,6 (0,11)	1,89 (0,18)	2,04 (0,38)	1,69 (0,57)
5 meters (s)	1,18 (0,12)	1,15 (0,15)	1,15 (1,5)	1,16 (0,13)	1,124 (0,17)	1,16 (0,29)
10 meters (s)	1,96 (0,12)	1,85 (0,30)	1,94 (0,15)	1,86 (0,15)	1,91 (0,11)	1,90 (0,42)
20 meters (s)	3,54 (0,22)	3,41 (0,25)	3,51 (0,26)	3,43 (0,20)	3,19 (0,13)	3,44 (0,71)
Agility (s)	5,5 (0,31)	5,46 (0,34)	5,51 (0,37)	5,53 (0,41)	5,53 (0,22)	5,51 (1,12)
Yo-Yo IR 1 (m)	487,1 (164,4)	657,0 (153,2)	702,6 (169,9)	963,6 (280,3)	1296 (406,5)	732 (298,5)

Non-linear changes were observed in the 5-, 10-, and 20-meter sprint tests and the CMJ). When aligned by CA, distinct curvatures were evident between ages 12 and 14 (Figures 2 to 6, left graphs). The 5-meter sprint exhibited the steepest slope, followed by the CMJ, 20-meter, and 10-meter sprints. This indicates that when aligned by CA, earlier developmental advancements were observed in the CMJ and sprint performance. Furthermore, alignment by PHV revealed a more consistent developmental pattern across all tests, though substantial inter-individual variation remained.

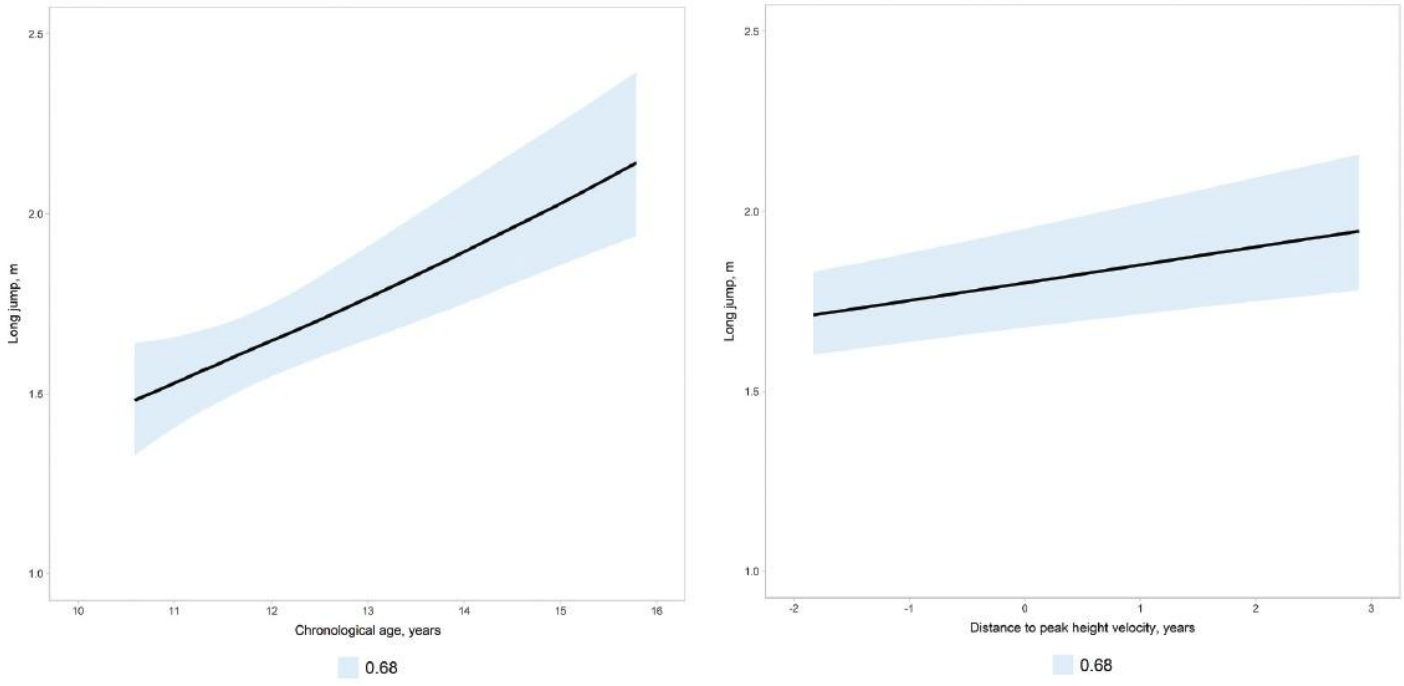
This study aimed to characterize the developmental trajectories of growth and physical performance parameters in young Brazilian football players, taking into account CA and age at PHV, through the application of a Bayesian multilevel regression modeling approach. While longitudinal studies on youth football development exist (Carvalho *et al*., 2017; Philippaerts *et al*., 2006; Bidaurrazaga-Letona, 2015, 2016; Huijgen *et al*., 2010; Valente-dos-Santos *et al*., 2012; Francioni *et al*., 2018), as well as in other sports (Carvalho *et al*., 2019; Kraemer *et al*., 2016; Mendes *et al*., 2021), this study is novel in its longitudinal application of PHV-aligned curves adjusted to a Brazilian football population.

Figure 2 - Physical performance in sprint test



Note: Development curves aligned by CA (left graph) and by PHV (right graph) of the 20-meter sprint test

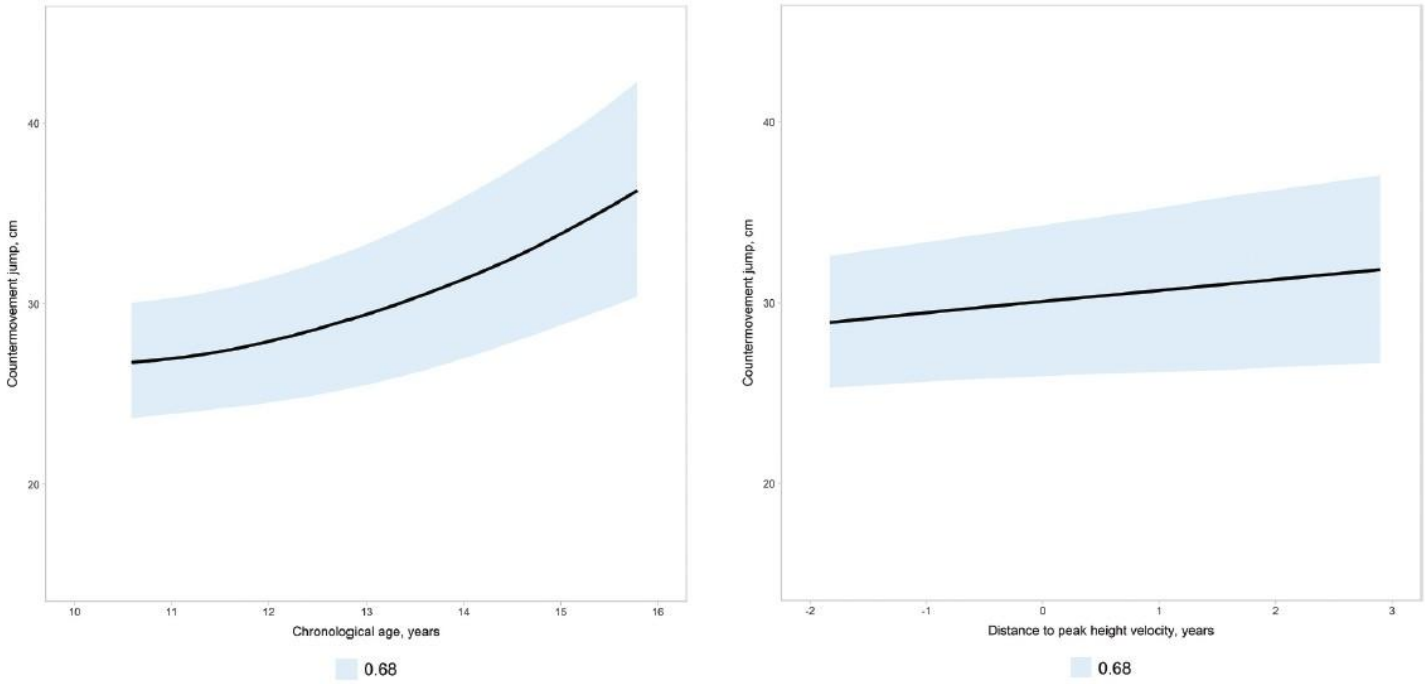
Figure 3 - Physical performance in long jump test



Note: Development curves aligned by CA (left graph) and by PHV (right graph) of the long jump test.

The main results indicated a non-linear growth pattern in stature and body mass, accompanied by a relatively stable sum of skinfolds in athletes aged 10.59 to 15.04 years. There was also a more consistent pattern of physical fitness development when adjusted for age at PHV compared to CA. The differences observed in timing and rates of development related to CA and biological maturity alignments are consistent with the literature and highlight the importance of considering biological maturity in athlete development, training, and selection processes (Lloyd & Oliver, 2012; Carvalho *et al*., 2017; 2019).

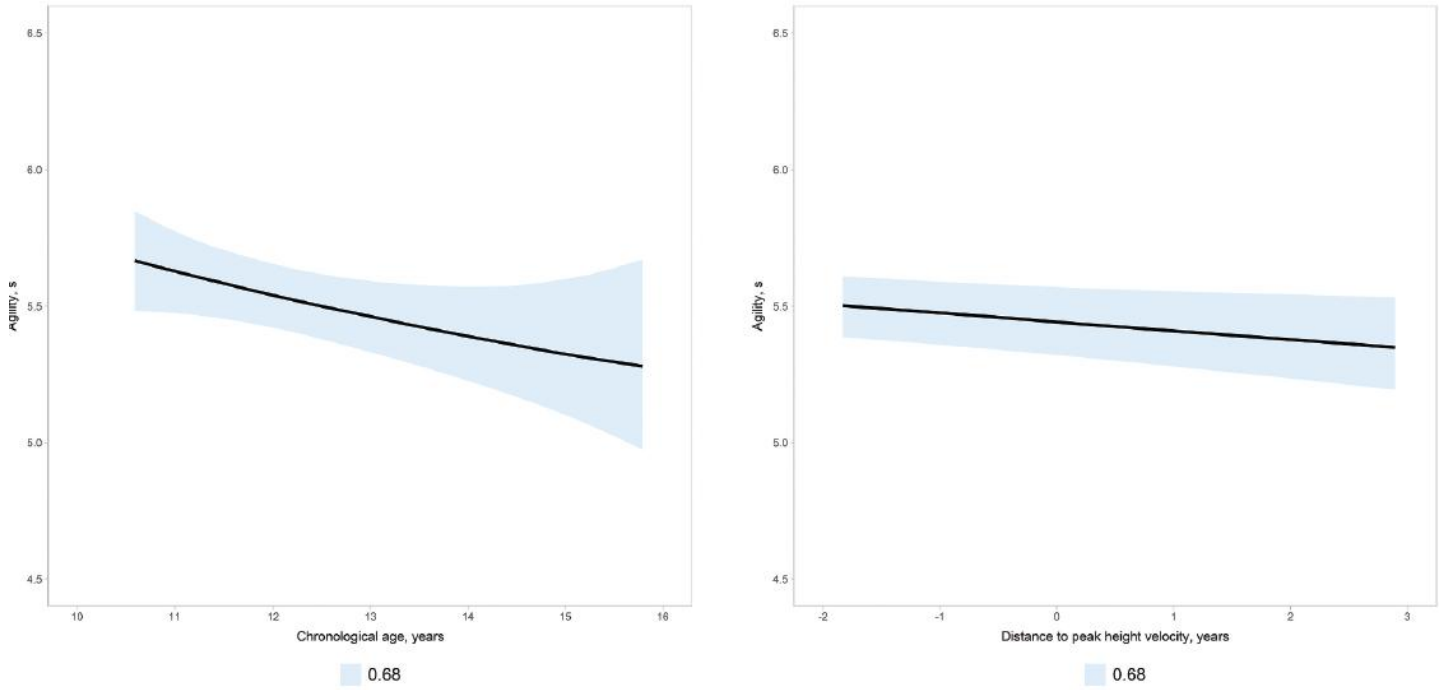
Figure 4 - Physical performance in CMJ test



Note: Development curves aligned by CA (left graph) and by PHV (right graph) of the CMJ test.

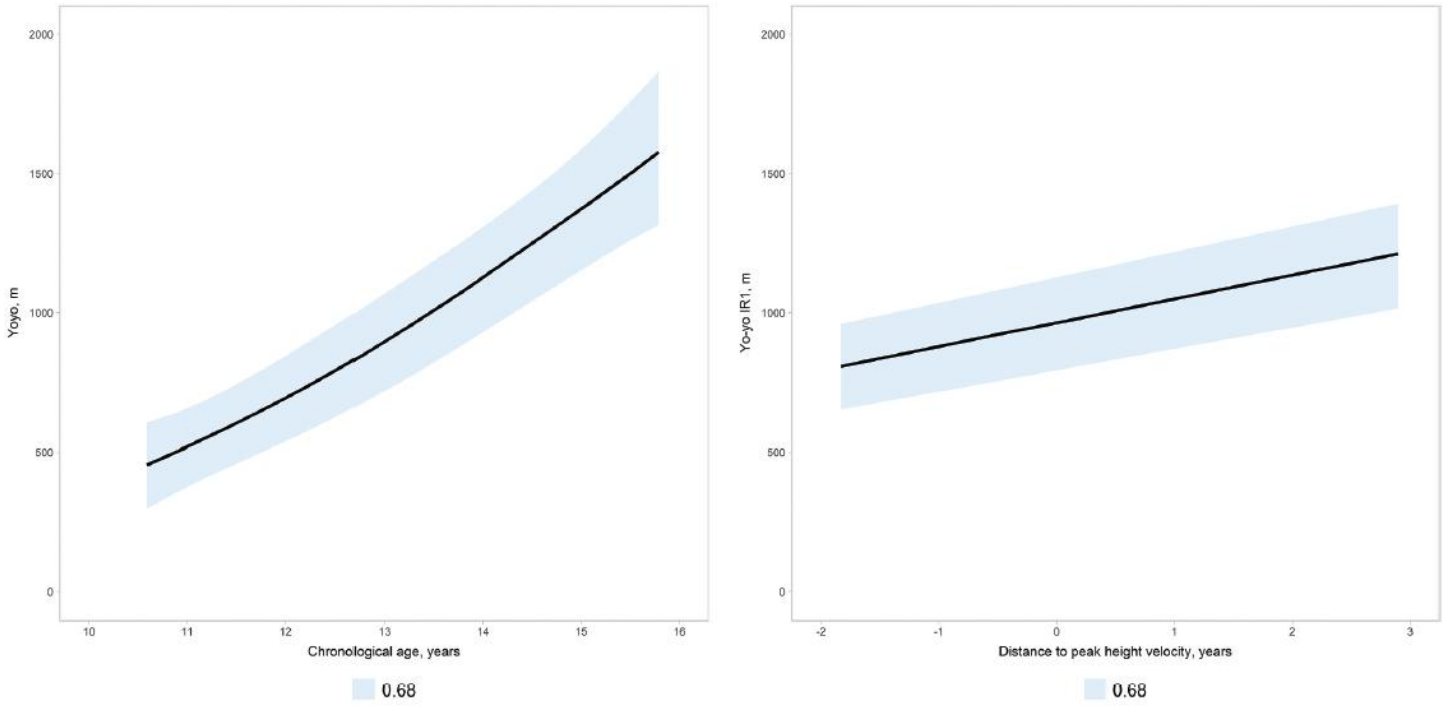
Stature and body mass increased non-linearly, with stature growth preceding body mass gain, consistent with previous research (Malina *et al*., 2009; Carvalho *et al*., 2017). Conversely, some studies report simultaneous stature and body mass increases (Philippaerts *et al*., 2006), potentially reflecting differences in study contexts and competitive levels. The consistent sum of skinfold values, along with the increase in body mass, indicates a growth in fat-free mass, which is typical in young athletes (Malina *et al*., 2009). Longitudinal studies confirm significant lean mass gains post-PHV in male footballers (Deprez *et al*., 2013; Philippaerts *et al*., 2006).

Figure 5 - Physical performance in agility test



Note: Development curves aligned by CA (left graph) and by age at PHV (right graph) of the agility test.

Figure 6 - Physical performance in intermittent endurance test



Note: Development curves aligned by CA (left graph) and by PHV (right graph) of the Yo-yo IR1 test.

The observed non-linear trends in sprint and CMJ tests, particularly around PHV (Figures 2 and 4), indicate accelerated physical performance development. Alignment by age at PHV, compared to CA, revealed a decreased rate of development across jump, sprint, agility, and aerobic intermittent endurance tests. This aligns with findings that biological maturity provides a more uniform developmental assessment (Carvalho *et al*., 2017). While CA-based analyses show higher development rates at younger ages and around PHV (Carvalho *et al*., 2017; Philippaerts *et al*., 2006), intermittent endurance development exhibits a linear development across ages, and it is expected that accelerated gains moments occur post-maturation (Deprez *et al*., 2014; Valente-dos-Santos *et al*., 2012).

These variations in physical developmental rates between CA and PHV alignments highlight the influence of biological factors, genetics, training, and contextual elements on physical development that occur throughout the maturation process. Before PHV, neural changes are predominant; however, after PHV, the effects of training lead to increases in muscle mass, strength, and power, due to a rise in anabolic hormones such as testosterone and growth hormones (Eskandarifarid *et al*., 2022; Lloyd & Oliver, 2012). As shown in Figures 2, 4, and 5, slight improvements are observed in sprint, CMJ, and agility before PHV, demonstrating the impact of the maturational process on physical fitness development and the timing of progress during and after PHV.

Consistent variation patterns across all physical tests in the PHV-aligned model underscore the impact of maturational timing on performance (Malina *et al*., 2009; Carvalho *et al*., 2017, 2019). The variation between individuals suggests that accounting for maturity differences results in a more standardized developmental process, consistent with findings in young female basketball (Carvalho *et al*., 2019) and male football players (Carvalho *et al*., 2017). These results challenge the current recruitment and selection practices in football, favoring biologically advanced individuals (Deprez *et al*., 2013; Albuquerque *et al*., 2024; Baxter-Jones *et al*., 2019; Albaladejo-Saura *et al*., 2021; Meylan *et al*., 2010). This approach increases the risk of prematurely excluding late-developing talents (Albuquerque *et al*., 2024; Carling *et al*., 2012; Figueiredo *et al*., 2009; Deprez *et al*., 2013).

This study has both limitations and strengths. The main limitation is that it was conducted within a single club and included only male athletes aged 10 to 15.5 years, which limits the generalizability of the findings. Future research should aim to include athletes of both sexes and a broader age range. A further limitation concerns the estimation of biological

maturation. Due to insufficient longitudinal growth data, we were unable to estimate individual age at PHV or maturity offset. Instead, we applied a population-level mean PHV (12,95 years) based on recent meta-analytic findings in youth athletes (Lima *et al*., 2023) to approximate maturational alignment. While this approach allows for a conservative, group-level interpretation, it does not account for inter-individual variability in maturation, and this limitation should be considered when interpreting the results. Although observed differences in physical performance trajectories may reflect underlying maturational variation, this interpretation remains speculative. Finally, future studies should consider examining training intensity and monitoring lean mass development to better understand factors contributing to physical fitness trajectories.

The findings emphasize the importance of integrating CA and biological maturity in youth football development assessments. Over-reliance on physical performance during selection risks overlooking late-maturing talents. Incorporating biological maturity allows for meaningful interpretations of young football players' development and supports the formulation of effective long-term developmental strategies. This approach enables the development of more precise training strategies, reduces the risk of injury, and fosters a more consistent selection process, thereby avoiding the exclusion of potential talents who experience later development of physical fitness.

Disclosure statement

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

Data availability statement

The data supporting the findings of this study and the code for reproducing the analyses and figures are publicly available at: https://osf.io/62w3p/.

Acknowledgements

The work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, process number 405316/2021-6). AGB was supported by a grant from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). VAD was supported by a grant from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Author contributions

AGB, HMC and TJL made substantial contributions to the conception or design of the work. AGB, HMC, MFSC, JO, VAD, RSP and TJL made substantial contributions to the data acquisition for the work. AGB, HMC, MFSC, RSP and TJL made substantial contributions to the analysis and interpretation of data. AGB, HMC, MFSC, JO, VAD, RSP and TJL made substantial contributions to drafting the work; AGB, HMC, MFSC, JO, VAD, RSP and TJL made substantial contributions to revising it critically for important intelectual content. AGB, HMC, MFSC, JO, VAD, RSP and TJL approve the content's publication and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the article and approved the submitted version.

REFERENCES

ABARGHOUEINEJAD, M. *et al*. Motor performance in male youth football players: A systematic review of longitudinal studies. *Sports*, v. 9, n. 4, p. 1–16, 2021.

ALBALADEJO-SAURA, M. *et al*. Relationship between biological maturation, physical fitness, and kinanthropometric variables of young athletes: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, v. 18, n. 1, p. 1–20, 2021.

ALBUQUERQUE, M. R. *et al*. Relative Age Effect and ACTN3 R577X and ACE I/D Polymorphisms in Brazilian Football Players: An Association Genetic Study. *Research Quarterly for Exercise and Sport*, p. 1–11, 2024.

ARMSTRONG, N. *Development of the youth athlete*. Routledge, 2019.

BANGSBO, J. *Fitness training in football: A scientific approach*. HO Storm, 1994.

BANGSBO, J.; MOHR, M.; KRUSTRUP, P. Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, v. 24, p. 665–674, 2006.

BARNES, C. *et al*. The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, v. 35, n. 13, p. 1095–1100, 2014.

BIDAURRAZAGA-LETONA, I. *et al*. Longitudinal field test assessment in a Basque football youth academy: A multilevel modeling framework to partition effects of maturation. *International Journal of Sports Medicine*, v. 36, n. 3, p. 234–240, 2015.

BIDAURRAZAGA-LETONA, I. *et al*. Progression in youth football: Selection and identification in youth football players aged 13–15 years. *Journal of Strength & Conditioning Research*, v. 33, n. 9, p. 2548–2558, 2017.

BOSCO, C.; LUHTANEN, P.; KOMI, P. V. A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology*, v. 50, p. 273–282, 1983.

BÜRKNER, P. Brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, v. 80, p. 1–28, 2017.

CARLING, C.; LE GALL, F.; MALINA, R. M. Body size, skeletal maturity, and functional characteristics of elite academy football players on entry between 1992 and 2003. *Journal of Sports Sciences*, v. 30, p. 1683–1693, 2012.

CARVALHO, H. M. *et al*. Pubertal development of body size and football-specific functional capacities in adolescent players. *Research in Sports Medicine*, v. 25, n. 4, p. 421–436, 2017.

CARVALHO, H. M. *et al*. Longitudinal changes of functional capacities among adolescent female basketball players. *Frontiers in Physiology*, v. 10, p. 339, 2019.

CARVALHO, H. M.; GONÇALVES, C. E. Mismatches in youth sports talent development. *Frontiers in Sports and Active Living*, v. 5, p. 1189355, 2023.

DEPREZ, D.; COUTTS, A. J.; FRANSEN, J.; DECONINCK, F. J. A.; LENOIR, M.; VAEYENS, R.; PHILIPPAERTS, R. Relative Age, Biological Maturation and Anaerobic Characteristics in Elite Youth Soccer Players. *International Journal of Sports Medicine*, 2013.

DEPREZ, D.; FRANSEN, J.; LENOIR, M.; PHILIPPAERTS, R.; VAEYENS, R. Characteristics of high-level youth football players: Variation by playing position. *Journal of Sports Sciences*, v. 33, n. 3, p. 243–254, 2015.

DEPREZ, D.; VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; LENOIR, M.; PHILIPPAERTS, R.; VAEYENS, R. Longitudinal development of explosive leg power from childhood to adulthood in football players. *International Journal of Sports Medicine*, v. 36, p. 672–679, 2015.

DORE, E.; MARTIN, R.; RATEL, S. *et al*. Gender differences in peak muscle performance during growth. *International Journal of Sports Medicine*, v. 26, p. 274–280, 2005.

ESKANDARIFARD, E.; SILVA, R.; NOBARI, H.; CLEMENTE, F. M.; PÉREZ-GÓMEZ, J.; FIGUEIREDO, A. J. Maturational effect on physical capacities and anabolic hormones in under-16 elite footballers: a cross-sectional study. *Sport Sciences for Health*, v. 18, n. 2, p. 297–305, 2022.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, v. 30, n. 7, p. 625–631, 2012.

FIGUEIREDO, A. J. *et al*. Characteristics of youth football players who drop out, persist, or move up. *Journal of Sports Sciences*, v. 27, n. 9, p. 883–891, 2009.

FRANCIONI, F. M.; FIGUEIREDO, A. J.; LUPO, C.; TERRIBILI, M.; CONDELLO, G.; TESSITORE, A. Intra-seasonal variation of anthropometrical, conditional, and technical tests in U14 football players. *RICYDE. Revista Internacional de Ciencias del Deporte*, v. 14, n. 53, p. 219–232, 2018.

GABRY, J.; SIMPSON, D.; VEHTARI, A. *et al*. Visualization in Bayesian workflow. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, v. 182, p. 389–402, 2019.

GELMAN, A.; HILL, J. *Data analysis using regression and multilevel/hierarchical models*. Cambridge University Press, 2007.

GOLDSTEIN, H. Efficient statistical modelling of longitudinal data. *Annals of Human Biology*, v. 13, p. 129–141, 1986.

HOPKINS, W. G. Measures of reliability in sports medicine and science. *Sports Medicine*, v. 30, n. 1, p. 1–15, 2000.

HUIJGEN, B. C. H. *et al*. Development of dribbling in talented youth football players aged 12–19 years: A longitudinal study. *Journal of Sports Sciences*, v. 28, n. 7, p. 689–698, 2010.

HUIJGEN, B. C. H. *et al*. Multidimensional performance characteristics in selected and deselected talented football players. *European Journal of Sport Science*, v. 14, n. 1, p. 2–10, 2014.

KAY, M. Tidybayes: Tidy data and geoms for Bayesian models. *Zenodo*, 2023.

KELLY, A. L.; WILLIAMS, C. A. Physical characteristics and the talent identification and development processes in male youth football: A narrative review. *Strength & Conditioning Journal*, v. 42, n. 6, p. 15–34, 2020.

LEONARDI, T. J. *et al*. Biological maturation, training experience, body size and functional capacity of adolescent female basketball players: A Bayesian analysis. *International Journal of Sports Science and Coaching*, v. 13, n. 5, p. 713–722, 2018.

LIMA, A. B.; QUINAUD, R. T.; GONÇALVES, C. E.; CARVALHO, H. M. Peak height velocity in young athletes: A longitudinal meta-analysis. *Journal of Sports Sciences*, v. 41, n. 2, p. 151–163, 2023.

LOHMAN, T. G.; ROCHE, A. F.; MARTORELL, R. *Anthropometric standardization reference manual*. Human Kinetics, 1988.

LOTURCO, I. *et al*. Maximum acceleration performance of professional football players in linear sprints: Is there a direct connection with change-of-direction ability? *PloS One*, v. 14, n. 5, e0216806, 2019.

LLOYD, R. S.; OLIVER, J. L. The youth physical development model: A new approach to long-term athletic development. *Strength & Conditioning Journal*, v. 34, n. 3, p. 61–72, 2012.

MALINA, R. M. Physical growth and biological maturation of young athletes. *Exercise and Sport Sciences Reviews*, v. 22, n. 1, p. 280–284, 1994.

MALINA, R. M. *et al*. Height, mass and skeletal maturity of elite Portuguese football players aged 11–16 years. *Journal of Sports Sciences*, v. 18, n. 9, p. 685–693, 2000.

MALINA, R. M. *et al*. Maturity-associated variation in the growth and functional capacities of youth football (football) players 13–15 years. *European Journal of Applied Physiology*, v. 91, p. 555–562, 2004.

MALINA, R. M.; BOUCHARD, C.; BAR-OR, O. *Growth, maturation, and physical activity*. Human Kinetics, 2009.

MALINA, R. M. *et al*. Observed and predicted ages at peak height velocity in soccer players. *PloS One*, v. 16, n. 7, e0254659, 2021.

MARFELL-JONES, S. *International standards for anthropometric assessment*. 2012.

MENDES, F. G.; NASCIMENTO, J. V.; SOUZA, E. R.; *et al*. Retrospective analysis of accumulated structured practice: A Bayesian multilevel analysis of elite Brazilian volleyball players. *High Ability Studies*, v. 29, p. 255–269, 2018.

MORAES, A. M.; QUINAUD, R. T.; FERREIRA, G. O. C.; *et al*. Age-, sex-, and maturity-associated variation in the phase angle after adjusting for size in adolescents. *Frontiers in Nutrition*, v. 9, 939714, 2022.

MEYLAN, C.; *et al*. Talent identification in football: The role of maturity status on physical, physiological and technical characteristics. *International Journal of Sports Science & Coaching*, v. 5, n. 4, p. 571–592, 2010.

OLIVA-LOZANO, J. M.; *et al*. Acceleration and sprint profiles of professional male football players in relation to playing position. *PloS One*, v. 15, n. 8, e0236959, 2020.

OLIVA-LOZANO, J. M.; FORTES, V.; LÓPEZ-DEL CAMPO, R.; RESTA, R.; MUYOR, J. M. When and how do professional soccer players experience maximal intensity sprints in LaLiga? *Science and Medicine in Football*, v. 7, n. 3, p. 288–296, 2023.

PEÑA-GONZÁLEZ, I.; JAVALOYES, A.; CERVELLÓ, E.; MOYA-RAMÓN, M. The maturity status but not the relative age influences elite young football players' physical performance. *Science and Medicine in Football*, v. 6, n. 3, p. 309–316, 2022.

PEÑA-GONZÁLEZ, I.; FERNÁNDEZ-FERNÁNDEZ, J.; MOYA-RAMÓN, M.; CERVELLÓ, E. Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. *Research Quarterly for Exercise and Sport*, v. 89, n. 3, p. 373–379, 2018.

PEREIRA, G.; MORSE, C.; UGRINOWITSCH, C.; RODACKI, A.; KOKUBUN, E.; FOWLER, N. Manipulation of rest period length induces different causes of fatigue in vertical jumping. *International Journal of Sports Medicine*, v. 30, n. 5, p. 325–330, 2009.

PHILIPPAERTS, R. M.; *et al*. The relationship between peak height velocity and physical performance in youth football players. *Journal of Sports Sciences*, v. 24, n. 3, p. 221–230, 2006.

PONS, E.; *et al*. A comparison of a GPS device and a multi-camera video technology during official football matches: Agreement between systems. *PloS One*, v. 14, n. 8, e0220729, 2019.

PRAAGH, E. V.; DORE, E. Short-term muscle power during growth and maturation. *Sports Medicine*, v. 32, p. 701–728, 2002.

REILLY, T.; *et al*. A multidisciplinary approach to talent identification in football. *Journal of Sports Sciences*, v. 18, n. 9, p. 695–702, 2000.

REILLY, T.; BANGSBO, J.; FRANKS, A. Anthropometric and physiological predispositions for elite football. *Journal of Sports Sciences*, v. 18, n. 9, p. 669–683, 2000.

SAEZ, E. de VILLAREAL; GONZÁLEZ-BADILLO, J. J.; IZQUIERDO, M. Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. *The Journal of Strength & Conditioning Research*, v. 22, n. 3, p. 715–725, 2008.

SANCHEZ-SANCHEZ, *et al*. Heart rate variability and physical demands of in-season youth elite soccer players. *International Journal of Environmental Research and Public Health*, v. 18, n. 4, 1391, 2021.

SOARES, A. L.; LIMA, A. B.; MIGUEL, C. G.; *et al*. Does early specialization provide an advantage in physical fitness development in youth basketball? *Frontiers in Sports and Active Living*, v. 4, 1042494, 2023.

STAN DEVELOPMENT TEAM. *Stan modeling language user's guide and reference manual* (version 2.19.2). Interaction Flow Modeling Language, 2020.

VAEYENS, R.; *et al*. A multidisciplinary selection model for youth football: The Ghent Youth Football Project. *British Journal of Sports Medicine*, v. 40, n. 11, p. 928–934, 2006.

VAEYENS, R.; LENOIR, M.; WILLIAMS, A. M.; PHILIPPAERTS, R. M. Talent identification and development programmes in sport: current models and future directions. *Sports Medicine*, v. 38, n. 9, p. 703–714, 2008.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. *Pediatric Exercise Science*, v. 24, p. 603–621, 2012.

VEHTARI, A.; GELMAN, A.; GABRY, J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, v. 27, p. 1413–1432, 2017.

VEHTARI, A.; GELMAN, A.; SIMPSON, D.; CARPENTER, B.; BÜRKNER, P.-C. Rank-Normalization, Folding, and Localization: An Improved R̂ for Assessing Convergence of MCMC (with Discussion). *Bayesian Analysis*, v. 16, n. 2, p. 667–718, 2021.

VIGNE, G.; *et al*. Activity profile in elite Italian football team. *International Journal of Sports Medicine*, v. 31, n. 5, p. 304–310, 2010.

WICKHAM, H. *Ggplot2: Elegant graphics for data analysis*. Springer, 2016. Disponível em: https://ggplot2.tidyverse.org.

WILLIAMS, A. M.; FORD, P. R.; DRUST, B. Talent identification and development in soccer since the millennium. In: *Science and football*, p. 3–14, 2023.

WORLD MEDICAL ASSOCIATION; *et al*. World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, v. 310, n. 20, p. 2191–2194, 2013.

3. ARTIGO 2

LONGITUDINAL EFFECTS OF COMPETITION EXPOSURE ON PHYSICAL FITNESS DEVELOPMENT IN YOUTH FOOTBALL: A BAYESIAN ANALYSIS

ABSTRACT

Purpose: This study analyzed the longitudinal effects of athletes' exposure status to games on the physical fitness development of male football players from a Brazilian club, using both chronological age (CA) and estimated age at peak height velocity (PHV) to approximate maturational timing. **Methods:** Seventy-six young football players (12.22 ± 1.20 years; CI: 10.59–15.04 years) from a Brazilian club were monitored over 20 months. During the 2022–2024 seasons, coaches classified the athletes as starters, reserves, or did not enter games. Athletes completed assessments of jumping, agility, intermittent endurance, and sprinting. A Bayesian multilevel regression approach was applied to analyze performance development across groups, based on both CA and age at PHV. **Results:** Physical fitness performance was more consistently aligned with age at PHV than with CA. Small differences were observed between starters and reserves, whereas athletes who did not participate in games showed considerably lower development. **Conclusion:** These findings highlight the importance of considering biological maturation when interpreting body size and performance in young football players. Different levels of exposure to training and games resulted in distinct patterns of physical development. Using both CA and age at PHV can support the design of more effective training strategies throughout long-term development and promote fairness by reducing the risk of overlooking late-maturing talents. Moreover, ensuring more balanced training loads and match exposure across athletes may foster a fairer developmental environment and help prevent the early exclusion of potential talents.

Keywords: Growth; Multilevel Regression; Jump; Sprint.

INTRODUÇÃO

Football is a sport characterized by high physical demands, with athletes covering about 10–12 km per match through intermittent efforts. The most intense actions, including jumps, accelerations, and changes of direction, are directly linked to the decisive moments of the game (Bangsbo, 1994; Reilly *et al*., 2000; Faude *et al*., 2012; Barnes *et al*., 2014; Oliva-Lozano *et al*., 2020; Sánchez-Sánchez *et al*., 2021). In recent years, these demands, which have become increasingly greater in top-level leagues, highlight the importance of developing strength and speed crucial for maintaining competitive performance (Reilly & Bangsbo, 2000; Vigne *et al*., 2010; Barnes *et al*., 2014; Pons *et al*., 2019; Oliva-Lozano *et al*., 2023).

The development of a successful football career results from the ongoing interaction among physical, technical, psychological, sociological, motivational, and contextual factors (Huijgen *et al*., 2014; Kelly & Williams, 2020; Reilly *et al*., 2000; Williams *et al*., 2020). Despite this complexity, talent identification programs have been introduced at increasingly younger ages, often favoring athletes with advanced biological maturity and physical fitness. (Albaladejo-Saura *et al*., 2021; Albuquerque *et al*., 2024; Bidaurrazaga-Letona *et al*., 2017; Carvalho *et al*., 2017; Malina *et al*., 2000; Meylan *et al*., 2010; Peña-González *et al*., 2018, 2022; Reilly *et al*., 2000; Vaeyens *et al*., 2006; Valente-dos-Santos *et al*., 2012). Within the same age group, marked differences in bone age, body composition, height, and hormone levels can be observed. These disparities result in athletes who mature early experiencing temporary physical advantages, such as greater strength, power, and aerobic capacity, compared to their later-maturing counterparts (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022).

However, early maturation does not guarantee better athletic performance in adulthood, as functional development curves tend to align with the moment of Peak Height Velocity (PHV) (Carvalho *et al*., 2017; Philippaerts *et al*., 2006). In other words, the physical advantages observed in early stages may not be sustained over time, leading to distortions in talent identification when long-term potential is not considered (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022). In this sense, although anthropometric measurements and physical attributes are widely used in youth soccer selection processes, their effectiveness in predicting professional success remains uncertain (Carling *et al*., 2012; Figueiredo *et al*., 2009). Additionally, there is no direct link between the age at PHV and adult stature (Malina *et al*., 2009), and early maturation does not inherently indicate better

adult performance, as functional development curves usually match the timing of PHV (Carvalho *et al*., 2017; Philippaerts *et al*., 2006). That is, early physical advantages may not last over time and can lead to biased talent identification if long-term potential is ignored (Carling *et al*., 2012; Vaeyens *et al*., 2008; Eskandarifarid *et al*., 2022; Peña-González *et al*., 2022).

Another factor that directly influences the physical development of football players is the loads imposed during matches and training sessions (Phillipaerts *et al*., 2006). The literature shows different patterns in training and match loads experienced by athletes with varying exposure statuses (e.g., starters, reserves, and those who did not enter in games) Starters (STR) generally experience higher match loads than reserves (RSV), including exposure time, total distance, high-intensity running, and accelerations, during competitive games (Anderson *et al*., 2016; Barreira *et al*., 2022; Clemente *et al*., 2024). Conversely, while Janusiak *et al*. (2023) highlight no difference in intensity of efforts between STR and RSV in the final minutes of matches, analyses that adjust loads based on playing time indicate that RSV experiences greater distances and higher intensities (Clemente *et al*., 2024; Castillo-Rodriguez *et al*., 2023). During training sessions, small differences between STR and RSV are observed, particularly concerning running, high-speed running, and sprints. However, it is noted that non-starting players spend more time training and cover greater total distances during sessions, which suggests an attempt to compensate for their reduced match exposure (Anderson *et al*., 2016).

Nonetheless, despite a higher training volume, high-intensity patterns remain similar across groups; these loads might not be sufficient to replicate the specific demands of matches, which could lead to a decline in physical fitness among athletes with less competitive exposure (Clemente *et al*., 2024; Anderson *et al*., 2016; Silva *et al*., 2011). Differences in loads experienced by athletes with different exposure statuses can lead to significant variations in total load accumulated throughout the week, which can affect the development of athletes' physical fitness (Clemente *et al*., 2024; Varjan *et al*., 2023). However, most current studies in youth soccer have used cross-sectional designs, providing only a snapshot of athlete development at a single point in time. Despite the acknowledged importance of tracking individual growth and performance trajectories, research on longitudinal physical fitness data remains limited in the existing literature (Bidaurrazaga-Letona *et al*., 2015; Huijgen *et al*., 2010, 2014). To our knowledge, no study has yet examined the longitudinal growth patterns in young football athletes with different levels of exposure, restricting our understanding of how playing time impacts physical, technical, and tactical development over time. Additionally, we

did not identify studies that consider athletes who are part of the group and participate in training, but do not receive opportunities. Longitudinal assessments enable the observation of changes in physical characteristics at both group and individual levels, offering insights into how biological maturation influences physical performance and response variability to training, ultimately helping to develop more effective training strategies (Abarghoueinejad *et al*., 2021; Malina *et al*., 2009). This gap underscores the need for longitudinal studies that explore the cumulative effects of training and match participation on athlete development.

Specifically, longitudinal studies on the physical development of young Brazilian athletes are scarce. Moreover, the consideration of biological maturation over time is rare, despite its well-documented effect on performance and selection processes. Additionally, there is a lack of research analyzing longitudinal differences in physical demands between starters and reserves in athlete development. Therefore, this study analyzed the longitudinal effects of athletes' exposure status to games on the physical fitness development of male football players from a Brazilian club, using both chronological age (CA) and estimated age at peak height velocity (PHV) to approximate maturational timing.

METHODOLOGY

Sample and Design

This research utilized a mixed longitudinal approach, featuring six assessment periods spanning three football seasons from August 2022 to March 2024, covering a total follow-up period of 20 months. Evaluations took place at three key points within each season: before the competition (assessments 3 and 6), during the competition (assessments 1 and 4), and after the competition (assessments 2 and 5).

The study sample consisted of 76 young male football players aged between 10.6 and 15.0 years, with a mean age of 12.2 years. Participants ranged from under-11 to under-17 categories at a local football club (specific club details anonymized). The inclusion criteria required completion of at least three assessments. The distribution of observations was as follows: 13 players (17.11%) completed all six assessments, 21 players (27.63%) completed five, 17 players (22.37%) completed four, and 25 players (32.89%) completed three.

The club participated in regional and state-level competitions organized by a governing body (details anonymized). Under-12, under-13, and under-14 athletes participated in three

weekly training sessions, each lasting two hours. In contrast, under-15 and under-17 athletes attended four weekly two-hour sessions, plus weekend matches, which were either competitive or friendly.

Ethical approval was obtained from the local university's research ethics committee. All participants, along with their parents or guardians, provided signed informed consent and assent. The study adhered to the principles of the Declaration of Helsinki (World Medical Association, 2013).

Procedures

Age and anthropometry

The chronological age (CA) was determined by calculating the number of days between the date of birth and the assessment date, expressed to the nearest 0.1 years. Stature and body mass were measured according to standardized protocols (Lohman, Roche, & Martorell, 1988). Stature was documented to the nearest 0.1 cm utilizing a portable stadiometer (Seca model 206, Hanover, MD). At the same time, body mass was quantified to the nearest 0.1 kg employing a calibrated portable scale (Seca model 770, Hanover, MD). Skinfold thicknesses, including triceps, subscapular, abdominal, pectoral, anterior thigh, and calf, were measured with a Cescorf® scientific caliper (85 mm capacity, 0.1 mm accuracy) in accordance with the guidelines established by the International Society for the Advancement of Kinanthropometry (Marfell-Jones, Stewart, & De Ridder, 2012). These skinfolds were summed to evaluate subcutaneous adipose tissue, though not the overall body fat percentage. Variations in repeated measurements were utilized to calculate the typical error of measurement, following Hopkins (2000). The typical measurement errors were found to be 4.7% for skinfold assessments and 0.1% for stature measurements.

Physical fitness parameters

Countermovement Jump (CMJ)

Lower limb vertical jump performance was assessed using the CMJ (Bosco *et al*., 1983; Saéz *et al*., 2008), employing an electronic contact mat (Jump System Pro, Cefise, Nova Odessa, Brazil). Each athlete performed three attempts, with 10 seconds of rest between jumps

(Pereira *et al*., 2009), and the highest jump height was recorded for analysis. All jumps were performed bilaterally, with athletes instructed to jump "as strongly, quickly, and powerfully as possible," while keeping their hands on their hips and self-selected knee and ankle flexion.

Long Jump

Lower limb horizontal jump performance was assessed by measuring horizontal jump distance using a tape measure fixed to the floor. Athletes started with their feet parallel, behind the starting line (zero mark), and were instructed to jump as far as possible, utilizing lower limb strength and arm swing. If an imbalance occurred, the attempt was invalidated, and the athlete repeated the jump after a 1-minute rest. Two valid jumps were performed, and the distance from the starting line to the first landing contact point was recorded to the nearest 0.01 cm.

Sprints

Speed performance was evaluated using four pairs of photocells (Cefise, Nova Odessa, Brazil) positioned at 0, 5, 10, and 20 meters. Athletes completed two trials, starting from a standing position 0.3 meters behind the starting line, with a 5-minute rest interval. For analysis, the fastest times at 5, 10, and 20 meters from the best sprint trial were used, rounded to the nearest 0.01 seconds.

Zig-Zag Test (Agility)

Agility was assessed using the Zig-zag test (Loturco *et al*., 2019). Two photocells (Cefise, Nova Odessa, Brazil) were placed at 0 and 20 meters, marking the start and finish points. The test involved four 5-meter sections, marked by cones at 100° angles, requiring rapid deceleration and acceleration around each cone. Athletes started 0.3 meters behind the first photocell and performed two maximum efforts, with a 5-minute rest between trials. The best time, recorded to the nearest 0.01 second, was used for analysis.

Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1)

Intermittent endurance was tested using the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Bangsbo, 1994). The protocol involved repeated 20-meter shuttle runs with a 5-second active recovery period within a 5-meter zone. Audio cues dictated the running pace, starting at 10 km/h and increasing rapidly during the initial stages (e.g., from 10 to 13.5 km/h in the first four stages). Afterward, the pace increased more gradually (e.g., 0.5 km/h every

eight shuttle bouts beyond stage five). The test ended when an athlete failed to reach the starting line before the audio cue on two consecutive occasions. The total distance covered (meters) corresponds to the last stage reached and was recorded for further analysis. All athletes were familiar with this protocol.

Level of match exposure throughout the season

Athlete exposure during the competitive season was evaluated through an online questionnaire constructed via Google Forms. Each coach received a document listing the complete squad of athletes within their respective age group (Under-12, Under-13, Under-14, Under-15, and Under-17) and was instructed to assess the exposure level of each athlete, considering participation in official matches. These assessments were performed for each team across the 2022, 2023, and 2024 seasons. Based on the evaluations, athletes were divided into three categories: (1) starter (STR): athletes who mainly start most matches as first-choice players; (2) Reserve (RSV): athletes who frequently serve as substitutes and occasionally start in the first team; or (3) Did not participate in games (DNPG): athletes who rarely or do not participate in matches and mainly take part in training sessions.

Statistical Analysis

To analyze developmental changes in physical fitness among young football athletes, we used a two-level Bayesian hierarchical growth model (Goldstein, 1986). This approach builds on our previous research (Carvalho *et al*., 2019; Soares *et al*., 2023; Miguel *et al*., 2025; Berger *et al*., 2025), capturing two types of variation: (1) changes within individuals over time and within groups (Level 1), and (2) differences in CA and developmental trajectories between athletes (Level 2).

In our study, which employed a 20-month mixed longitudinal design (from August 2022 to March 2024), we included CA, time, and their interaction as linear predictors. In the primary models, we assumed no correlation between intercept and slope parameters. This choice was based on two reasons: (i) initial model exploration showed no significant correlation between intercept and slope estimates across various outcomes; (ii) due to the uneven structure of the data and limited repeated measures per athlete, estimating these correlations could cause identifiability problems and hinder convergence. Although complete

longitudinal data might suggest dependencies between the intercept and slope, such effects were not observed in our dataset and were therefore not modeled.

All outcome variables were standardized prior to modeling by subtracting the sample mean and dividing by two standard deviations (Gelman & Hill, 2007). This approach improves convergence, enables coefficients to be interpreted as approximate effect sizes, and increases stability in regularised models by putting predictors on similar scales. It also facilitates prior specification and reduces the impact of measurement units.

Considering the noise inherent in physiological outcomes and the imbalance in repeated measures data, we took a cautious approach. To facilitate a biologically meaningful interpretation of changes in physical fitness, we converted CA into a centered variable indicating years from the population's mean age at PHV. Specifically, we subtracted 12.95 years- derived from a recent meta-analysis (Lima *et al*., 2023), from each athlete's CA at each measurement. This transformation creates a maturity-related timescale that indicates the number of years before or after the estimated population-level PHV each measurement occurred. While individual estimates of age at PHV would be ideal, our data lacked the longitudinal detail necessary for such modeling. Additionally, common anthropometric prediction equations are known to be less valid in athletic populations (Carvalho & Gonçalves, 2023). Therefore, we used this conservative, population-level alignment strategy, understanding that there is variability in maturational timing among individuals (Carvalho *et al*., 2017; Malina, 1994).

For each model, we ran four chains of 2000 iterations each, with a 1000-iteration warm-up. This approach was sufficient for achieving convergence and obtaining a suitable effective sample size. We assessed convergence using the $\hat{R}$ statistic (Vehtari *et al*., 2021), which compares between-chain and within-chain variances. Convergence was confirmed when $\hat{R}$ was below 1.01 for all parameters and quantities of interest (Vehtari *et al*., 2021).

Model adequacy was assessed using posterior predictive checks (Gabry *et al*., 2019; Vehtari *et al*., 2017) and residual plots to determine if the models produced size-independent outcomes, particularly when body mass variation was substantial. The models were fit in R (R Core Team, 2018) with the "brms" package (Bürkner, 2017), which relies on Stan (Stan Development Team, 2020). Model predictions were obtained via the "tidybayes" package

(Kay, 2023) and visualized using "ggplot2" (Wickham, 2016). Data and scripts are available at https://osf.io/anw6e/?view_only=237f260c61a444ebbdf41a56d8920998.

RESULTS

Table 1 shows the descriptive characteristics of the study sample at baseline. Longitudinal changes in stature, body mass, and the sum of skinfolds for each group are previously published (Berger *et al*., 2025). Figures 1, 2, 3, 4, and 5 (left graphs) demonstrate the development of neuromuscular performance across the three groups analyzed, aligned by CA.

Table 1 - Sample characteristics at baseline

	U-11 (n=14)	U-12 (n=22)	U-13 (n=17)	U-14 (n=16)	U-15 (n=7)	Total (n=76)
Chronological age	10.76 (0.1)	11.43 (0.32)	12.35 (0.43)	13.5 (0.18)	14.4 (0.34)	12.23 (1.20)
Stature (cm)	143.71 (8.36)	146.34 (4.24)	154.22 (6.13)	164.78 (6.71)	169.03 (7.01)	153.65 (10.99)
Body mass (kg)	38.42 (6.47)	40.1 (4.48)	43.81 (7.94)	52.1 (8.30)	61.4 (9.90)	45.28 (10.07)
Sum of skinfold (mm)	45.5 (12.7)	48.33 (11.68)	46.23 (15.01)	51.48 (17.33)	42.12 (10.33)	47.27 (21.71)
CMJ (cm)	27.31 (4.13)	27.84 (3.88)	29.6 (3.74)	31.79 (5.42)	34.44 (7.79)	29.67 (5.11)
Long jump (m)	1.59 (0.15)	1.52 (0.16)	1.6 (0.11)	1.89 (0.18)	2.04 (0.38)	1.69 (0.57)
20 meters (s)	3.54 (0.22)	3.41 (0.25)	3.51 (0.26)	3.43 (0.20)	3.19 (0.13)	3.44 (0.71)
Agility (s)	5.5 (0.31)	5.46 (0.34)	5.51 (0.37)	5.53 (0.41)	5.53 (0.22)	5.51 (1.12)
Yo-Yo IR 1 (m)	487.1 (164.4)	657.0 (153.2)	702.6 (169.9)	963.6 (280.3)	1296 (406.5)	732 (298.5)

For CMJ (Figure 2), at younger ages, the DNPG group displayed slightly higher values compared to STR and RSV. However, both STR and RSV surpassed the DNPG group, with the performance gap gradually widening in older age categories. RSV shows slightly higher results than STR at all ages. In the long jump (Figure 3A), all three groups exhibit similar trends in development rates and absolute values.

A similar pattern is observed in sprint performance (Figure 4), where differences between groups are minimal at younger ages but become more pronounced as players mature, with STR and RSV consistently outperforming DNPG. RSV shows a slightly higher rate of

improvement than STR over time. The agility (Figure 5) analysis follows a consistent overall trend, with STR exhibiting the fastest development rate, followed by RSV.

However, DNPG experiences a decline in performance capacity. Around age 12, only minor differences are observed among the groups. The disparities increase notably as players approach and pass PHV. The intermittent endurance test (Figure 6), however, shows a different pattern from the other physical tests. The DNPG group has inferior absolute values at younger ages compared to STR and RSV. Nonetheless, the improvement rates in DNPG are higher than in the other groups, and they reach better performance levels after approximately 14 years. The STR group exhibits a faster improvement rate than RSV and achieves higher absolute values by approximately 16 years.

Figures 1, 2, 3, 4, and 5 (right graphs) illustrate the development of neuromuscular performance across the three groups, aligned by age from/to PHV. When results are aligned by PHV, consistent trends appear across all four tests. The minor differences between groups occur during the pre-PHV stage (around -1 PHV), whereas after PHV, the gap between STR and RSV compared to DNPG widens significantly. In CMJ (Figure 1), STR shows a slightly higher development rate than RSV, although their absolute values remain slightly lower. Similar improvement rates are observed in sprint performance (Figure 3) across the groups, with a slightly higher rate in the RSV group. However, STR and RSV show significantly higher absolute values compared to DNPG. In agility (Figure 4), STR consistently outperforms both RSV and DNPG, with RSV demonstrating intermediate performance and DNPG lagging behind. The long jump development analysis (Figure 2) shows similar improvement rates among groups, with STR having the highest absolute values, followed by RSV and DNPG. As in the CA-based analysis, the highest rate of improvement is observed in the DNPG group, followed by STR and RSV.

Figure 1 - Countermovement jump by CA (left grafh), and by PHV (right graph)

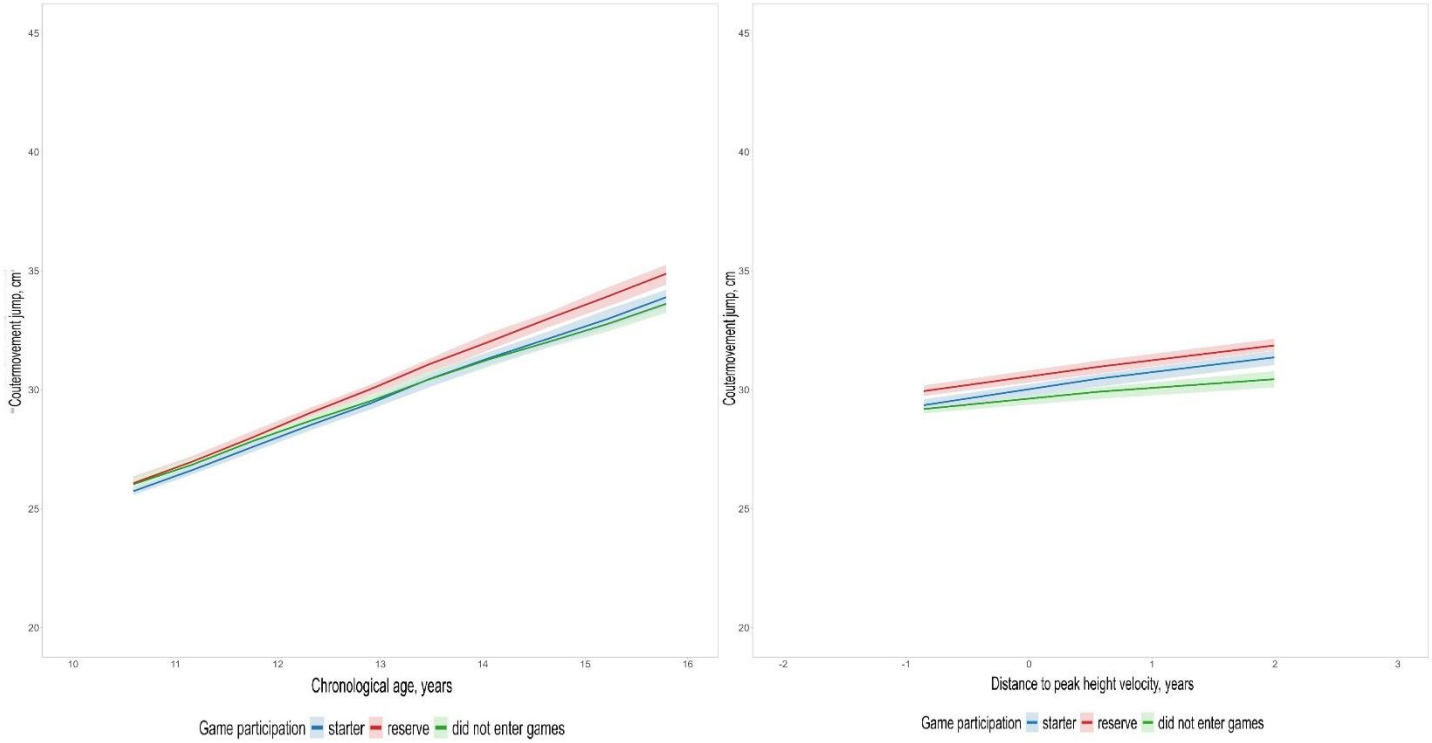


Figure 2 - Long jump aligned by CA (left grafh), and by PHV (right graph)

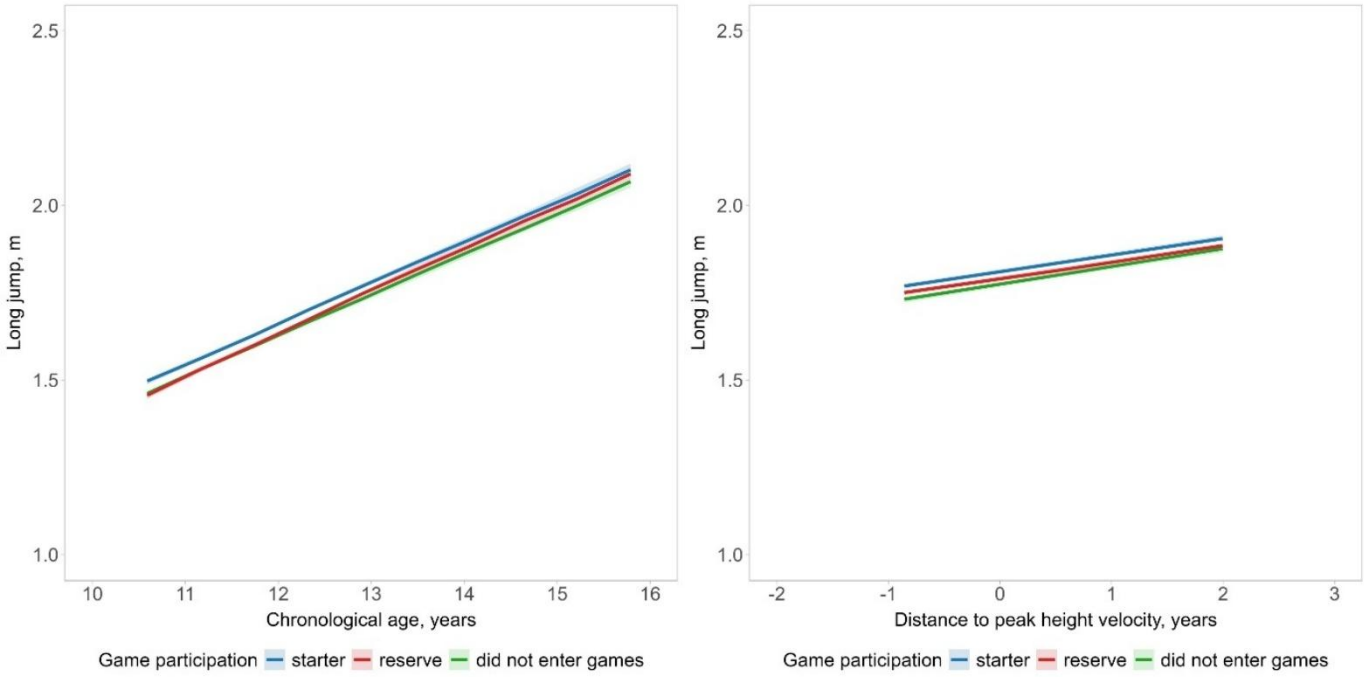


Figure 3 - 20 meters sprint aligned CA (left grafh), and by PHV (right graph)

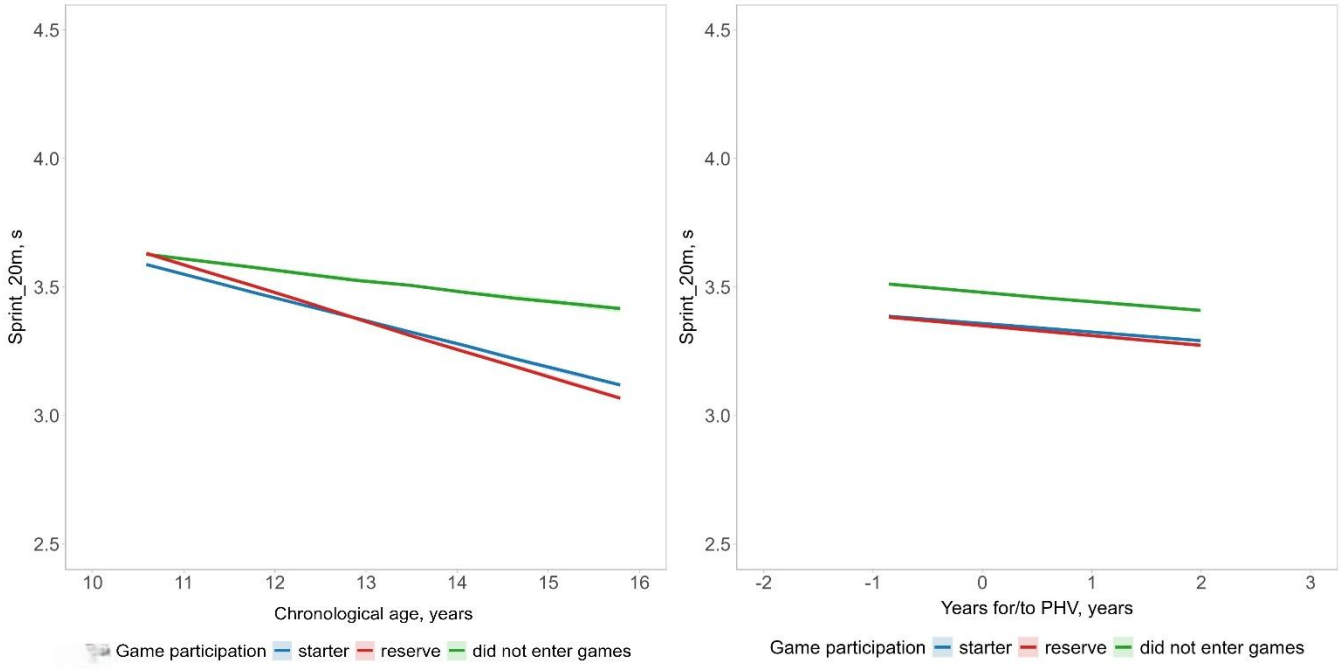


Figure 4 - Agility aligned CA (left grafh), and by PHV (right graph)

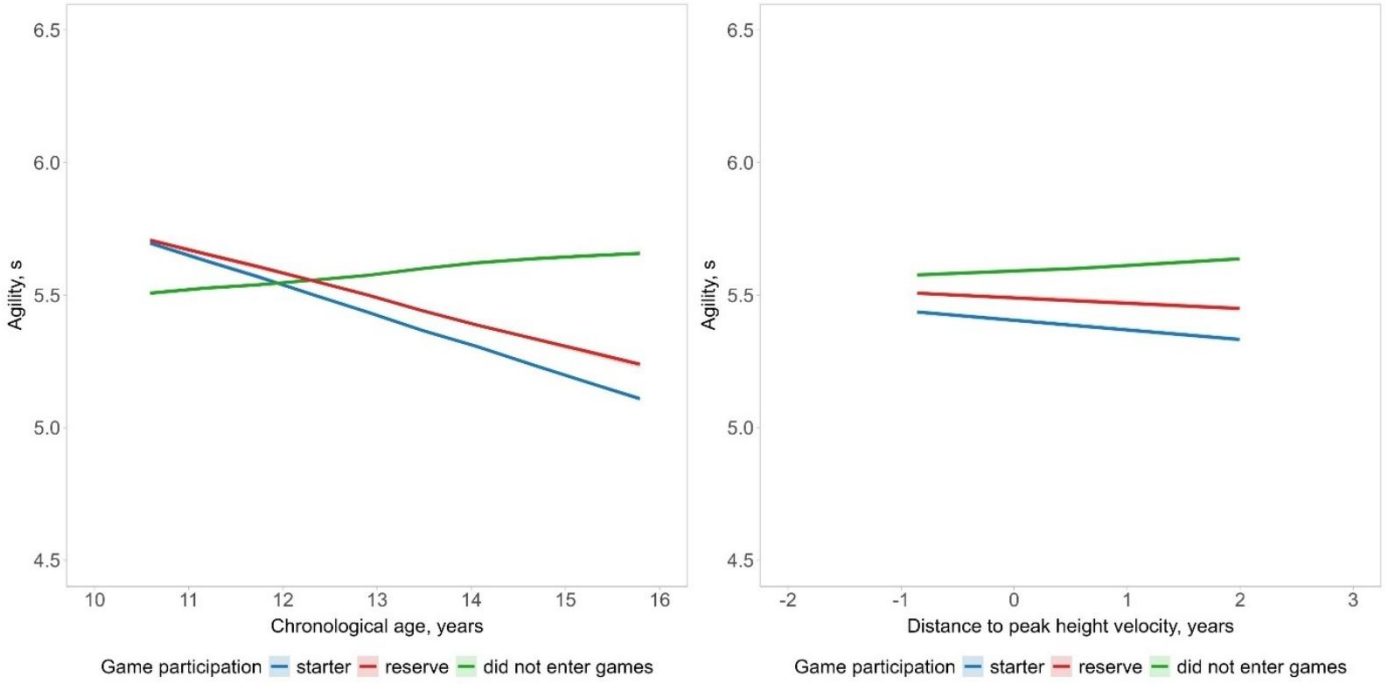
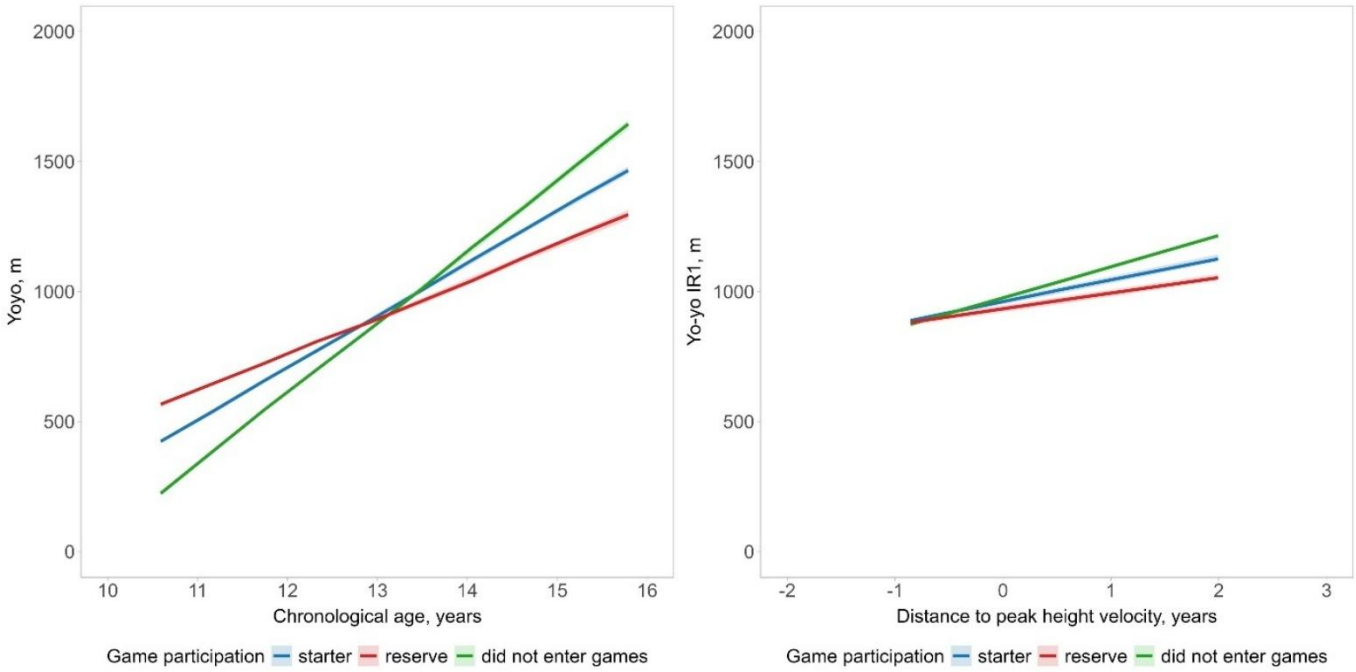


Figure 5 - Intermittent endurance aligned by CA (left grafh), and by PHV (right graph)



DISCUSSION

This study analyzed the longitudinal effects of athletes' exposure status to games on the physical fitness development of male football players from a Brazilian club, using both chronological age (CA) and estimated age at peak height velocity (PHV) to approximate maturational timing. The primary findings revealed significantly varied patterns of physical fitness development among the exposure groups, with pronounced differences demonstrating higher rates of improvement in STR and RSV when compared to the DNPG group. There was also a more consistent pattern of physical fitness development when adjusted for age at PHV compared to CA.

To our knowledge, this is the first study to consider not only the STR and RSV in developmental fitness analysis but also to recognize that players are part of the training group without receiving opportunities during matches throughout the season. These athletes display different patterns of improvement across all assessments. The jump tests show slight differences between exposure groups. In the CMJ, a lower rate of improvement is observed for the DNPG group, while small absolute values are seen for this group in the long jump test. This trend is also evident in the sprint and agility tests, although with more noticeable differences

in both absolute values and rates. Thus, even though the process of physical development is influenced by multiple factors, the amount of training land match loads appears as one of the pillars of training periodization (Clemente *et al*., 2024; Anderson *et al*., 2016; Varjan *et al*., 2023).

The similar patterns of fitness development in STR and RSV can be explained by the high load RSV experiences during the season. Although previous studies indicate that, at certain times of the week or in specific competitive situations, reserve players have lower training loads than starters (Clemente *et al*., 2024; Anderson *et al*., 2016; Silva *et al*., 2011; Varjan *et al*., 2023), the results of this study, by allowing the classification of players into three exposure categories, suggest that the total amount of stimulus received by the reserves (athletes who frequently participate in games) was sufficient for them to follow the physical development trends observed in the STR throughout the season.

Interestingly, in the intermittent endurance test, the DNPG group demonstrates higher rates of improvement, surpassing those of the STR and RSV groups. This study did not control the training content; therefore, we can precisely describe the reason for this result. However, we speculate that players who do not participate in games are most exposed to aerobic activities on days close to games, when the time of work and total distance of STR and RSV tend to decrease (Anderson *et al*., 2016). Moreover, aerobic capacities tend to continue developing before the peak height velocity, and deviations from this trend may become apparent when analyses extend to older age groups (Deprez *et al*., 2014; Valente-dos-Santos *et al*., 2012). This interpretation is reinforced by Reynolds *et al*. (2021), who observed that under-23 athletes exhibit performance levels similar to professional players in terms of high-speed running distance and total stress load, whereas under-18 athletes display comparatively reduced values.

The observed differences in timing and development rates related to CA and biological maturity alignments suggest a more consistent pattern of development in PHV analysis, supported by longitudinal research (Berger *et al*., 2025; Carvalho *et al*., 2017, 2019). As shown in CA-aligned Figures 1A, 3A, and 5A, a change in group patterns occurs around age 13, close to the mean age of PHV in soccer players (Lima *et al*., 2021), with differences becoming more noticeable at older ages, highlighting how maturation affects physical fitness development and the timing of progress during and after PHV. The greatest differences post-PHV result from increased levels of anabolic hormones, such as testosterone and growth hormones, which boost training effects, leading to increased muscle mass, strength, and power. In contrast, neural

changes are the main factor driving improvements in physical fitness pre-PHV (Eskandarifarid *et al*., 2022; Lloyd & Oliver, 2012). However, this reality changes when the analyses are made by the PHV alignments. The reduced variations in physical development rates and differences between groups in maturity graphs (Figures 1B, 2B, 3B, 4B and 5B) emphasize the variation in timing and pace of the maturation process among athlete age groups.

In youth football, significant differences in physical fitness levels are noticeable within the same age group, and these disparities can lead to favoring the most athletic players, who are then more exposed to loads during games and training sessions. This situation tends to benefit athletes who mature early and develop fitness before late-maturing players (Carling *et al*., 2012). However, football talent involves multiple abilities, and future talents are not necessarily those with greater physical qualities at a younger age (Williams *et al*., 2020), as the functional development curves are aligned with the timing of PHV (Carvalho *et al*., 2017; Philippaerts *et al*., 2006). Therefore, analyzing the development patterns of physical capacities between exposure groups emphasizes the importance for coaches and staff to properly manage training loads for all groups (Clemente *et al*., 2024), ensuring that late-maturing athletes are not overlooked.

This study has some limitations and strengths. The primary limitation is that we did not control for individual training loads in each group. Future research could analyze the specific content and loads assigned to each group in more detail. Additionally, the research was conducted with only one club and included only male athletes aged 10 to 15.5 years, which restricts how broadly the results can be applied. Further investigations should include athletes of both genders and a wider age range. Another limitation involves estimating biological maturation. Due to limited longitudinal growth data, we couldn't determine individual age at PHV or maturity offset. Instead, we used a population-average PHV (12,95 years), based on recent meta-analyses of youth athletes (Lima *et al*., 2023), to estimate maturational status. While this method offers a cautious group-level estimate, it does not capture individual differences in maturation, which should be considered when interpreting the results. Although differences in physical performance development might reflect maturation differences, this remains speculative. Future studies should explore training intensity and monitor lean mass development to better understand what influences physical fitness progression.

The findings highlight the importance of integrating CA and biological maturity in youth football development assessments. Over-reliance on physical performance during

selection risks overlooking late-maturing talents. Incorporating biological maturity enables meaningful interpretations of young football players' development and supports the creation of effective, long-term developmental strategies. Furthermore, differences in patterns of physical fitness improvement highlight the need to provide better competitive experiences and equal workloads for all athlete groups, thus preventing situations in which players with reduced capacity at a young age do not follow a growth trend. Considering maturity and promoting equal opportunities and experiences for all groups, especially at younger ages, enables the development of more precise training strategies and fosters a more consistent selection process, thereby preventing the dropout and/or exclusion of potential talents who develop physically later.

REFERENCES

ABARGHOUEINEJAD, M. *et al*. Motor performance in male youth football players: a systematic review of longitudinal studies. Sports, v. 9, n. 4, p. 1–16, 2021.

ALBALADEJO-SAURA, M. *et al*. Relationship between biological maturation, physical fitness, and kinanthropometric variables of young athletes: a systematic review and meta-analysis. International Journal of Environmental Research and Public Health, v. 18, n. 1, p. 1–20, 2021.

ALBUQUERQUE, M. R. *et al*. Relative age effect and ACTN3 R577X and ACE I/D polymorphisms in Brazilian football players: an association genetic study. Research Quarterly for Exercise and Sport, p. 1–11, 2024.

ANDERSON, L.; ORME, P.; DI MICHELE, R.; CLOSE, G. L.; MILSOM, J.; MORGANS, R.; DRUST, B.; MORTON, J. P. Quantification of seasonal-long physical load in soccer players with different starting status from the English Premier League: implications for maintaining squad physical fitness. International Journal of Sports Physiology and Performance, v. 11, p. 1038–1046, 2016.

BANGSBO, J. Fitness training in football: a scientific approach. HO Storm, 1994.

BARNES, C.; ARCHER, D. T.; HOGG, B.; BUSH, M.; BRADLEY, P. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BERGER, A.; CARVALHO, H.; CARDOSO, M.; OLIVEIRA, J.; DELAVALD, V.; PINTO, R.; LEONARDI, T. Longitudinal development of physical fitness in young football players: a Bayesian analysis. Research Quarterly for Exercise and Sport, v. 18, p. 1–10, 2025.

BIDAURRAZAGA-LETONA, I. *et al*. Longitudinal field test assessment in a Basque football youth academy: a multilevel modeling framework to partition effects of maturation. International Journal of Sports Medicine, v. 36, n. 3, p. 234–240, 2015.

BIDAURRAZAGA-LETONA, I. *et al*. Progression in youth football: selection and identification in youth football players aged 13–15 years. Journal of Strength & Conditioning Research, v. 33, n. 9, p. 2548–2558, 2017.

BOSCO, C.; LUHTANEN, P.; KOMI, P. V. A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology and Occupational Physiology, v. 50, p. 273–282, 1983.

BÜRKNER, P. Brms: an R package for Bayesian multilevel models using Stan. Journal of Statistical Software, v. 80, p. 1–28, 2017.

CARLING, C.; LE GALL, F.; MALINA, R. M. Body size, skeletal maturity, and functional characteristics of elite academy football players on entry between 1992 and 2003. Journal of Sports Sciences, v. 30, p. 1683–1693, 2012.

CARVALHO, H. M. *et al*. Longitudinal changes of functional capacities among adolescent female basketball players. Frontiers in Physiology, v. 10, p. 339, 2019.

CARVALHO, H. M. *et al*. Pubertal development of body size and football-specific functional capacities in adolescent players. Research in Sports Medicine, v. 25, n. 4, p. 421–436, 2017.

CARVALHO, H. M.; GONÇALVES, C. E. Mismatches in youth sports talent development. Frontiers in Sports and Active Living, v. 5, p. 1189355, 2023.

CASTILLO-RODRÍGUEZ, A.; GONZÁLEZ-TÉLLEZ, J. L.; FIGUEIREDO, A.; CHINCHILLA-MINGUET, J. L.; ONETTI-ONETTI, W. Starters and non-starters soccer players in competition: is physical performance increased by the substitutions?. *BMC Sports Science, Medicine and Rehabilitation*, v. 15, n. 1, p. 33, 2023.

CLEMENTE, F.; PILLITTERI, G.; VIEIRA, L. H. P.; RABBANI, A.; ZMIJEWSKI, P.; BEATO, M. Balancing the load: a narrative review with methodological implications of compensatory training strategies for non-starting soccer players. Biology of Sport, v. 41, n. 4, p. 173–185, 2024.

DEPREZ, D.; COUTTS, A. J.; FRANSEN, J.; DECONINCK, F. J. A.; LENOIR, M.; VAEYENS, R.; PHILIPPAERTS, R. Relative age, biological maturation and anaerobic characteristics in elite youth soccer players. International Journal of Sports Medicine, v. 34, n. 10, p. 897–903, 2013.

ESKANDARIFARD, E.; SILVA, R.; NOBARI, H.; CLEMENTE, F. M.; PÉREZ-GÓMEZ, J.; FIGUEIREDO, A. J. Maturational effect on physical capacities and anabolic hormones in under-16 elite footballers: a cross-sectional study. Sport Sciences for Health, v. 18, n. 2, p. 297–305, 2022.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. Journal of Sports Sciences, v. 30, n. 7, p. 625–631, 2012.

FIGUEIREDO, A. J. *et al*. Characteristics of youth football players who drop out, persist, or move up. Journal of Sports Sciences, v. 27, n. 9, p. 883–891, 2009.

GABRY, J.; SIMPSON, D.; VEHTARI, A. *et al*. Visualization in Bayesian workflow. Journal of the Royal Statistical Society: Series A (Statistics in Society), v. 182, p. 389–402, 2019.

GELMAN, A.; HILL, J. Data analysis using regression and multilevel/hierarchical models. Cambridge: Cambridge University Press, 2007.Goldstein, H. (1986). Efficient statistical modelling of longitudinal data. *Annals of Human Biology*, 13, 129–141.

HUIJGEN, B. C. H. *et al*. Development of dribbling in talented youth football players aged 12–19 years: a longitudinal study. Journal of Sports Sciences, v. 28, n. 7, p. 689–698, 2010.

HUIJGEN, B. C. H. *et al*. Multidimensional performance characteristics in selected and deselected talented football players. European Journal of Sport Science, v. 14, n. 1, p. 2–10, 2014.

JANUSIAK, M.; SILVA, A. F.; SILVA, R.; KOSENDIAK, A.; BOGDAŃSKI, B.; SMOTER, M.; PRAÇA, G.; CLEMENTE, F. M. Testing variations between starters and substitute players in terms of total distance, high-speed running, and sprinting distance: a descriptive study on professional male soccer players. Biology of Sport, v. 41, n. 2, p. 95–103, 2024.

KAY, M. Tidybayes: tidy data and geoms for Bayesian models. Zenodo, 2023.

KELLY, A. L.; WILLIAMS, C. A. Physical characteristics and the talent identification and development processes in male youth football: a narrative review. Strength & Conditioning Journal, v. 42, n. 6, p. 15–34, 2020.

LIMA, A. B.; QUINAUD, R. T.; GONÇALVES, C. E.; CARVALHO, H. M. Peak height velocity in young athletes: a longitudinal meta-analysis. Journal of Sports Sciences, v. 41, n. 2, p. 151–163, 2023.

LLOYD, R. S.; OLIVER, J. L. The youth physical development model: a new approach to long-term athletic development. *Strength & Conditioning Journal*, v. 34, n. 3, p. 61–72, 2012.

LOHMAN, T. G.; ROCHE, A. F.; MARTORELL, R. Anthropometric standardization reference manual. Human Kinetics, 1988.

MALINA, R. M. *et al*. Height, mass and skeletal maturity of elite Portuguese football players aged 11–16 years. Journal of Sports Sciences, v. 18, n. 9, p. 685–693, 2000.

MALINA, R. M. Physical growth and biological maturation of young athletes. Exercise and Sport Sciences Reviews, v. 22, n. 1, p. 280–284, 1994.

MALINA, R. M.; BOUCHARD, C.; BAR-OR, O. Growth, maturation, and physical activity. Human Kinetics, 2009.

MARFELL-JONES, S. International standards for anthropometric assessment. 2012.

MEYLAN, C. *et al*. Talent identification in football: the role of maturity status on physical, physiological and technical characteristics. International Journal of Sports Science & Coaching, v. 5, n. 4, p. 571–592, 2010.

MIGUEL, C. G.; SOARES, A. L.; LIMA, A. B.; KARASIAK, F. C.; GALVÃO, L. G.; LEONARDI, T. J.; FOSTER, C.; GONÇALVES, C. E.; CARVALHO, H. M. Developmental changes in the physical fitness of young female and male basketball players: a Bayesian analysis. Journal of Sports Medicine and Physical Fitness, v. 65, n. 10, p. 1296–1305, 2025.

OLIVA-LOZANO, J. M.; FORTES, V.; KRUSTRUP, P.; MUYOR, J. M. Acceleration and sprint profiles of professional male football players in relation to playing position. PLoS One, v. 15, n. 8, e0236959, 2020.

OLIVA-LOZANO, J. M.; FORTES, V.; LÓPEZ-DEL CAMPO, R.; RESTA, R.; MUYOR, J. M. When and how do professional soccer players experience maximal intensity sprints in LaLiga? Science and Medicine in Football, v. 7, n. 3, p. 288–296, 2023.

PEÑA-GONZÁLEZ, I.; FERNÁNDEZ-FERNÁNDEZ, J.; MOYA-RAMÓN, M.; CERVELLÓ, E. Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. Research Quarterly for Exercise and Sport, v. 89, n. 3, p. 373–379, 2018.

PEÑA-GONZÁLEZ, I.; JAVALOYES, A.; CERVELLÓ, E.; MOYA-RAMÓN, M. The maturity status but not the relative age influences elite young football players' physical performance. Science and Medicine in Football, v. 6, n. 3, p. 309–316, 2022.

PEREIRA, G.; MORSE, C.; UGRINOWITSCH, C.; RODACKI, A.; KOKUBUN, E.; FOWLER, N. Manipulation of rest period length induces different causes of fatigue in vertical jumping. International Journal of Sports Medicine, v. 30, n. 5, p. 325–330, 2009.

PHILIPPAERTS, R. M.; *et al*. The relationship between peak height velocity and physical performance in youth football players. Journal of Sports Sciences, v. 24, n. 3, p. 221–230, 2006.

PONS, E. *et al*. A comparison of a GPS device and a multi-camera video technology during official football matches: agreement between systems. PLoS One, v. 14, n. 8, e0220729, 2019.

REILLY, T.; BANGSBO, J.; FRANKS, A. Anthropometric and physiological predispositions for elite football. Journal of Sports Sciences, v. 18, n. 9, p. 669–683, 2000.

REILLY, T.; WILLIAMS, A. M.; NEVILL, A.; FRANKS, A. A multidisciplinary approach to talent identification in soccer. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

REYNOLDS, J.; CONNOR, M.; JAMIL, M.; BEATO, M. Quantifying and comparing the match demands of U18, U23, and 1ST team English professional soccer players. Frontiers in Physiology, v. 12, p. 706451, 2021.

ROESCHER, C. R.; ELFERINK-GEMSER, M. T.; HUIJGEN, B. C. H.; VISSCHER, C. Soccer endurance development in professionals. International Journal of Sports Medicine, v. 31, n. 3, p. 174–179, 2010.

SAEZ, E.; DE VILLAREAL, G.; GONZÁLEZ-BADILLO, J. J.; IZQUIERDO, M. Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. The Journal of Strength & Conditioning Research, v. 22, n. 3, p. 715–725, 2008.

SANCHEZ-SANCHEZ, J. *et al*. Heart rate variability and physical demands of in-season youth elite soccer players. International Journal of Environmental Research and Public Health, v. 18, n. 4, p. 1391, 2021.

SILVA, J. R.; MAGALHÃES, J. F.; ASCENSÃO, A. A.; OLIVEIRA, E. M.; SEABRA, A. F.; REBELO, A. N. Individual match playing time during the season affects fitness-related parameters of male professional soccer players. *The Journal of Strength & Conditioning Research*, v. 25, n. 10, p. 2729–2739, 2011.

SOARES, A. L.; LIMA, A. B.; MIGUEL, C. G. *et al*. Does early specialization provide an advantage in physical fitness development in youth basketball? Frontiers in Sports and Active Living, v. 4, p. 1042494, 2023.

VAEYENS, R. *et al*. A multidisciplinary selection model for youth football: the Ghent Youth Football Project. British Journal of Sports Medicine, v. 40, n. 11, p. 928–934, 2006.

VAEYENS, R.; LENOIR, M.; WILLIAMS, A. M.; PHILIPPAERTS, R. M. Talent identification and development programmes in sport: current models and future directions. Sports Medicine, v. 38, n. 9, p. 703–714, 2008.

VARJAN, M.; HANK, M.; KALATA, M.; CHMURA, P.; MALA, L.; ZAHALKA, F. Weekly training load differences between starting and non-starting soccer players. Journal of Human Kinetics, v. 90, p. 125, 2023.Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, 27, 1413–1432.

VEHTARI, A.; GELMAN, A.; SIMPSON, D.; CARPENTER, B.; BÜRKNER, P.-C. Rank-normalization, folding, and localization: an improved R for assessing convergence of MCMC (with discussion). Bayesian Analysis, v. 16, n. 2, p. 667–718, 2021.

VIGNE, G. *et al*. Activity profile in elite Italian football team. International Journal of Sports Medicine, v. 31, n. 5, p. 304–310, 2010.

WILLIAMS, M.; FORD, P.; DRUST, B. Talent identification and development in soccer since the millennium. Journal of Sports Sciences, v. 38, n. 11–12, p. 1199–1210, 2020.

4. ARTIGO 3

EFFECTS OF A 12-WEEK IN-SEASON SMALL-SIDED GAMES TRAINING ON NEUROMUSCULAR PROPERTIES IN YOUNG FOOTBALL PLAYERS

ABSTRACT

Purpose: This study examined changes in neuromuscular properties of youth football players during a competitive cycle using game-based training strategies. **Methods:** Thirty-five young football players (mean age 16.05 ± 2.03 years old) from two Brazilian clubs participated in this study. Neuromuscular properties were measured through both knee extensors and flexors concentric and flexor eccentric isokinetic peak torque, as well as a concentric fatigue protocol. In addition, muscle morphology was measured through Dual-Energy X-ray Absorptiometry. A Bayesian multilevel regression modeling approach was employed to analyze the development of neuromuscular performance and physical changes. **Results:** The findings indicate that (a) only small pre-to-post changes were observed in peak torque, fatigue, and legs lean mass; (b) substantial athletes interindividual heterogeneity was detected across all tests; (c) lean mass was associated with isokinetic peak torque levels, although no significant changes emerged in the time-based analyses; and (d) small differences were identified in the rate of change for peak torque development between limbs comparison (dominant vs non-dominant), particularly for eccentric knee flexion. **Conclusion:** Reduced increases in isokinetic peak torque and in legs lean mass were observed at the group level; however, substantial variation in neuromuscular adaptations emerged among athletes following the small-sided games approach. These findings highlight the necessity of customizing training loads when relying solely on small-sided football games and formal games, indicating a need for additional methods to prevent muscle strength imbalances and decrease the variability of stimuli and training loads among players.

Keywords: game-based, isokinetic, fatigue, soccer.

INTRODUCTION

Football performance increasingly relies on physical abilities such as strength, power, speed, and endurance (Bangsbo *et al*., 2006; Reilly *et al*., 2000; Otero-Esquina *et al*., 2017), with a significant need for high-intensity actions (Barnes *et al*., 2014; Faude *et al*., 2012; Pons *et al*., 2019; Oliva-Lozano *et al*., 2020). The congested football calendar leads to competitive overload, which results in accumulated fatigue (FAT) and contributes to higher rates of musculoskeletal injuries (Altarriba-Bartes *et al*., 2020; Nédélec *et al*., 2012; Cezarino *et al*., 2020; Dupont, 2010). Therefore, coaches and technical staff face the challenge of developing effective strategies to reduce FAT while balancing performance demands (Otero-Esquina *et al*., 2017; Gabbet *et al*., 2014).

During matches, athletes perform complex motor tasks (e.g., jumps, sprints, changes of direction, physical challenges, and shots) that heavily rely on athletes' strength and power capacities, which are essential for maintaining muscle explosive force, postural stability, and technical performance (Aktug *et al*., 2015; Cometti *et al*., 2001; Lehance *et al*., 2009; Morin *et al*., 2015; Julien *et al*., 2008; Dowson *et al*., 1998). The quadriceps stabilize and extend the knee, while the hamstrings contribute to hip extension, knee flexion, and eccentric control for joint stabilization (Pietraszewski *et al*., 2025; Lehance *et al*., 2009; Ruas *et al*., 2015). Isokinetic assessments are widely used to evaluate these neuromuscular qualities, such as strength deficits, inter-limb asymmetries, hamstrings-quadriceps ratio, and FAT index, enabling the identification of muscular imbalances, monitoring adaptations to training, and supporting return-to-play decisions following injury (Grazioli *et al*., 2023; Baroni *et al*., 2020).

Importantly, body composition directly influences these neuromuscular capacities, as excess fat impairs movement efficiency and increases injury risk; higher lean mass is associated with enhanced strength and power (Valente dos Santos *et al*., 2012; Ishida *et al*., 2021). Therefore, training strategies should consider both the development of strength and the maintenance of an optimal balance between lean and fat mass (Suarez-Arrones *et al*., 2018).

The short preseason and limited recovery time between matches, combined with interference effects, make implementing strength training modalities particularly challenging. (Branquinho *et al*., 2024; Balagué *et al*., 2024). Furthermore, football athletes need to improve not only their physical performance but also enhance their technical and tactical skills, both individually and as a team (Hill-Hass *et al*., 2011). Therefore, optimizing training time,

strategies, and methodology is essential to achieve high performance, maintain workload balance, and lower injury rates (Otero-Esquina *et al*., 2017; Iacono *et al*., 2017).

In this context, small-sided games (SSG) offer a practical strategy to develop football-specific demands in an integrated manner (Hill-Hass *et al*., 2011; Iacono *et al*., 2019). By modifying field size or the number of players and rules, SSG replicates match intensity and technical-tactical challenges while improving decision-making in FAT situations (Hill-Hass *et al*., 2011; Clemente *et al*., 2024; Gabbett *et al*., 2008). While SSG in small spaces increases intensity requirements and ball engagement, larger fields boost external load by amplifying sprinting and running distances at higher speeds (Hill-Hass *et al*., 2011; Iacono *et al*., 2019).

These games can cause significant physiological stress, impacting cardiovascular, metabolic, and muscular systems, including markers of muscle damage, and have been shown to effectively improve football players' physical abilities (Jeffreys *et al*., 2004; Bekris *et al*., 2022; Bujalance-Moreno *et al*., 2019; Hill-Hass *et al*., 2011; Iacono *et al*., 2017, 2019). However, the literature also points out several limitations, challenges, and gaps related to SSG. Variations in game formats (e.g., number of players and rules) and in individual participation, influenced by player position, roles, technical skill, fitness levels, and motivation, can significantly alter the physiological stimulus among players and negatively impact individual physical development (Hůlka & Strniště, 2021; Makar *et al*., 2023; Iacono *et al*., 2019). Despite the growing research on the physiological and performance effects of SSG, little attention has been given to inter-individual variability and muscular adaptations in KE and KF (Feng *et al*., 2025); as a result, our understanding of how these methods affect muscle balance and injury risk remains limited (Cezarino *et al*., 2021).

To our knowledge, there is no evidence regarding the effects of football training based on game movements on lower-limb muscular strength, particularly concerning between-limb adaptations and changes in body composition. Therefore, this study aimed to examine the physical changes and neuromuscular performance adaptations in young football players over a 12-week period during a competitive phase, during which they exclusively engaged in SSG training. Additionally, it assessed individual athlete responses by exploring variations among individuals through bilateral analysis and investigating potential factors related to body composition that may contribute to these differences. Understanding how these methods influence changes in body composition and the strength and FAT response, especially in the

quadriceps and hamstring muscles, coaches can adjust training routines to improve performance, promote muscular balance around the knee joint, and reduce the risk of injury.

METHODS

Experimental design

This study employed a pre- and post-intervention design conducted over a 12-week duration during the in-season phase of competitive football. Young male athletes from two football teams completed four training sessions per week in addition to weekend matches or friendly games, following their regular training routines based on SSG. The researchers did not influence any training decisions or match practices, ensuring that the interventions reflected the teams' typical football methodologies.

Subjects

The study involved 35 young male football athletes (mean age: 16.05 ± 2.03 years; body mass: 64.6 ± 9.77 kg; height: 173.8 ± 8.3 cm; body fat: 10.2 ± 3.2%) from the under-17 and under-20 categories of two football clubs in Rio Grande do Sul, Brazil. The clubs participated in regional and state-level competitions organized by the Rio Grande do Sul Football Federation. Team 1 consisted of 26 players, and Team 2 had nine players who completed both pre- and post-evaluations. Both teams followed their regular training routines, including four to five sessions per week and matches or friendlies on weekends. Only athletes without reported injuries in the last 6 months participated.

The research ethics committee at the Federal University of Rio Grande do Sul (CAAE 60188922.3.0000.5347) approved this study. All athletes, together with their parents or legal guardians, provided signed informed consent and assent. The study adhered to the ethical guidelines outlined in the Declaration of Helsinki (World Medical Association, 2013).

Training methods

The training content and method were reported by coaches using a personal notebook. All training activities were recorded by the researchers using el Sistema Integral para el

Análisis de las Tareas de Entrenamiento (SIATE, Ibanez *et al*., 2016). The training tasks were tabulated using the SIATE method in an electronic data sheet to verify the methodologies proposed by the coaches. The group of analyses comprised small, medium, and large-sized games (Clemente *et al*., 2024; Hill-Haas *et al*., 2011). The researchers did not influence any methodological decisions related to the team training sessions.

A total of 91 activities, spread across 48 sessions, were registered by Team 1. Twenty-five activities (27.5%) involved large SSG dimensions (8x8 or more); 29 activities (31.9%) involved medium SSG (between 5x5 and 7x7); and 22 activities (24.2%) involved small SSG dimensions (at 4x4); while 15 activities (16.5%) were formal games. In the case of Team 2, a total of 64 activities were distributed across 43 sessions. Among these, 19 activities (33.9%) were conducted using large playing formats (8x8 or more); 14 activities (25.0%) involved medium SSG (between 5x5 and 7x7); and 7 activities (12.5%) involved small SSG (at 4x4); while 25 activities (44.6%) were formal games. In both teams, no additional method of physical training was implemented during the study period.

Procedures

Each team completed its assessment on a different day. Pre- and post-intervention evaluations were performed at least 72 hours after the last match to reduce FAT effects. The testing sequence included body composition assessment via DXA and isokinetic testing of the DL and NDL to measure PT and FAT. Team 1 was evaluated during the last part of the 2022 season, while Team 2 was assessed in the same period of the 2024 season.

Neuromuscular properties assessments

Isokinetic peak torque

Both dominant and non-dominant legs were evaluated. The athletes were asked to identify their dominant leg, referring to "which leg they use to kick a ball, preferably" (Aagard *et al.,* 1998; Baroni *et al.,* 2018). Throughout the protocol, participants were instructed to perform each contraction with maximum effort and as fast and hard as possible ("as hard and fast as possible"), to ensure maximal muscle force production (Maffiuletti *et al*., 2016; Sahaly *et al*., 2001). Additionally, verbal encouragement was provided at all times, along with real-

time visual feedback displayed on a monitor placed in front of the participants to track the force curve. The concentric PT of the KE and KF, as well as the eccentric PT of KF, were assessed using an isokinetic dynamometer, Cybex Norm (Cybex, division of Lumex Inc., Ronkonkoma, NY, USA), or a Biodex System 3 (Biodex Medical Systems, Shirley, NY, USA). Team 1 performed the pre- and post-evaluations using the Cybex, while Team 2 used the Biodex for their pre- and post-evaluations. Inter-machine reliability indicated high to very high reproducibility of PT between the dynamometer models (Alvares *et al*., 2015). The same protocol was administered to both teams, executed by two researchers experienced in dynamometer assessments.

Before data collection, both isokinetic dynamometers were calibrated following the manufacturer's instructions. The protocol began with a five-minute general warm-up on a cycle ergometer (Movement Technology, BM2700, São Paulo, Brazil) at a self-reported comfortable speed. Initially, participants were positioned on the equipment with the trunk flexed at 85°, and the knee joint was aligned with the rotation axis of the dynamometer. The leg, thigh, torso, and pelvis were secured with straps to prevent compensatory movements during testing. Strap positions varied between devices, but the dynamometer lever arm was set similarly, with the pad positioned 2 cm above the lateral malleolus (Alvares *et al*., 2015).

A specific warm-up followed, consisting of ten submaximal dynamic contractions at 120°/s to each test. The PT of KE and KF was assessed during five consecutive maximal voluntary contractions (MVCs) performed in the concentric-concentric mode at 60°/s (range of motion: 0–90°, 0° = full extension). The eccentric PT of KF was assessed during five MVCs at 60°/s. The highest PT value from these contractions was used for analysis. Throughout the protocol, participants were instructed to perform each contraction with maximum effort and as fast and hard as possible ("as hard and fast as possible"), to ensure maximal muscle force production (Maffiuletti *et al*., 2016; Sahaly *et al*., 2001). Additionally, verbal encouragement was provided at all times, along with real-time visual feedback displayed on a monitor placed in front of the participants to track the force curve.

After the PT test, participants completed a muscle FAT assessment using an isokinetic dynamometer. The isokinetic protocol performed by the athletes consisted of 33 consecutive concentric contractions for knee flexion and extension at an angular velocity of 300°/s. The first repetition was discarded, and only 30 valid repetitions were adopted for performance decrement and FAT index calculations, as additional repetitions were included to allow the

exclusion of invalid initial contractions potentially influenced by familiarization. A specific warm-up was performed with 10 submaximal contractions at 120°/s (0–90° range of motion, 0° = full extension), followed by three submaximal repetitions as a pre-test, with a 30-s interval between the pre-test and maximal test and a 60-s interval between maximal tests (Fortes *et al*., 2023). The percentage of torque reduction was calculated by comparing the average torque of the last three valid repetitions with the average torque of the best three repetitions within the first five valid repetitions. The final FAT index, expressed as a percentage, represented the relative variation in torque throughout the test (Pinto *et al*., 2018; Machado *et al*., 2023).

Body composition assessment

Total and regional body composition, as well as lean and fat mass specifically for the lower limbs separated by dominant and non-dominant legs, was assessed using Dual-Energy X-ray Absorptiometry (DXA) (Hologic Discovery W, Hologic Inc., Marlborough, MA, USA). Participants were instructed to refrain from physical activity prior to the assessment, wear lightweight clothing free from metallic objects, and empty their bladders before the procedure. During the assessment, participants were positioned in a supine posture, aligned, and centered on the examination table with their hips and shoulders extended to enable a full-body scan by the X-ray beam (Machado *et al*., 2023). The radiation dose during the scan was extremely low, not exceeding 1 μSv, as reported by Bolanowski and Nilsson (2001). The DXA equipment was calibrated before each assessment according to the manufacturer's specifications.

Statistical Analysis

Initially, separate Bayesian linear mixed-effects models were fitted for each outcome, including concentric and eccentric PT, regional fat and legs lean mass for DL and NDL, as well as the between-limbs difference considering both PT and FAT in each assessment. Each model included time (pre- vs. post-intervention) as a fixed effect and participant ID as a random intercept to account for repeated measures. Additionally, final models were fitted, adding legs lean mass (DL or NDL, according to the specific limb of each model). Weakly informative priors were specified for all parameters: normal priors (mean = 0, SD = 1) for intercepts and fixed effects, and exponential priors (rate = 1) for random effect standard deviations. For each model, we ran four chains of 4000 iterations each, with a 2000-iteration warm-up. This

approach was sufficient for achieving convergence and obtaining a suitable effective sample size. We assessed convergence using the $\hat{R}$ statistic (Vehtari *et al*., 2021), which compares between-chain and within-chain variances. Convergence was confirmed when $\hat{R}$ was below 1.01 for all parameters and quantities of interest (Vehtari *et al*., 2021). Posterior predictive checks were performed to evaluate model fit, and conditional effects were visualized to illustrate the estimated impact of time on each outcome variable. Estimates are reported as posterior means with 95% credible intervals. To analyse the agreement between measured PT and FAT in the final models and predicted values, we use Bland-Altman graphs (supplementary files; Giavarina, 2015).

Models were fitted using R (R Core Team, 2018) with the "brms" package (Bürkner, 2017), which utilises Stan (Stan Development Team, 2020). Model predictions were extracted with the "tidybayes" (Kay, 2023) and visualised with the "ggplot2" package (Wickham, 2016).

RESULTS

Table 1 shows the descriptive statistics of the sample's pre- and post-changes in anthropometry and body composition, while Table 2 reports the variations in PT and FAT test performances. Table 3 (Apêndice E) presents the relationship analysis between lean mass and PT performances.

Figures 2, 3, and 4 illustrate the development of PT in both the DL and NDL. The DL showed small but improvements, especially in KEconPT (Figure 2) and KFeccPT (Figure 4), whereas no meaningful changes were observed in NDL.

The progression of FAT in both DL and NDL is shown in Figures 5 and 6. Both legs exhibited increased FAT levels, indicating a decline in performance. KEconcFAT (Figure 5) increased in both legs, with a larger decrease seen in the NDL. Additionally, KFconcFAT (Figure 6) in the DL leg also demonstrated a decline in performance.

Table 1 – Physical characteristics

	Mean Pre (SD)	Mean Post (SD)	Mean difference (SD)
Chronological age (years)	16.05 (2.03)	16.33 (2.00)	-
Stature (cm)	172.77 (8.34)	173.78 (8.22)	-
Body mass (kg)	64.50 (9.77)	66.38 (9.48)	1.747 (1.591)
Legs Lean mass (kg)	52.36 (7.80)	53.32 (7.56)	0.965 (1.304)
Body fat (kg)	10.16 (3.16)	10.63 (2.94)	0.470 (1.005)
Legs lean mass (kg)	18.23 (2.94)	18.63 (2.90)	0.393 (0.718)
Legs fat mass (kg)	4.31 (1.17)	4.42 (1.05)	0.111 (0.419)
Dominant leg lean mass (kg)	9.15 (1.47)	9.35 (1.42)	0.194 (0.380)
Dominant leg fat mass (kg)	2.16 (0.56)	2.22 (0.53)	0.052 (0.246)
Non-dominant leg lean mass (kg)	9.08 (1.49)	9.28 (1.52)	0.199 (0.441)
Non-dominant leg fat mass (kg)	2.14 (0.63)	2.2 (0.54)	0.058 (0.221)

Changes in the composition of legs lean mass (Figure 1) and fat mass (complementary material) of the lower limbs showed a slight increase in both. The analysis of the relationship between PT levels and lean mass indicates a positive association. However, the relationship between lean mass and PT changes over time is not clearly evident (Table 3, Apêndice E).

The models comparing differences between DL and NDL, in pre- and post-periods, show balanced group adaptations. The slopes of the regression lines in Figures 7, 8, and 9 indicate a tendency toward positive differences between the DL and NDL, suggesting greater changes in favor of the DL, particularly in the eccentric PT test.

When analyzing the athletes individually, a similar pattern was observed across all physical tests and body composition assessments. In both the pre- and post-intervention phases, results showed wide variation, indicating significant differences among athletes. Likewise, the training responses over the 12 weeks were mixed, including improvements, maintenance, and declines in both physical performance and body composition parameters.

Table 2 - Neuromuscular properties measurements and variation across 12 weeks.

Isokinetic	Mean Pre (SD)	Mean Post (SD)	Mean Difference (SD)
KEconPT dominant (N.m)	189.3 (45.86)	202 (44.00)	12.74 (24.7)
KEconPT non-dominant (N.m)	197 (47.33)	206.91 (46.19)	11.5 (21.9)
KFconPT dominant (N.m)	115.2 (32.97)	124.4 (36.28)	9.2 (18.2)
KFconPT non-dominant (N.m)	108.54 (29.5)	116.06 (30.09)	9.53 (22.1)
KFeccPT dominant (N.m)	139.76 (46)	154.09 (42.66)	14.33 (24.8)
KFeccPT non-dominant (N.m)	141.57 (38.8)	148.15 (43.39)	7.67 (24.7)
KEconFAT dominant (%)	-31.13 (7.12)	-33.84 (6.79)	-2.70 (9.01)
KEconFAT non-dominant (%)	-29.23 (9.00)	-33.62 (8.75)	-4.77 (9.58)
KFconFAT dominant (%)	-33.10 (11.31)	-39.23 (10.14)	-5.63 (8.67)
KFconFAT non-dominant (%)	-32.04 (11.20)	-34.3 (10.34)	-2.09 (13.70)

Figure 1 - Legs lean mass

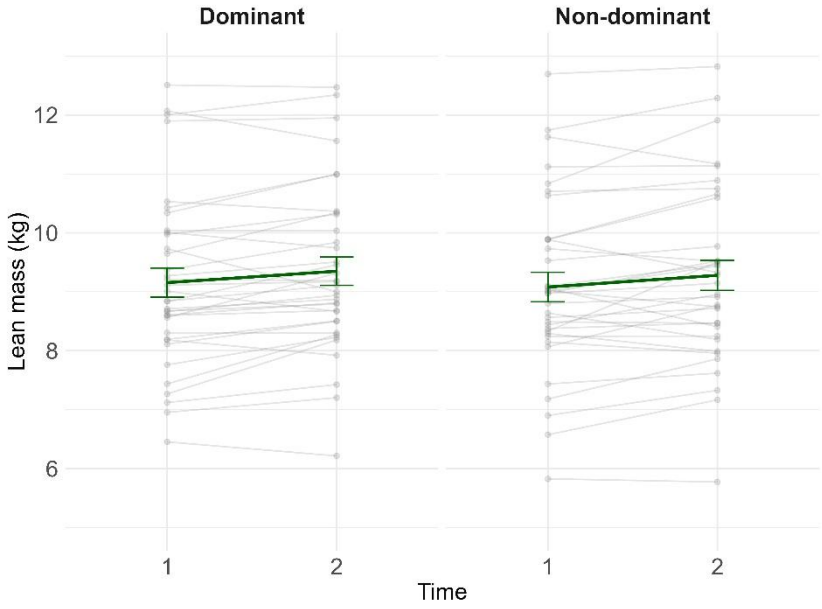


Figure 2 - Knee extensor concentric peak torque (KEconcPT)

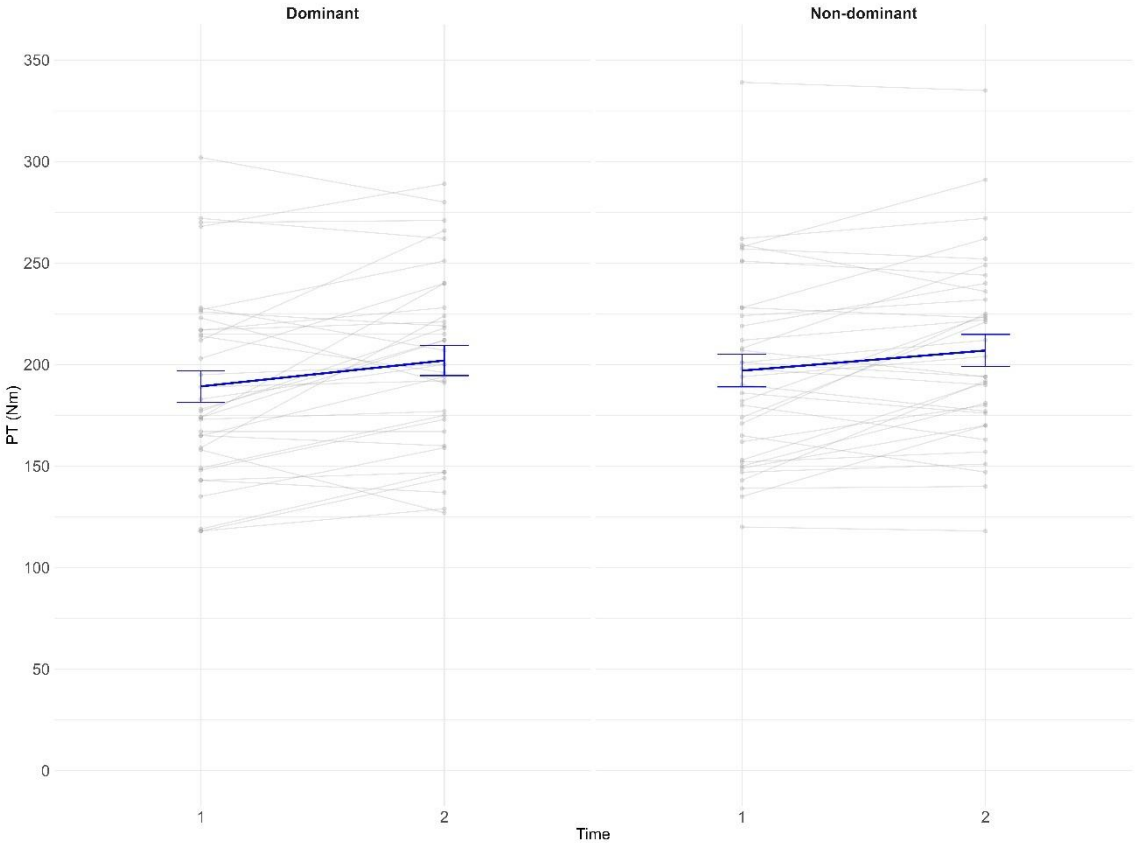


Figure 3 - Knee flexor concentric peak torque (KFconcPT)

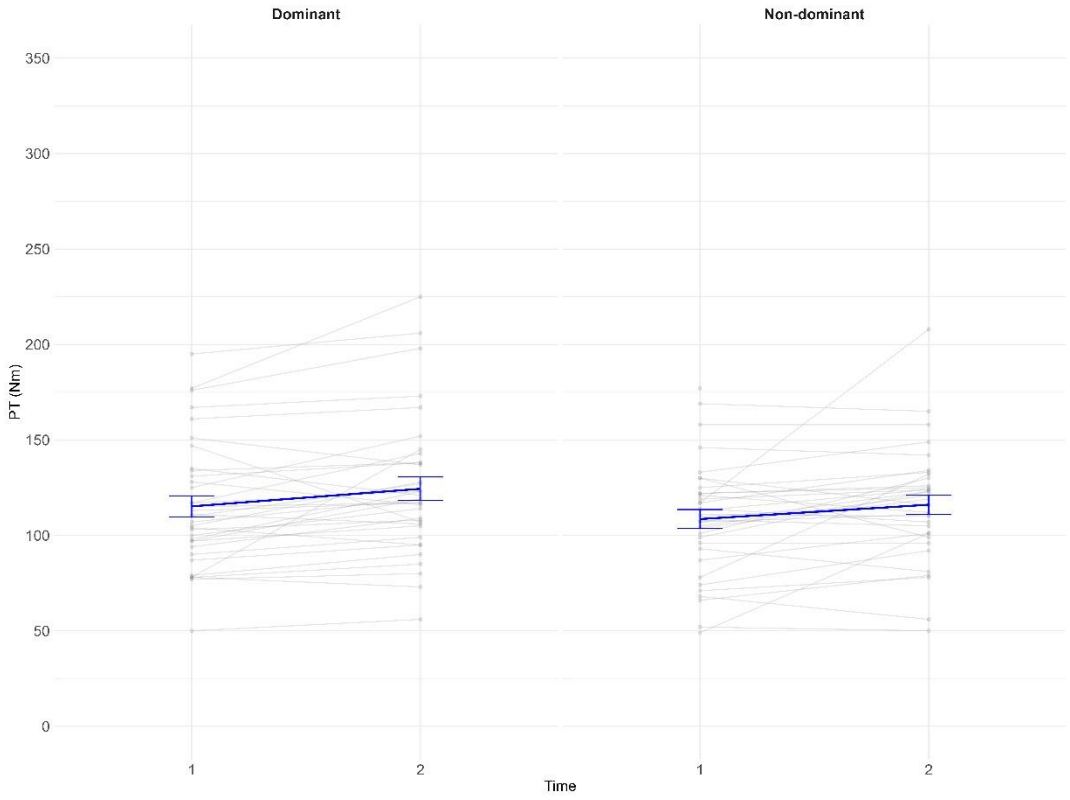


Figure 4 - Knee flexor eccentric peak torque (KFeccPT)

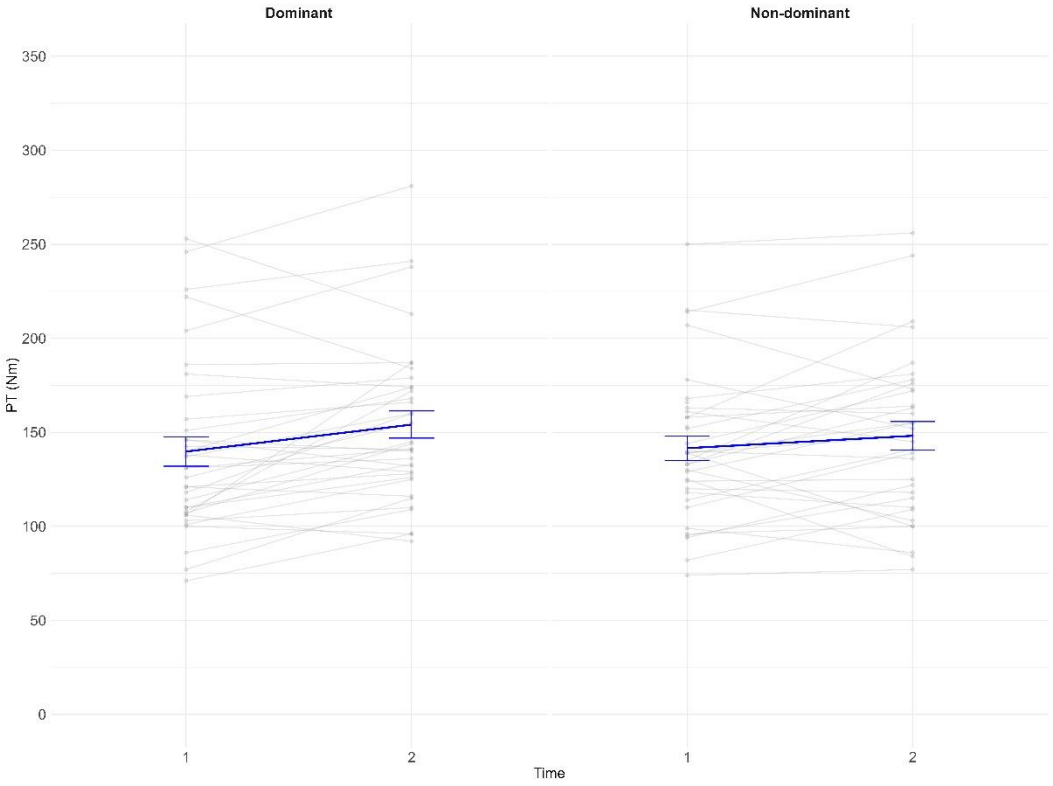


Figure 5 - Knee extensor concentric fatigue (KEconFAT)

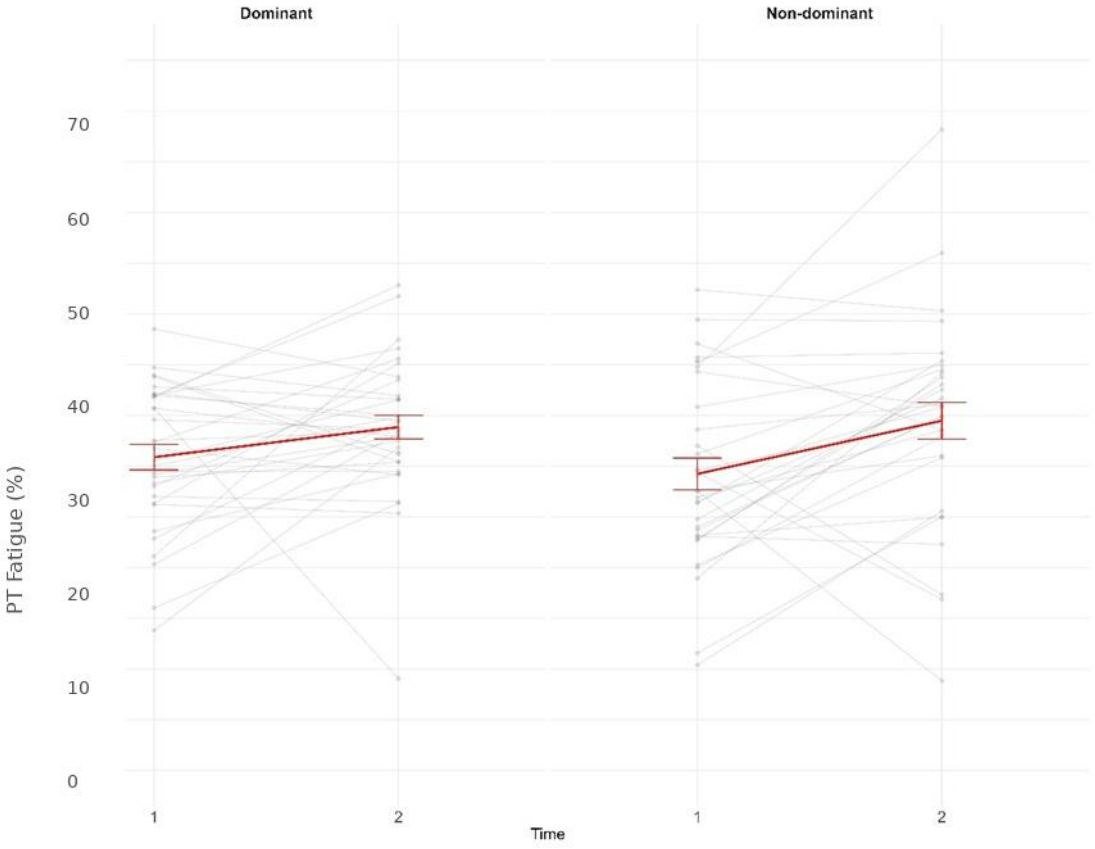


Figure 6 - Knee flexor concentric fatigue (KFconcFAT)

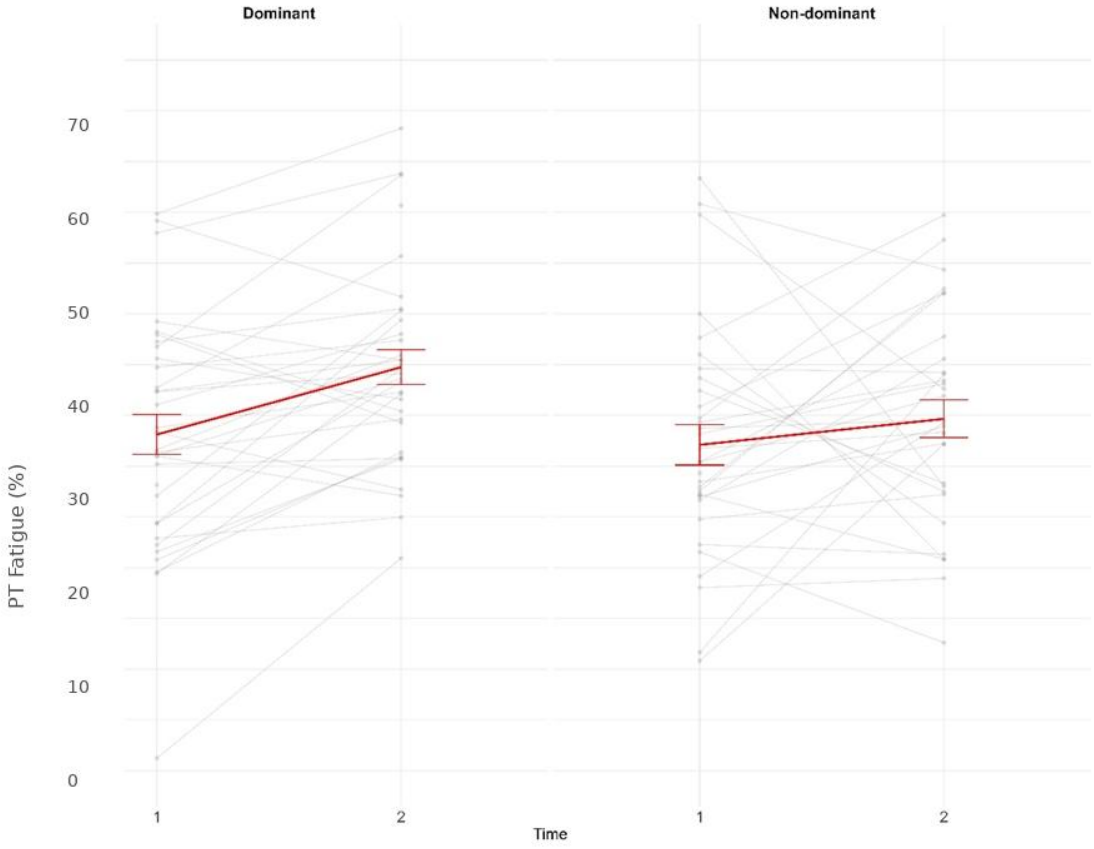


Figure 7 - Differences between dominant and non-dominant leg in KEconcPT changes

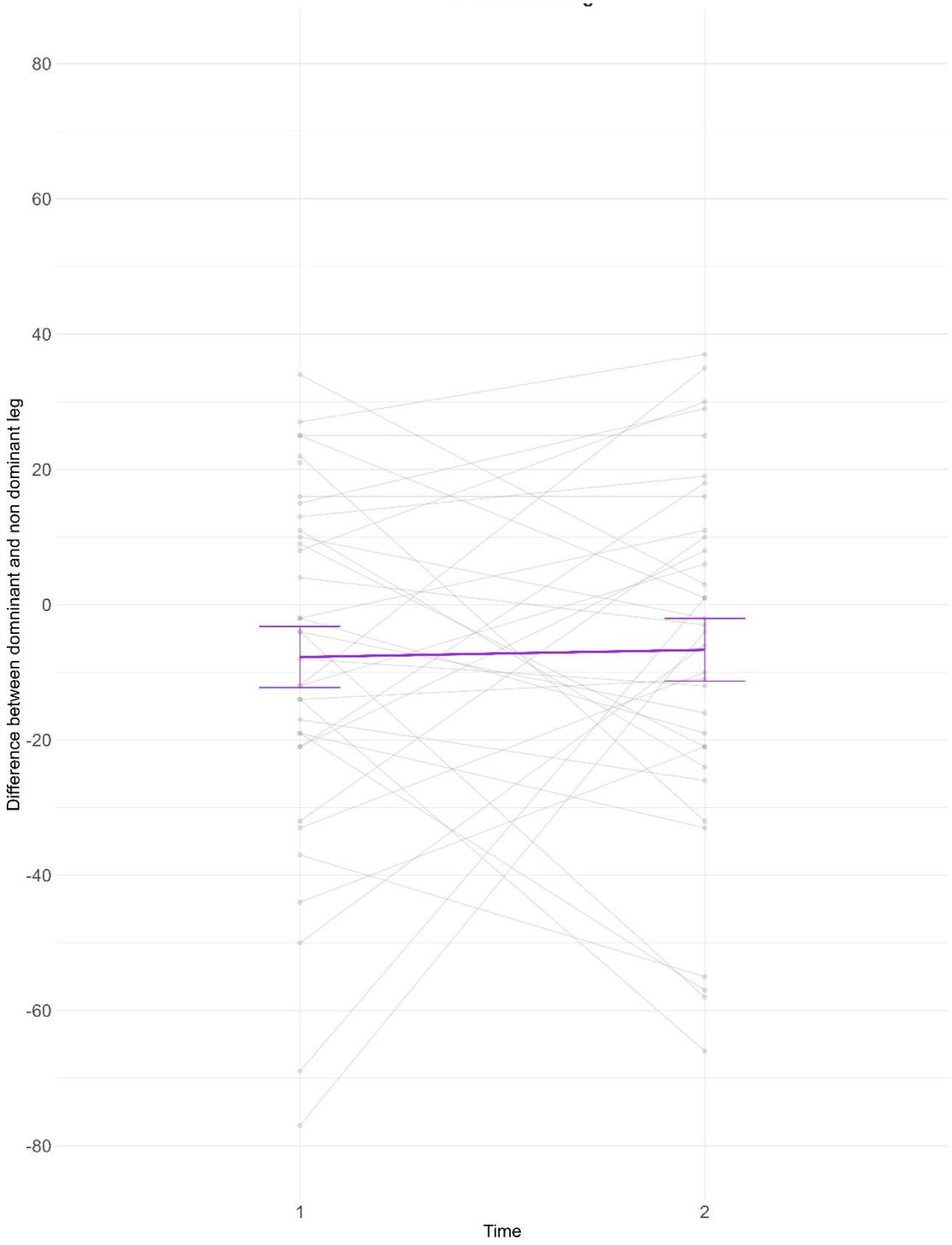


Figure 8 - Differences between dominant and non-dominant leg in KFconcPT change

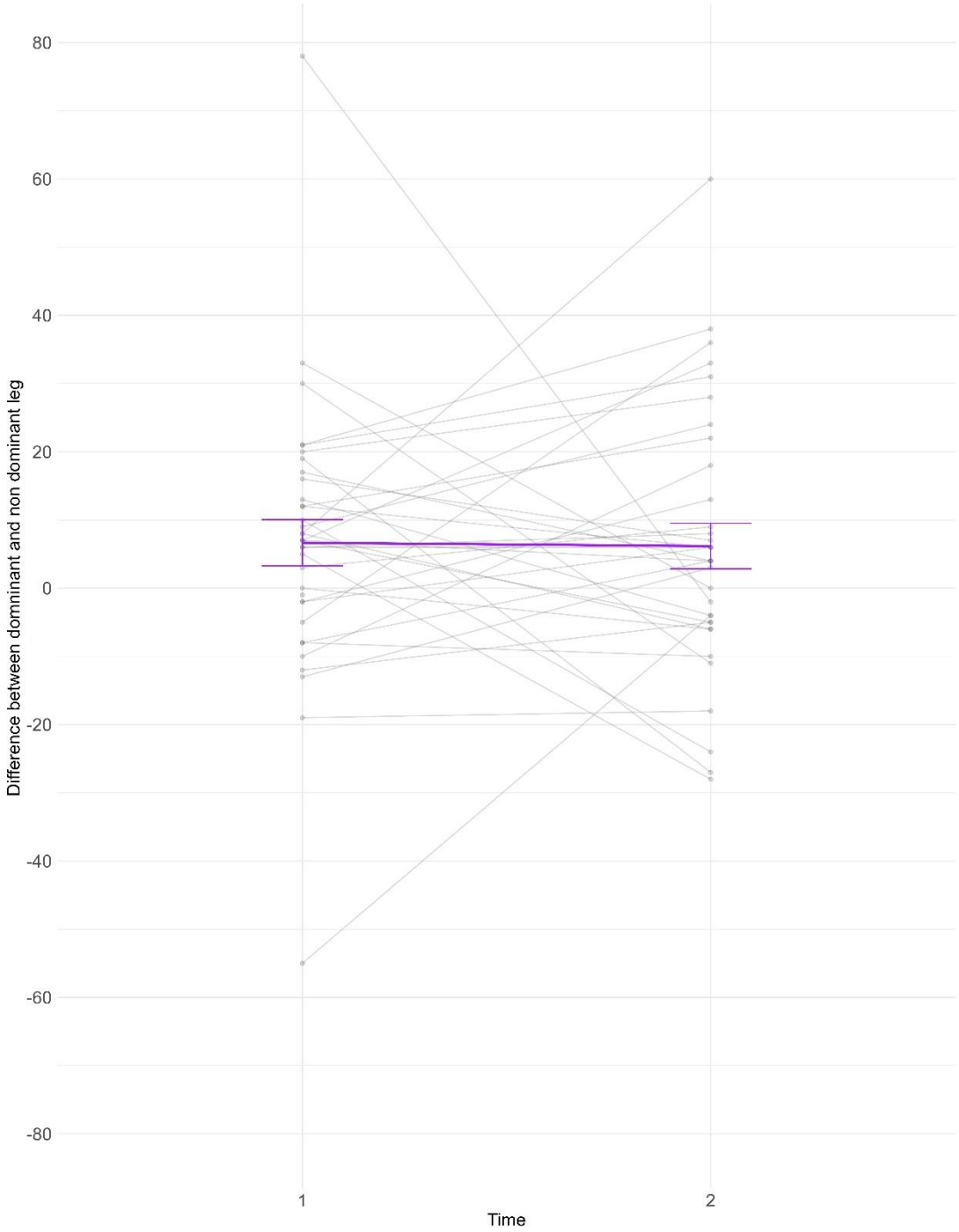
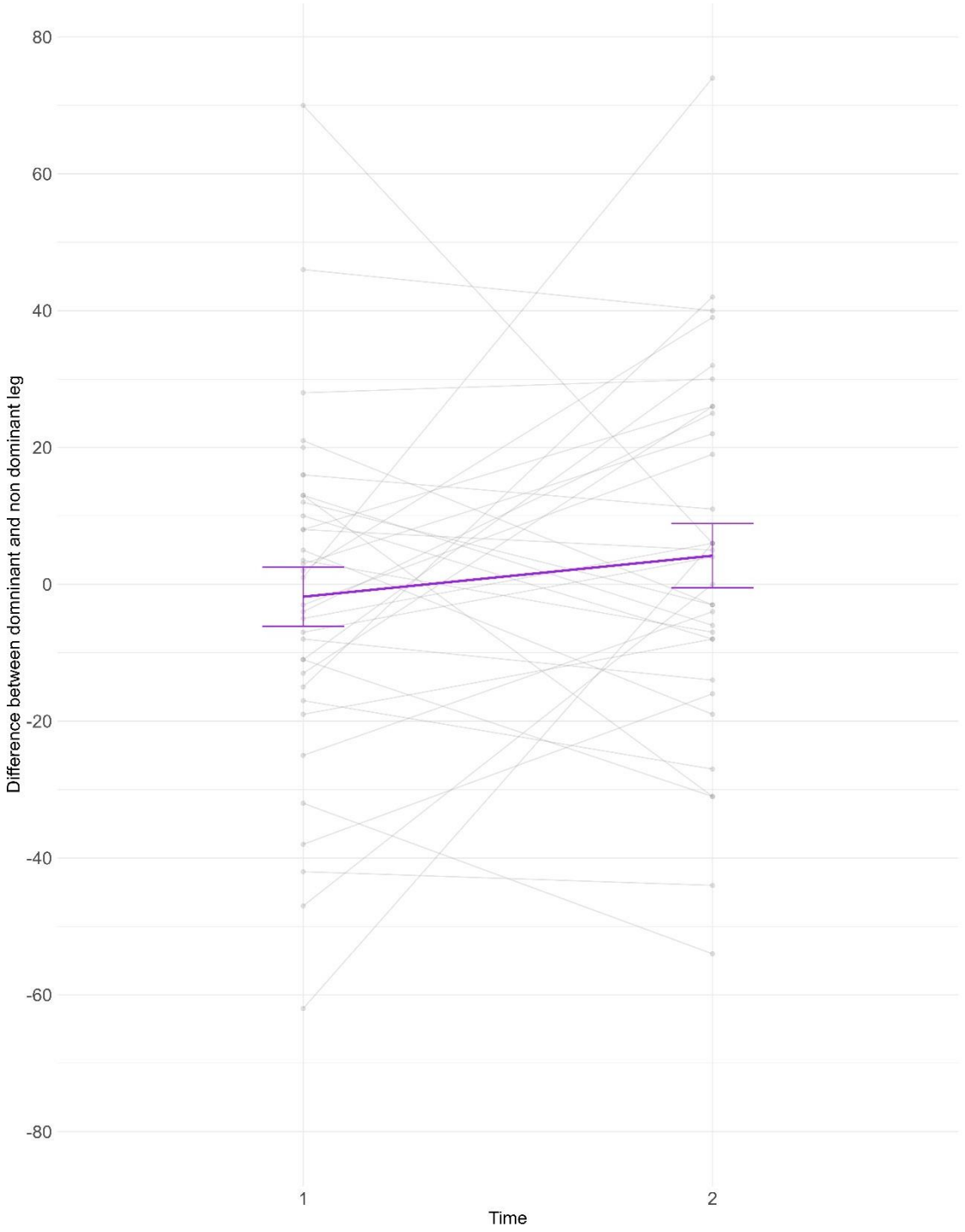


Figure 9 - Differences between dominant and non-dominant leg in KFeccPT changes



DISCUSSION

The present study examines the effect of 12-weeks of in-season SSG-focused training on lower limb neuromuscular function and composition in young football players. The analysis of the athlete group changes indicated that this period resulted in: a) modest gains in PT observed in DL, along with a slight increase in muscular FAT in DL and NDL; b) a small rise in both lean mass and fat mass, with a significant link between lean mass levels and PT in both legs; c) a slight increase tendence in performance asymmetry in KFeccPT between DL and NDL development; d) athletes exhibited heterogeneous responses across all physical tests, reflecting varied developmental profiles and marked interindividual differences in training adaptation.

In both teams, the SSG activities were conducted as a methodological approach designed to enhance athletes' physical, technical, and tactical skills through specific football activities. Without incorporating specific methods and exercises aimed at promoting targeted advancements in strength or hypertrophy, the training period has resulted in a modest rate of adaptation in PT and alterations in the composition of the lower limbs (Table 2, Figures 1, 2, 3, and 4). These results can be associated with the characteristics of the stimulus imposed by SSG and game-related movements (Clemente *et al*., 2024; Bujalance-Moreno *et al*., 2019; Hill-Haas *et al*., 2011).

Despite the minor changes observed, it is clear that KEconPT and KFeccPT show better trends in the DL compared to the NDL (Figures 1 to 3). These differences may result from the asymmetric nature of the modality, which requires uneven loading and movement patterns between limbs. These are repeated countless times through years of training, and potentially loading each leg differently can lead to distinct adaptations in each leg (Carey *et al*., 2001). Lehance *et al*., 2009; Lees, Nolan, 1998; Sangnier, Tourney-Chollet, 2007). The differences in PT changes between DL and NDL are visible in Figures 7, 8, and 9. Although the group averages show minor between-limb differences in pre- and post-evaluations, individual changes reveal significant variability. While the between-limb relationship is still unclear, the slope of the regression lines suggests a tendency for the DL to have a greater advantage over the NDL in eccentric PT. The repetitive, mostly unilateral demands of soccer training and competition are widely linked to the development of interlimb asymmetries and muscle imbalances (Lehance *et al*., 2009; Masuda *et al*., 2005; Železnik *et al*., 2022; DeLang *et al*., 2021; Hart *et al*., 2016).

High-intensity actions, such as jumps, accelerations, and decelerations, impose significant mechanical stress on both anaerobic and aerobic systems, which can further accentuate these differences by creating unequal loads on each limb during training and matches (Fousekis *et al*., 2010; Lehance *et al*., 2009; Osgnach *et al*., 2010). During high-speed movements, the DL is responsible for stability, while the NDL handles impact absorption (Zhang *et al*., 2021). Additionally, in ball-handling actions like dribbling, passing, and shooting, elite athletes use the DL over 80% of the time, and this percentage tends to increase among amateur and youth athletes (Carey *et al*., 2001). Conversely, the NDL is used to support the body and maintain stability during these movements (Wong *et al*., 2007; DeLang *et al*., 2021).

The isokinetic muscular FAT test was conducted at a high angular velocity of 300°/s, a condition that more accurately reflects the football context movements (Dowson *et al*.,1998; Newman *et al*., 2004). Results indicated a small trend toward increased FAT, particularly in KFconFAT in DL and KEconFAT in NDL. These findings suggest that, beyond not clearly enhancing the capacity for PT production, a short period of SSG training not significantly contribute to improving the ability to sustain repeated high-intensity muscular efforts. Additionally, a slight tendency toward greater FAT in the KF over KE was observed both pre- and post-test, consistent with previous literature (Sangnier, Tourny-Chollet, 2007; Machado *et al*., 2023; Pinto *et al*., 2018). The FAT is a complex phenomenon involving both central (nervous system) and peripheral (muscular) factors. The central reduction in neural drive, discharge rates, as well as the accumulation of metabolites in muscles and substrate depletion, can contribute to diminished physiological performance (Marshall *et al*., 2014; Allen *et al*., 2008). The movements involved in sport training, as SSG and formal matches, are intricate neuromuscular actions that may aid in enhancing nervous system activity, increasing discharge rates and motor unit activation, as well as ATP resynthesis (Duchateau *et al*., 2006). However, the unpredictability of the games led to difficulties in controlling the number and intensity of actions performed by athletes, which may have contributed to the individual heterogeneity of changes observed in the grey rates in Figures 5 and 6.

Examining the relationship between body composition and physical performance throughout the training period revealed a positive correlation between muscle mass and PT levels, implying that a greater volume of lower-body musculature contributes to

improved neuromuscular performance. These results are corroborated by existing literature, which indicates that excess adipose tissue adversely affects, whereas lean mass supports, neuromuscular performance in football athletes (Suarez-Arronez *et al*., 2018; 2019). No association was observed between changes in lean mass and PT levels over the 12-week training period, suggesting that football training isolated may be insufficient to promote significant muscle hypertrophy without other specific methods. Positive changes in lean mass are more common during the pre-season, while smaller changes appear in the middle to the end of the competition year in soccer players (Silva *et al*., 2022). The training methods employed at various points in the season may affect this trend, as strength training and higher loads are most evident during pre-season periods (Silva *et al*., 2022; Jeong *et al*., 2011).

Strength-focused interventions of similar duration have produced different outcomes when alternative training modalities were combined with football activities in football players (Grazioli *et al*., 2023; Faude *et al*., 2017; Ferrini *et al*., 2025). These findings suggest that complementary strength-oriented interventions, particularly those emphasizing eccentric actions or NDL extensor/flexor strength, may provide a more specific and effective stimulus for neuromuscular adaptations, reducing imbalances, compared to SSG-based training alone. Moreover, these methods enable the assessment of athletes' neuromuscular capacities, allowing for more individualized prescriptions with load control.

In both the PT and FAT tests, this study documents notable individual variations, demonstrated by the grey bars in Figures 1 to 6. The group of athletes did not show a uniform development pattern, with improvements, maintenance of performance levels, and even declines being observed. This suggests that the potential various individual loads experienced during SSG and formal games, influenced by factors such as playing role, position, motivation, and personal characteristics, can significantly impact the determination of developmental rates. Future research should investigate the progression of each leg while accounting for individual training loads, thereby providing further insights into this discussion.

Practical applications

This study investigated changes in PT, FAT, and legs lean mass in young football athletes who completed a 12-week training program exclusively based on SSG approaches and formal games. The results showed slight improvements in PT and decreased FAT muscular resistance, with significant variability among individuals. These findings align with the literature on SSG, which highlights the difficulty of controlling individual load due to various factors related to the unpredictability of the game and the diversity of athletes' characteristics. Therefore, it is noted that training focused exclusively on game-related movements, while useful for football-specific preparation, can be challenging, especially to promote adaptations in neuromuscular function. Additionally, different development rates between the DL and NDL limbs, as well as between concentric and eccentric PT, may lead to greater muscular imbalances and an increased risk of injury. In this context, supplementing football training with targeted reinforcement and using tools to monitor individual loads could be an effective strategy, emphasizing the promotion of inter-limb balance and reduction of asymmetries.

Limitations

The analyses conducted in this study have certain limitations. It is generally recognized that starters and substitutes show varying performance levels during training sessions and competitive matches, as do athletes with different positions and functions in the games. However, the study did not consider the individual training loads of the athletes throughout the research period. Future research on SSGs could investigate the impact of individual training loads on the development of athletes' physical capacities and the progression of strength and FAT. Additionally, the period examined represents only part of the competitive season, during which changes in body composition, strength, and FAT resistance are ongoing processes. Therefore, longitudinal studies could offer a more comprehensive understanding of these factors in relation to SSG-based training.

REFERENCES

AAGAARD, P, SIMONSEN, EB, MAGNUSSON, SP, LARSSON, B, AND DYHRE POULSEN, P. A new concept for isokinetic hamstring: Quadricepsmuscle strength ratio. Am J Sports Med 26: 231–237, 1998.

ALTARRIBA-BARTES, A.; PEÑA, J.; VICENS-BORDAS, J.; MILÀ-VILLAROEL, R.; CALLEJA-GONZÁLEZ, J. Post-competition recovery strategies in elite male soccer players. Effects on performance: A systematic review and meta-analysis. 2020.

ALVARES, D. A. R. J. B.; RODRIGUES, R.; DE AZEVEDO FRANKE, R.; SILVA, B. G. C.; PINTO, R. S.; VAZ, M. A.; BARONI, B. M. Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. Physical Therapy in Sport, v. 16, p. 59–65, 2015.

BALAGUÉ, N.; HRISTOVSKI, R.; POL, R.; BORRALO, A.; GARCÍA-RETORTILLO, S. Preventing or promoting muscle injuries? Strength training as a risk factor in professional football. Apunts Sports Medicine, v. 59, n. 224, 2024.

BANGSBO, J.; MOHR, M.; KRUSTRUP, P. Physical and metabolic demands of training and match-play in the elite football player. Journal of Sports Sciences, v. 24, n. 7, p. 665–674, 2006.

BARNES, C.; ARCHER, D. T.; HOGG, B.; BUSH, M.; BRADLEY, P. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BARONI, B. M.; RUAS, C. V.; RIBEIRO-ALVARES, J. B.; PINTO, R. S. Hamstring-to-quadriceps torque ratios of professional male soccer players: a systematic review. The Journal of Strength & Conditioning Research, v. 34, n. 1, p. 281–293, 2020.

BEDOYA, A. A.; MILTENBERGER, M. R.; LOPEZ, R. M. Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. The Journal of Strength & Conditioning Research, v. 29, n. 8, p. 2351–2360, 2015.

BEKRIS, E.; BOURDAS, D. I.; MYLONIS, E.; ISPIRLIDIS, I.; ZACHARAKIS, E. D.; KATIS, A. Effect of 3 vs. 3 soccer small-sided game on various performance, inflammatory, muscle damage and hormonal indicators in semi-professional players. Sports, v. 10, n. 7, p. 102, 2022.

BOLANOWSKI, M.; NILSSON, B. E. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. Medical Science Monitor, v. 7, n. 5, p. 1029–1033, 2001.

BRANQUINHO, L.; DE FRANÇA, E.; TEIXEIRA, J. E.; TITTON, A.; LEITE DE BARROS, L. F.; CAMPOS, P.; MARINHO, D. A.; FORTE, P.; CAPERUTO, E. C.; THOMATIELI DOS SANTOS, R. V.; FERRAZ, R. Identifying the ideal weekly training load for in-game performance in an elite Brazilian soccer team. Frontiers in Physiology, v. 15, p. 1341791, 2024.

BÜRKNER, P. Brms: An R package for Bayesian multilevel models using Stan. Journal of Statistical Software, v. 80, n. 1, p. 1–28, 2017

CEZARINO, L. G.; DA SILVA GRÜNINGER, B. L.; SILVA, R. S. Injury profile in a Brazilian first-division youth soccer team: a prospective study. Journal of Athletic Training, v. 55, n. 3, p. 295–302, 2020.

DE HOYO, M.; GONZALO-SKOK, O.; SAÑUDO, B.; CARRASCAL, C.; PLAZA-ARMAS, J. R.; CAMACHO-CANDIL, F.; OTERO-ESQUINA, C. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. *The Journal of Strength & Conditioning Research*, v. 30, n. 2, p. 368–377, 2016.

DELANG, M. D.; SALAMH, P. A.; FAROOQ, A.; TABBEN, M.; WHITELEY, R.; VAN DYK, N.; CHAMARI, K. The dominant leg is more likely to get injured in soccer players: systematic review and meta-analysis. *Biology of Sport*, v. 38, n. 3, p. 397–435, 2021.

DELLAL, A.; OWEN, A.; WONG, D. P.; KRUSTRUP, P.; VAN EXSEL, M.; MALLO, J. Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science*, v. 31, n. 4, p. 957–969, 2012.

DUPONT, G.; NEDELEC, M.; MCCALL, A.; MCCORMACK, D.; BERTHOIN, S.; WISLØFF, U. Effect of 2 soccer matches in a week on physical performance and injury rate. *The American Journal of Sports Medicine*, v. 38, n. 9, p. 1752–1758, 2010.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, v. 30, n. 7, p. 625–631, 2012.

FAUDE, O.; RÖSSLER, R.; PETUSHEK, E. J.; ROTH, R.; ZAHNER, L.; DONATH, L. Neuromuscular adaptations to multimodal injury prevention programs in youth sports: a systematic review with meta-analysis of randomized controlled trials. *Frontiers in Physiology*, v. 8, p. 791, 2017.

FENG, J.; RODRÍGUEZ FERNÁNDEZ, A., *et al*. Impact of small-sided game formats on electromyographic responses in college students. Journal of Sports Science and medicine, v. 24, n. 4, p. 729–738, 2025.

FORTES, R. P.; MACHADO, C. L. F.; BARONI, B. M.; NAKAMURA, F. Y.; PINTO, R. S. Relationship between maximal strength and hamstring-to-quadriceps ratios in balanced and unbalanced legs in futsal athletes. Sport Sciences for Health, v. 19, n. 4, p. 1169–1176, 2023.

GABBETT, T. J.; WHYTE, D. G.; HARTWIG, T. B.; WESCOMBE, H.; NAUGHTON, G. A. The relationship between workloads, physical performance, injury and illness in adolescent male football players. Sports Medicine, 2014.

GRAZIOLI, R.; INÁCIO, M.; LOPEZ, P.; FREITAS, S. R.; CUNHA, G. D. S.; MACHADO, C. L. F.; VEECK, F.; BARONI, B. M.; CADORE, E. L.; PINTO, R. S.

Effects of eccentric-emphasized leg curl intervention on muscle strength imbalance markers in professional soccer players during pre-season. Journal of Bodywork and Movement Therapies, v. 35, p. 28–32, 2023.

HART, N. H.; NIMPHIUS, S.; WEBER, J.; SPITERI, T.; RANTALAINEN, T.; DOBBIN, M.; NEWTON, R. Musculoskeletal asymmetry in football athletes: a product of limb function over time. 2016.

HILL-HAAS, S. V.; DAWSON, B.; IMPELLIZZERI, F. M.; COUTTS, A. J. Physiology of small-sided games training in football: a systematic review. Sports Medicine, v. 41, n. 3, p. 199–220, 2011.

HŮLKA, K.; STRNIŠTĚ, M. Fitness improvements of young soccer players after high volume or small sided games interventions. Biology of Sport, v. 38, n. 4, p. 573–578, 2021.

IACONO, A. D.; MARTONE, D.; CULAR, D.; MILIC, M.; PADULO, J. Game profile–based training in soccer: a new field approach. The Journal of Strength & Conditioning Research, v. 31, n. 12, p. 3333–3342, 2017.Iacono, A. D., Beato, M., & Unnithan, V. (2019). Effects of Game Profile–Based Training and Small-Sided Games on Physical Performance of Elite Young Soccer Players.

IBÁÑEZ, S. J.; FEU, S.; CAÑADAS, M. Sistema integral para el análisis de las tareas de entrenamiento, SIATE, en deportes de invasión. E-balonmano.com: Revista de Ciencias del Deporte, v. 12, n. 1, p. 3–30, 2016.

ISHIDA, A.; TRAVIS, S. K.; STONE, M. H. Associations of body composition, maximum strength, power characteristics with sprinting, jumping, and intermittent endurance performance in male intercollegiate soccer players. Journal of Functional Morphology and Kinesiology, 2021.

JASTRZEBSKI, Z.; BARNAT, W.; DARGIEWICZ, R.; JASKULSKA, E.; SZWARC, A.; RADZIMIŃSKI, Ł. Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. International Journal of Sports Science & Coaching, v. 9, n. 5, p. 1169–1179, 2014.

JEFFREYS, I. The use of small-sided games in the metabolic training of high school soccer players. Strength and Conditioning Journal, v. 26, n. 5, p. 77–78, oct. 2004.

JULLIEN, H.; BISCH, C.; LARGOUËT, N.; MANOUVRIER, C.; CARLING, C. J.; AMIARD, V. Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players? Journal of Strength and Conditioning Research, v. 22, n. 2, p. 404–411, mar. 2008.

KAY, M. Tidybayes: tidy data and geoms for Bayesian models. Zenodo, 2023.

LEHANCE, C., BINET, J., BURY, T., & CROISIER, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian journal of medicine & science in sports*, *19*(2), 243-251.

MACHADO, C. L.; NAKAMURA, F. Y.; DE ANDRADE, M. X.; DOS SANTOS, G. C.; CARLET, R.; BRUSCO, C. M.; REISCHAK-OLIVEIRA, A.; VOSER, R. D. C.; PINTO, R. S. Total and regional body composition are related with aerobic fitness performance in elite futsal players. Journal of Bodywork and Movement Therapies, v. 35, p. 164–168, 2023.

MAFFIULETTI, N. A.; AAGAARD, P.; BLAZEVICH, A. J.; FOLLAND, J.; TILLIN, N.; DUCHATEAU, J. Rate of force development: physiological and methodological considerations. European Journal of Applied Physiology, v. 116, n. 6, p. 1091–1116, 2016.

MAKAR, P.; SILVA, A.; KAWCZYŃSKI, A.; AKYILDIZ, Z.; YILDIZ, M.; PRAÇA, G.; CLEMENTE, F. Variability of peak speed and sprinting actions during the same small-sided games: within- and between-player variations inspected over four consecutive weeks. Biology of Sport, v. 40, n. 4, p. 959–965, 2023.

MICHAILIDIS, Y.; FOUROS, I. G.; PRIMPA, E.; MICHAILIDIS, C.; AVLONITI, A.; CHATZINIKOLAOU, A.; ... KAMBAS, A. Plyometrics' trainability in preadolescent soccer athletes. The Journal of Strength & Conditioning Research, v. 27, n. 1, p. 38–49, 2013.

MORIN, J. B.; GIMENEZ, P.; EDOUARD, P.; ARNAL, P.; JIMENEZ-REYES, P.; SAMOZINO, P.; ... MENDIGUCHIA, J. Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. Frontiers in Physiology, v. 6, dec. 2015. doi:10.3389/fphys.2015.00404

NÉDÉLEC, M.; MCCALL, A.; CARLING, C.; LEGALL, F.; BERTHOIN, S.; DUPONT, G. Recovery in soccer: part I - post-match fatigue and time course of recovery. Sports Medicine, 2012.

OLIVA-LOZANO, J. M.; FORTES, V.; KRUSTRUP, P.; MUYOR, J. M. Acceleration and sprint profiles of professional male football players in relation to playing position. PLoS One, v. 15, n. 8, e0236959, 2020.

OSGNACH, C.; POSER, S.; BERNARDINI, R.; RINALDO, R.; DI PRAMPERO, P. E. Energy cost and metabolic power in elite soccer: a new match analysis approach. Medicine & Science in Sports & Exercise, v. 42, n. 1, p. 170–178, 2010.

OTERO-ESQUINA, C.; DE HOYO LORA, M.; GONZALO-SKOK, Ó.; DOMÍNGUEZ-COBO, S.; SÁNCHEZ, H. Is strength-training frequency a key factor to develop performance adaptations in young elite soccer players?. European Journal of Sport Science, v. 17, n. 10, p. 1241–1251, 2017.

PIETRASZEWSKI, P.; MASZCZYK, A.; ZAJĄC, A.; GOŁAŚ, A. Muscle activity and biomechanics of sprinting: a meta-analysis review. Applied Sciences, v. 15, n. 9, p. 4959, 2025.

PINTO, M. D.; BLAZEVICH, A. J.; ANDERSEN, L. L.; MIL-HOMENS, P.; PINTO, R. S. Hamstring-to-quadriceps fatigue ratio offers new and different muscle function

information than the conventional non-fatigued ratio. Scandinavian Journal of Medicine & Science in Sports, v. 28, n. 1, p. 282–293, 2018.

PONS, E.; GARCÍA-CALVO, T.; RESTA, R.; BLANCO, H.; LÓPEZ DEL CAMPO, R.; DÍAZ GARCÍA, J.; PULIDO, J. J. A comparison of a GPS device and a multi-camera video technology during official football matches: agreement between systems. PLOS ONE, v. 14, n. 8, e0220729, 2019. https://doi.org/10.1371/journal.pone.0220729

REILLY, T.; WILLIAMS, A. M.; NEVILL, A.; FRANKS, A. A multidisciplinary approach to talent identification in soccer. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

SAHALY, R.; VANDEWALLE, H.; DRISS, T.; MONOD, H. Maximal voluntary force and rate of force development in humans–importance of instruction. European Journal of Applied Physiology, v. 85, p. 345–350, 2001.

STERN, D.; GONZALO-SKOK, O.; LOTURCO, I.; TURNER, A.; BISHOP, C. A comparison of bilateral vs. unilateral-biased strength and power training interventions on measures of physical performance in elite youth soccer players. The Journal of Strength & Conditioning Research, v. 34, n. 8, p. 2105–2111, 2020.

SUAREZ-ARRONES, L.; LARA-LOPEZ, P.; TORRENO, N.; SAEZ DE VILLARREAL, E.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Effects of strength training on body composition in young male professional soccer players. Sports, v. 7, n. 5, p. 104, 2019.

SUAREZ-ARRONES, L.; PETRI, C.; MALDONADO, R. A.; TORRENO, N.; MUNGUÍA-IZQUIERDO, D.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Body fat assessment in elite soccer players: cross-validation of different field methods. Science and Medicine in Football, v. 2, n. 3, p. 203–208, 2018.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. Pediatric Exercise Science, v. 24, p. 603–621, 2012.

VEHTARI, A.; GELMAN, A.; SIMPSON, D.; CARPENTER, B.; BÜRKNER, P.-C. Rank-normalization, folding, and localization: an improved $\hat{R}$ for assessing convergence of MCMC (with discussion). Bayesian Analysis, v. 16, n. 2, p. 667–718, 2021.

WICKHAM, H. Ggplot2: elegant graphics for data analysis. Springer, 2016. https://ggplot2.tidyverse.org

WING, C. E.; TURNER, A. N.; BISHOP, C. J. Importance of strength and power on key performance indicators in elite youth soccer. Journal of Strength and Conditioning Research, v. 34, n. 7, p. 2006–2014, jul. 2020.

WONG, P.-L.; CHAMARI, K.; CHAOUACHI, A.; MAO, D. W.; WISLØFF, U.; HONG, Y. Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. British Journal of Sports Medicine, v. 41, p. 84, 2007.

WORLD MEDICAL ASSOCIATION *et al*. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA, v. 310, n. 20, p. 2191–2194, 2013.

ZHANG, Q.; LÉAM, A.; FOURÉ, A.; WONG, D. P.; HAUTIER, C. A. Relationship between explosive strength capacity of the knee muscles and deceleration performance in female professional soccer players. *Frontiers in Physiology*, v. 12, p. 723041, 2021.

5. ARTIGO 4

ARE NEUROMUSCULAR MAXIMAL CAPACITIES RELATED TO FATIGUE MEASURES IN YOUNG FOOTBALL PLAYERS?

ABSTRACT

Purpose: This study aimed to examine the correlation between (I) peak levels of neuromuscular performance tests and various fatigue indicators, and (II) different fatigue assessment protocols, among young football players. **Methods:** Twenty-eight young male football players (mean age 18.6 ± 1.40 years) from a Brazilian club performed assessments of maximal neuromuscular capacities, including peak torque (PT) during concentric knee extension (KE) and flexion (KF), maximal sprint performance (35 meters), and countermovement jump (CMJ). Fatigue responses were evaluated using the Running-based Anaerobic Sprint Test (RAST), CMJ under fatigued conditions, and an isokinetic fatigue protocol. **Results:** No correlations were found between maximum performance and the corresponding fatigue tests, nor between the fatigue measurements. **Conclusion:** The absence of a correlation between maximal tests and fatigue assessments indicates that achieving high levels of strength, speed, and power does not necessarily imply the ability to sustain these efforts repeatedly. Moreover, fatigue tests, although influenced by similar central and peripheral factors, elicit different responses, highlighting the complexity of neuromuscular actions and the need to select assessments appropriate to the specific objective. These findings suggest that maximal capacity evaluations may not fully capture the complexity of fatigue, highlighting the need for caution when using such tests to assess training adaptations or to provide an accurate evaluation of a player's functional performance.

Keywords: game-based, isokinetic, fatigue, soccer.

INTRODUCTION

Football is an intermittent sport characterized by short recovery periods interspersed with periods of high-intensity activity (Bangsbo, 1994; Oliva-Lozano *et al*., 2020; Reilly *et al*., 2000). Both adult and youth athletes cover approximately 10-12 km per match, with a substantial portion of this distance involving intense activity (Sánchez-Sánchez *et al,* 2021). Players perform around 250 high-intensity actions per game, including accelerations, decelerations, changes of direction, physical challenges, shots, and jumps (Stølen *et al*., 2005). In elite leagues, maximum sprints reaching speeds over 30 km/h and covering 30 to 50 meters typically occur at the start of the match and during the final 15 minutes of the game (Oliva-Lozano *et al*., 2023). These findings underscore the importance for elite athletes not only to perform at high intensity but also to repeatedly execute explosive movements efficiently while managing energy expenditure (Oliva-Lozano *et al*., 2023).

High-intensity movements performed during football matches depend on physical capacities such as strength, speed, and power, which collectively determine a player's ability to sprint, jump, and rapidly change direction (Stølen *et al*., 2005; Mohr *et al*., 2003). Thus, literature related to football has increasingly focused on the physical development of athletes. Studies aiming to understand the factors that determine performance and progress during in training strategies (Lehnert *et al*., 2017; de Hoyo *et al*., 2015; Faude *et al*., 2012; Ferrini *et al*., 2025), the effects of the maturation process in young athletes (Carvalho *et al*., 2019; Leonardi *et al*., 2018; Berger *et al*., 2025; Phillipaerts *et al*., 2006; Deprez *et al*., 2015), and to identify elements that contribute to talent identification (Fortin-Guichard *et al*., 2022; Williamns *et al*., 2020; Carling *et al*., 2012), traditionally assess the neuromuscular capacities through maximal tests, including peak torque (PT), jump performance (e.g., countermovement or squat jumps), sprint tests, change-of-direction assessments, repeated-sprint ability, and intermittent endurance tests.

However, an elite football player must be able not only to produce high levels of strength, speed, and power to execute complex and varied motor tasks during a match, but also to maintain the ability to sustain these performance levels throughout the entire game (Reilly & Bangsbo, 2000; Vigne *et al*., 2010). Fatigue is defined as the decrease in maximum force or desired performance output, which limits both physical and cognitive functions (Gandevia, 2001; Enoka and Duchateau, 2016). This decrease results from the

interaction of central and peripheral mechanisms, including reduced neural drive and changes in muscle contractile properties, ion imbalances, and depletion of energy substrates (Allen *et al.*, 2008; Glaister *et al.*, 2005). It is essential in sports science, as it affects not only physical output but also technical execution and decision-making, particularly in team sports such as football (Mohr *et al*., 2003).

Performance tests specific to football have been developed to better simulate the actual game (Buchheit *et al*., 2010). Maximal sprint and jump tests are widely used to assess players' explosive capabilities and acceleration potential, as reliable indicators of neuromuscular capacities. These assessments provide valuable insights into lower-limb power production and fatigue monitoring in team-sport contexts (Armada-Cortés *et al*., 2022). The CMJ's positive sensitivity to identifying fatigue leads to the implementation of protocols involving jumps after bouts of maximal sprints or after training sessions and matches, to quantify the decline in explosive performance over efforts (Jiménez-Reyes *et al*., 2018). Additionally, the decrement in maximal speed is assessed in repeated sprint protocols, which are reliable and widely used tools to evaluate anaerobic capacity (Jiménez-Reyes *et al*., 2016, 2018). In contrast, laboratory-based assessments such as isokinetic dynamometry are considered the gold standard for evaluating muscle-specific strength and fatigue under controlled conditions, particularly in knee extensors and flexors (Ekstrand *et al*., 2016; Baroni *et al*, 2020).

Therefore, while a maximal test evaluates an athlete's maximal neuromuscular potential, fatigue-based tests assess the ability to sustain performance over time under repeated or prolonged high-intensity efforts. However, the accuracy of relying only on maximal tests for monitoring development, adjusting training, and talent identification remains unclear. Exclusive dependence on maximal assessments may consequently neglect critical facets of match performance, underscoring the importance of supplementary evaluations that combine assessments of maximal capacities with fatigue tolerance. To our knowledge, no study has systematically examined the relationship between maximal neuromuscular performance assessments with different fatigue resistance tests in football players, representing a gap in the literature. Therefore, this study aims to examine the correlation between: (I) peak levels of neuromuscular performance tests and various fatigue indicators, and (II) different fatigue assessment protocols, among young football players.

METHODOLOGY

The research is a cohort study using data from an evaluation conducted mid-year during the in-season period. The study involved 28 young male soccer athletes, with an average age of 18.6 ± 1,40 years, from the under-20 football team in Rio Grande do Sul, Brazil. The club participating in the study competed in regional and state-level competitions organized by the Rio Grande do Sul Football Federation. Weekly, athletes attended four two-hour training sessions, in addition to participating in competitive or friendly games on weekends.

Ethical approval for this study was granted by the research ethics committee at the Federal University of Rio Grande do Sul (CAAE 60188922.3.0000.5347). All athletes and their parents or legal guardians provided informed consent and assent. This study adhered to the ethical principles outlined in the Declaration of Helsinki (World Medical Association, 2013).

Procedures

Physical Assessments

Running-based Anaerobic Sprint Test (RAST)

To assess the athletes' anaerobic power, the Running-based Anaerobic Sprint Test (RAST) (Zacharogiannis *et al*., 2004) was used. The test involves six all-out sprints of 35 meters each, starting from a stationary position, with a 10-second rest between sprints. Photocells (CEFISE®, Nova Odessa, Brazil), placed at the start and finish lines, measured the total time for each run. The athlete's best performance was the fastest time of six sprints, while the difference between the fastest and the slowest times was noted as the fatigue index (Zagato *et al*., 2008; Andrade *et al*., 2014).

Countermovement jump (CMJ)

The evaluation of lower limb muscular power in the vertical plane was conducted by having athletes perform the CMJ (BOSCO *et al*., 1983; SAÉZ *et al*., 2008) with an electronic contact mat (Jump System Pro, Cefise, Nova Odessa, Brazil). To assess

maximal jump capacity, each athlete performed three CMJ attempts to achieve their highest jump. All jumps were performed bilaterally. The players were instructed to jump "as strongly, quickly, and powerfully as possible." Participants were always asked to keep their hands on their hips, with knees and ankles fully bent. A 3% variation was established as the maximum allowable difference between valid attempts, and the highest jump was recorded for analysis.

Following the RAST, athletes performed one CMJ trial after 30 seconds of rest and another trial after 2 minutes of rest. A fatigue index was then calculated as the difference between the maximal CMJ and the jumps performed under fatigued conditions (Alba-Giménez *et al*., 2022)

Isokinetic peak torque and fatigue

Both dominant and non-dominant legs were evaluated. The athletes were asked to identify their dominant leg, referring to "which leg they use to kick a ball, preferably" (Aagard *et al.,* 2998; Baroni *et al.,* 2018). Throughout the protocol, participants were instructed to perform each contraction with maximum effort and as fast and hard as possible ("as hard and fast as possible"), to ensure maximal muscle force production (Maffiuletti *et al.,* 2016; Sahaly *et al.,* 2001). Additionally, verbal encouragement was provided at all times, along with real-time visual feedback displayed on a monitor placed in front of the participants to track the force curve. The concentric PT of the KE and KF, as well as the eccentric PT of KF, were assessed using an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA).

Before data collection, both isokinetic dynamometers were calibrated following the manufacturer’s instructions. The protocol began with a five-minute general warm-up on a cycle ergometer (Movement Technology, BM2700, São Paulo, Brazil) at a self-reported comfortable speed. Initially, participants were positioned on the equipment with the trunk flexed at 85°, and the knee joint was aligned with the rotation axis of the dynamometer. The leg, thigh, torso, and pelvis were secured with straps to prevent compensatory movements during testing. Strap positions varied between devices, but the dynamometer lever arm was set similarly, with the pad positioned 2 cm above the lateral malleolus (Alvares *et al*., 2015).

A specific warm-up followed, consisting of ten submaximal dynamic contractions at 120°/s to each test. The PT of KE and KF was assessed during five consecutive maximal voluntary contractions (MVCs) performed in the concentric-concentric mode at 60°/s (range of motion: 0–90°, 0° = full extension). The eccentric PT of KF was assessed during five MVCs at 60°/s. The highest PT value from these contractions was used for analysis. Throughout the protocol, participants were instructed to perform each contraction with maximum effort and as fast and hard as possible ("as hard and fast as possible"), to ensure maximal muscle force production (Maffiuletti *et al.*, 2016; Sahaly *et al.*, 2001). Additionally, verbal encouragement was provided at all times, along with real-time visual feedback displayed on a monitor placed in front of the participants to track the force curve.

After the PT test, participants completed a muscle FAT assessment using an isokinetic dynamometer. The isokinetic protocol performed by the athletes consisted of 33 consecutive concentric contractions for knee flexion and extension at an angular velocity of 300°/s. The first repetition was discarded, and only 30 valid repetitions were adopted for performance decrement and FAT index calculations, as additional repetitions were included to allow the exclusion of invalid initial contractions potentially influenced by familiarization. A specific warm-up was performed with 10 submaximal contractions at 120°/s (0–90° range of motion, 0° = full extension), followed by three submaximal repetitions as a pre-test, with a 30-s interval between the pre-test and maximal test and a 60-s interval between maximal tests (Fortes *et al.*, 2023). The percentage of torque reduction was calculated by comparing the average torque of the last three repetitions with the average torque of the best three repetitions within the first five repetitions. The final FAT index, expressed as a percentage, represented the relative variation in torque throughout the test (Pinto *et al.*, 2018; Machado *et al.*, 2023).

Experimental Design

Each athlete was evaluated during a single visit to the Laboratório de Pesquisa em Exercício da Universidade Federal do Rio Grande do Sul. In the morning session, participants underwent laboratory testing, including assessments of PT and fatigue of the KE and KF. In the afternoon, activities began at least 2 hours after the laboratory tests

and at least 1 hour after lunch. The athletes followed this protocol on an athletics track: (1) maximal countermovement jump (CMJ) assessment, then a 5-minute rest; (2) evaluation with the Running Anaerobic Sprint Test (RAST); (3) a CMJ assessment 30 seconds after the last sprint of the RAST; and (4) another CMJ assessment 2 minutes after the last sprint.

Statistical Analysis

Initially, all presuppositions for a correlational analysis are checked. First, we verify normality using the Shapiro-Wilk test. Afterward, we observed, using a boxplot, the presence of outliers for all variables. The third step was to fit the linear regressions and visually inspect the distribution plots to determine if the relationship between variables was linear. In the end, we checked the homogeneity of the residual and the standardized residual distributions. All variables failed at least one of the above tests, and based on these preliminary assessments, we used the Spearman correlation tests. We adopted the significance value of 0,05 and the results were interpreted as poor (until 0.20), fair (from 0.21 to 0.50), moderate (from 0.51 to 0.70), very strong (from 0.71 to 0.90), and perfect (from 0.91 to 1.00) (Chan *et al*., 2003; Akoglu *et al*., 2018). The analysis was conducted in R (R Core Team, 2018) using the "dplyr" (Wickham *et al*., 2023) and "ggplot2" (Wickham *et al*., 2016) packages.

RESULTS

The pattern of athletes' performance fatigue in RAST, CMJ, and isokinetic assessments is presented in Figures 1, 2, and 3, respectively. No correlations were found between maximum performance and the corresponding fatigue tests. The results indicated that the correlation between CMJ best jump and fatigue after 30 seconds (rho = 0.006, p = 0.975), CMJ best jump and fatigue after 2 minutes (rho = -0.050, p = 0.810), RAST better time and RAST fatigue (rho = 0.363, p = 0.069), peak torque of the dominant concentric extensor and fatigue of the dominant concentric extensor (rho = 0.205, p = 0.360), peak torque of the dominant concentric flexor and fatigue of the dominant concentric flexor (rho = 0.288, p = 0.194), peak torque of the non-dominant concentric

extensor and fatigue of the non-dominant concentric extensor (rho = 0.168, p = 0.454), peak torque of the non-dominant concentric flexor and fatigue of the non-dominant concentric flexor (rho = -0.338, p = 0.123), was not statistically significant, suggesting no meaningful association was observed. No correlations were also found between fatigue measurements, considering the relationship between the isokinetic machine and field tests, and between CMJ and RAST test (Table 1).

Table 1 – Correlation (rho) and significance between fatigue measured on the isokinetic machine and fatigue in field tests

	CMJ fatigue after 30 seconds	CMJ fatigue after 2 minutes	RAST fatigue
NDL KEconFAT	0.262 (0.251)	0.361 (0.108)	0.357 (0.112)
DL FKconFAT	-0.016 (0.946)	0.221 (0.335)	-0.147 (0.524)
NDL KEconFAT	-0.024 (0.918)	-0.038 (0.872)	-0.126 (0.586)
NDL KFconFAT	-0.172 (0.457)	0.178 (0.440)	0.071 (0.760)d
RAST fatigue	0.092 (0.662)	-0.030 (0.888)	NA

Figure 1 – Running-based anaerobic sprint test

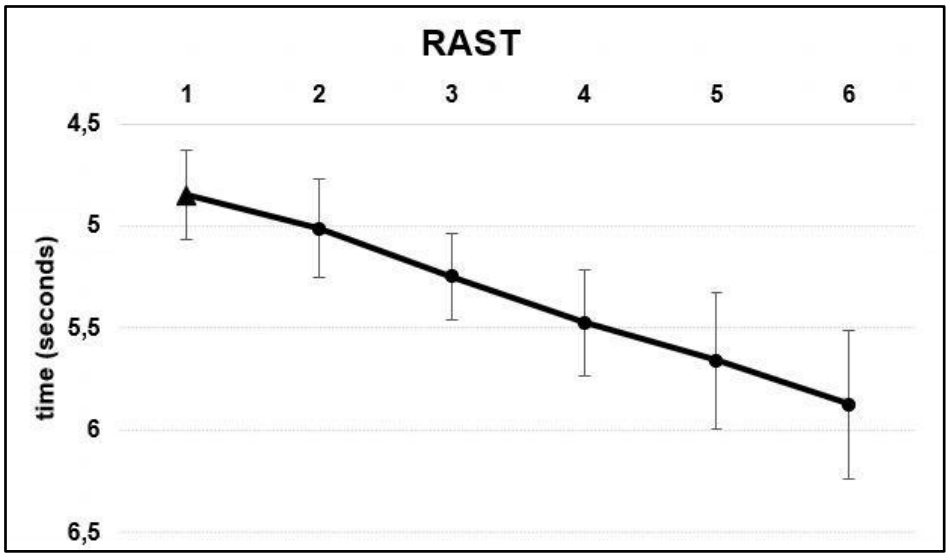


Figure 1- Running Anaerobic Sprint Test (RAST) performance of youth football athletes. (▲) Maximal 35-meter sprint performance, (●) Sprints performance in fatigue conditions.

Figure 2 - Countermovement jump test assessments

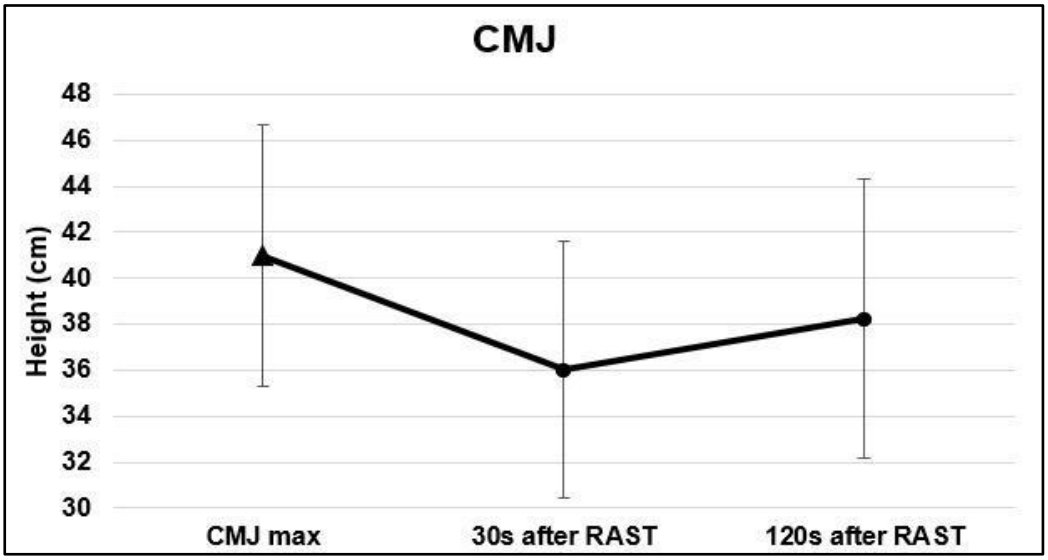


Figure 2- Countermovement Jump (CMJ) performance of youth football athletes.
(▲) Maximal jump performance. (●) Jump performance in fatigue conditions.

DISCUSSION

This study aims to examine the correlation between (I) peak levels of neuromuscular performance tests and various fatigue indicators, and (II) different fatigue assessment protocols, among young football players. The findings primarily indicate that there is no correlation between maximum capacities in sprinting, jumping, and PT of KE and KF, as measured by the fatigue indicators. Additionally, no association is observed among the various fatigue assessments. In this context, the study suggests that the mechanisms responsible for the maximum production of velocity, power, and torque do not indicate a greater capacity for resistance. Furthermore, we emphasize that each fatigue test provides distinct responses to physiological processes, depending on the specificity of the imposed demand, which highlights the complexity and multifactorial nature of fatigue.

The explosive performance in activities such as maximum sprints and vertical jumps results from a complex integration of neuromuscular and biomechanical factors (Pietraszewski *et al*., 2025; Maffiuletti *et al*., 2016). During a sprint, the gluteus maximus and hamstrings are primarily responsible for hip extension, propulsion, and deceleration control, while the quadriceps stabilize and extend the knee upon ground contact. The

synergistic action of the gastrocnemius and soleus muscles enables efficient plantar flexion, reducing contact time and maximizing force transfer (Pietraszewski *et al*., 2025). In vertical jumping, the quadriceps serve as the main force generator for knee extension, while the gluteus maximus and hamstrings promote hip extension and propulsion. The gastrocnemius and soleus contribute to plantar flexion, optimizing force transfer to the ground and enhancing jump performance (McMahon *et al*., 2018; Bobbert & van Ingen Schenau, 1988). The efficient execution of these movements depends on the central nervous system's ability to coordinate muscle activation sequences, maximize motor unit recruitment, and synchronize the actions of agonist and antagonist muscles (Jimenez-Reyes *et al*., 2016, 2018; Pietraszewski *et al*., 2025). Therefore, the ability to produce force rapidly in concentric and eccentric actions is a key determinant of performance in sprints and jumps (Mitchell *et al*., 2022; Pietraszewski *et al*., 2025).

Figure 3 - Isokinetic peak torque and fatigue assessment

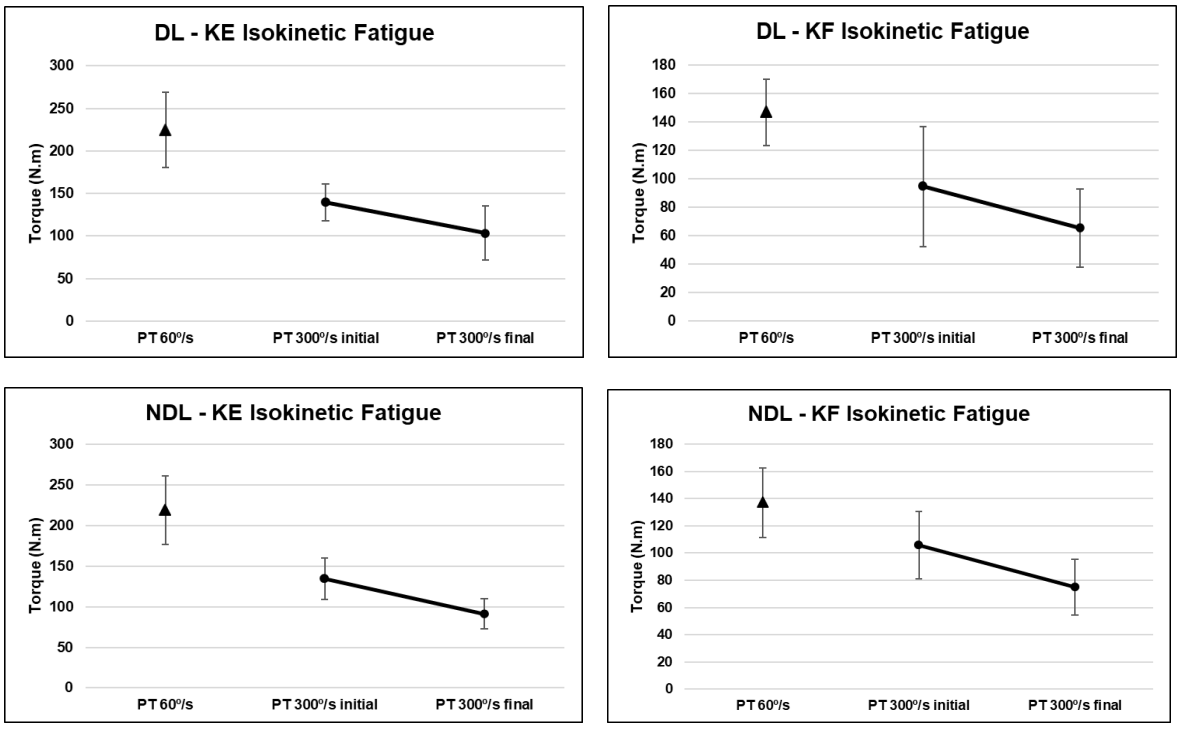


Figure 3 - CMJ performance of youth football athletes.

(▲) Peak torque at 60º/s. (●) Peak torque in fatigue protocol at 300º/s.

Conversely, the measurement of PT in KE and KF at 60º/s, attributable to its non-explosive nature, reflects the interaction between muscle activation capacity and structural characteristics, such as cross-sectional area, muscle architecture, and fiber composition (Maffiuletti *et al.*, 2016; Yoshiko *et al.,* 2023). Greater strength is associated with high neuromuscular activity among muscles of similar size, indicating that neural determinants can be as important as, or even more important than, structural factors (Yoshiko *et al*., 2023).

Repeated sprint tests are reliable tools for evaluating the anaerobic capacity of athletes in intermittent sports, such as football (Goodall *et al*., 2015; Meckel *et al*., 2009; Alba-Jiménez *et al*., 2022; Jiménez-Reyes *et al*., 2016, 2018). The decline in sprint performance (Figure 1) is attributed to changes in the intramuscular environment and adaptations in motor unit activation patterns, which alter movement mechanics and reduce performance (Jiménez-Reyes, 2016, 2018). Even during initial bouts, supraspinal fatigue develops quickly due to high neural demand on high-threshold motor units and disruption of metabolic homeostasis, decreasing mechanical efficiency (Goodall *et al*., 2015). A progressive depletion of ATP, phosphocreatine (PCr), and glycogen occurs during repeated sprints. Initially, ATP resynthesis relies mainly on PCr and anaerobic glycolysis; however, as efforts accumulate, the glycolytic contribution decreases, and aerobic metabolism becomes more relevant (Glaister *et al*., 2005; Gaitanos *et al*., 1993). These metabolic changes lead to the accumulation of lactate, hydrogen ions (H^+), and inorganic phosphate (Pi), which disrupt the Na^+/K^+ pump, inhibit Ca^{2+} release, and impair neuromuscular function. This manifests in the mechanics of running, characterized by increased ground contact time, decreased hip and knee flexion, shortened stride length, reduced horizontal force application, and impaired eccentric hamstring function (Pietraszewski *et al*., 2025; Romero *et al*., 2022).

The effect of repeated sprints on lower limb power, assessed via the CMJ, shows that recovery periods of 30 seconds and 2 minutes only partially restore maximum power (Figure 2). The metabolic and neuromuscular alterations resulting from repeated sprints reduce the efficiency of the stretch-shortening cycle, impair the recruitment of fast-twitch fibers, and limit the contractile capacity of lower limb muscles, resulting in decreased jump height and reduced explosive power (Allen *et al*., 2008; Baylor & Hollingworth, 1988). This decline in jump height and in the sprint velocity (Figure 1) correlates with the

accumulation of lactate and ammonia (Jiménez-Reyes *et al*., 2018). In isokinetic assessments, the fatigue of the knee extensors and flexors was examined in the dominant and non-dominant limbs (Figure 3). This type of test isolates muscle groups, allowing observation of specific fatigue patterns. The absence of rest periods between intense repetitions intensifies metabolic acidosis and hinders ATP resynthesis, inhibiting the action of the central nervous system and reducing torque production (Glaister *et al*., 2005; Allen *et al*., 2008; Linnamo *et al*., 1998). Thus, the reduction in maximum torque is strongly associated with peripheral factors, while losses in the fast force production involve both central and peripheral components (Morel *et al*., 2015).

Therefore, performance in explosive activities such as vertical jumps, maximum sprints, and torque production depends on the interaction between musculoskeletal and neural factors, including efficient motor unit recruitment, activation of type II fast fibers, and coordination between agonists and antagonists. However, this study suggests that the ability to generate high PT, speed, and power in the lower limbs does not guarantee maintenance of performance during repeated efforts, highlighting the difference between maximum instantaneous performance and fatigue resistance. Thus, assessing maximum capacity does not necessarily reflect the neuromuscular ability to efficiently restore ATP, phosphocreatine, and glycogen, buffer acidosis, and sustain high levels of neural activation to maintain performance.

Reductions in performance on the RAST (Armada-Cortés *et al*., 2022), decrements CMJ height (Alba-Giménez *et al*., 2022), and declines in isokinetic PT (Veeck *et al*., 2023) are commonly used methods to assess fatigue levels in football players. However, as shown in Tables 1 and 2, there is no direct association between the results obtained in the three tests, reflecting the complexity of each fatigue mechanism. Although they share similar physiological mechanisms, differences in movement nature, intensity, duration, and rest periods between repetitions determine distinct physiological responses, which explain the lack of correlation between the tests. Consistent with these findings, studies indicate that different fatigue protocols based on repeated sprints produce distinct physiological responses, even with the same total volume of work, suggesting that even for the same movement, neuromuscular fatigue responses may vary (Meckel *et al*., 2009; Alba-Jiménez *et al*., 2022).

The results of this study highlight those measures of maximum capacity do not allow for generalizations about fatigue response or performance in repeated effort situations. The findings emphasize the complexity of the mechanisms involved in assessing fatigue across different testing protocols. The lack of correlation between maximal neuromuscular capacities and fatigue tests demonstrates the limitations of analyses based solely on maximum performance measures. These results challenge traditional approaches to evaluating the development of young athletes, as isolated maximum values may not fully reflect the specific demands of soccer. In other words, the isolated assessment of strength, power, or maximum speed provides only a partial view of sports performance; it is also essential to consider fatigue resistance and rapid recovery capacity to understand functional performance in real competition contexts.

Practical applications

The current study showed that maximum tests of speed, jumping, and isokinetic peak torque assessments of the knee extensors and flexors did not correlate with fatigue measures. These results caution against relying solely on maximum values for talent identification or assessing physical development based on training or maturation. Although maximum capacity is an important performance indicator, depending only on this measure can lead to misinterpreting athletes' actual functional abilities and their fatigue resistance mechanisms, especially in sports with high physical demands. Additionally, the lack of correlation among fatigue assessments emphasizes the complexity of these mechanisms and highlights the need for caution when interpreting and extrapolating the results of each test.

The athlete's precise monitoring enables the identification of their responses to the training program, facilitating precise adjustments to internal and external loads. Additionally, fatigue tests help analyze both the acute fatigue caused by sessions and the athlete's resistance capacity. In practice, this enables informed decisions about training intensity, volume, and recovery, optimizing performance and preventing overload. Since each test responds differently to the complexity of neuromuscular fatigue mechanisms, selecting the appropriate test should consider the specific objectives of the assessment.

Limitations

In the present study, fatigue assessments were conducted and monitored based on performance levels and their effects under fatigue conditions. However, the discussions and interpretations are primarily based on existing literature rather than direct measurements from the sample being studied. Therefore, while the arguments align with established physiological mechanisms, caution should be exercised when applying these conclusions to the specific participants of this study. Future research, including direct assessments of neuromuscular and metabolic markers, would yield more accurate insights.

REFERENCES

AKOGLU. User's guide to correlation coefficients. Turkish Journal of Emergency Medicine, v. 18, n. 3, p. 91–93, 2018.

AKTUĞ, Z. B.; HARBILI, E.; HARBILI, S. Comparison of isokinetic knee strength between the dominant and non-dominant legs and relationships among isokinetic strength, vertical jump, and speed performance in soccer players. Turkiye Klinikleri Journal of Sports Sciences, v. 8, n. 1, p. 8-14, jan. 2016.]

ALLEN, D. G.; LAMB, G. D.; WESTERBLAD, H. Skeletal muscle fatigue: cellular mechanisms. Physiological Reviews, v. 88, n. 1, p. 287-332, jan. 2008.

ALTARRIBA-BARTES, A.; PEÑA, J.; VICENS-BORDAS, J.; MILÀ-VILLAROEL, R.; CALLEJA-GONZÁLEZ, J. Post-competition recovery strategies in elite male soccer players. Effects on performance: a systematic review and meta-analysis. PLoS One, v. 15, n. 10, e0240135, 2 out. 2020.

ALVARES, DE ARAUJO RIBEIRO, J. B.; RODRIGUES, R.; DE AZEVEDO FRANKE, R.; SILVA, B. G. C.; PINTO, R. S.; VAZ, M. A.; BARONI, B. M. Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. Physical Therapy in Sport, v. 16, p. 59–65, 2015.

ANDRADE, V. L.; SANTIAGO, P. R.; KALVA FILHO, C. A.; CAMPOS, E. Z.; PAPOTI, M. Reproducibility of Running Anaerobic Sprint Test for soccer players. The Journal of Sports Medicine and Physical Fitness, v. 56, n. 1–2, p. 34–38, 2014.

BALAGUÉ, N.; HRISTOVSKI, R.; POL, R.; BORRALLO, A.; GARCÍA-RETORTILLO, S. Preventing or promoting muscle injuries? Strength training as a risk factor in professional football. Apunts Sports Medicine, v. 59, n. 224, 2024.

BANGSBO, J.; MOHR, M.; KRUSTRUP, P. Physical and metabolic demands of training and match-play in the elite football player. Journal of Sports Sciences, v. 24, p. 665–674, 2006.

BARNES, C.; ARCHER, D. T.; HOGG, B.; BUSH, M.; BRADLEY, P. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BARONI, B. M.; RUAS, C. V.; RIBEIRO-ALVARES, J. B.; PINTO, R. S. Hamstring-to-quadriceps torque ratios of professional male soccer players: a systematic review. *The Journal of Strength & Conditioning Research*, v. 34, n. 1, p. 281–293, 2020.

BEDOYA, A. A.; MILTENBERGER, M. R.; LOPEZ, R. M. Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. Journal of Strength & Conditioning Research, v. 29, n. 8, p. 2351–2360, 2015.

BEKRIS, E.; BOURDAS, D. I.; MYLONIS, E.; ISPIRLIDIS, I.; ZACHARAKIS, E. D.; KATIS, A. Effect of 3 vs. 3 soccer small-sided game on various performance, inflammatory, muscle damage and hormonal indicators in semi-professional players. Sports, v. 10, n. 7, p. 102, 2022.

BOBBERT, M. F.; VAN INGEN SCHENAU, G. J. Coordination in vertical jumping. Journal of Biomechanics, v. 21, n. 3, p. 249–262, 1988.

BOLANOWSKI, M.; NILSSON, B. E. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. Medical Science Monitor, v. 7, n. 5, p. 1029–1033, 2001.

BRANQUINHO, L.; DE FRANÇA, E.; TEIXEIRA, J. E.; TITTON, A.; LEITE DE BARROS, L. F.; CAMPOS, P.; MARINHO, D. A.; FORTE, P.; CAPERUTO, E. C.; THOMATIELI DOS SANTOS, R. V.; FERRAZ, R. Identifying the ideal weekly training load for in-game performance in an elite Brazilian soccer team. Frontiers in Physiology, v. 15, p. 1341791, 2024.

BUJALANCE-MORENO, P.; LATORRE-ROMÁN, P. Á.; GARCÍA-PINILLOS, F. A systematic review on small-sided games in football players: acute and chronic adaptations. Journal of Sports Sciences, v. 37, n. 8, p. 921–949, 2019.Bürkner, P. (2017). Brms: An R package for Bayesian multilevel models using Stan. Journal of Statistical Software, 80(1), 1–28.

CAREY, D. P.; SMITH, G.; SMITH, D. T.; SHEPHERD, J. W.; SKRIVER, J.; ORD, L.; RUTLAND, A. Footedness in world soccer: an analysis of France'98. Journal of Sports Sciences, v. 19, n. 11, p. 855–864, 2001.

CEZARINO, L. G.; DA SILVA GRÜNINGER, B. L.; SILVA, R. S. Injury profile in a Brazilian first-division youth soccer team: a prospective study. Journal of Athletic Training, v. 55, n. 3, p. 295–302, 2020.

CHAN, Y. H. Biostatistics 104: correlational analysis. Singapore Medical Journal, v. 44, n. 12, p. 614–619, 2003.

CLEMENTE, F.; PILLITTERI, G.; VIEIRA, L. H. P.; RABBANI, A.; ZMIJEWSKI, P.; BEATO, M. Balancing the load: a narrative review with methodological implications of compensatory training strategies for non-starting soccer players. Biology of Sport, v. 41, n. 4, p. 173–185, 2024.

COMETTI, G.; MAFFIULETTI, N. A.; POUSSON, M.; CHATARD, J. C.; MAFFULLI, N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. International Journal of Sports Medicine, v. 22, n. 1, p. 45–51, 2001.

DE HOYO, M.; GONZALO-SKOK, O.; SAÑUDO, B.; CARRASCAL, C.; PLAZA-ARMAS, J. R.; CAMACHO-CANDIL, F.; OTERO-ESQUINA, C. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. Journal of Strength & Conditioning Research, v. 30, n. 2, p. 368–377, 2016.

DE HOYO, M.; POZZO, M.; SAÑUDO, B.; CARRASCO, L.; GONZALO-SKOK, O.; DOMÍNGUEZ-COBO, S.; MORÁN-CAMACHO, E. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. International Journal of Sports Physiology and Performance, v. 10, n. 1, p. 46–52, 2015.

DELANG, M. D.; SALAMH, P. A.; FAROOQ, A.; TABBEN, M.; WHITELEY, R.; VAN DYK, N.; CHAMARI, K. The dominant leg is more likely to get injured in soccer players: systematic review and meta-analysis. Biology of Sport, v. 38, n. 3, p. 397–435, 2021.

DELLAL, A.; OWEN, A.; WONG, D. P.; KRUSTRUP, P.; VAN EXSEL, M.; MALLO, J. Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. Human Movement Science, v. 31, n. 4, p. 957–969, 2012.

DOWSON, M. N.; NEVILL, M. E.; LAKOMY, H. K.; NEVILL, A. M.; HAZELDINE, R. J. Modelling the relationship between isokinetic muscle strength and sprint running performance. Journal of Sports Sciences, v. 16, n. 3, p. 257–265, 1998.

DUCHATEAU, J.; SEMMLER, J. G.; ENOKA, R. M. Training adaptations in the behavior of human motor units. Journal of Applied Physiology, v. 101, n. 6, p. 1766–1775, 2006.DUPONT, G.; NEDELEC, M.; MCCALL, A.; MCCORMACK, D.; BERTHOIN, S.; WISLØFF, U. Effect of 2 soccer matches in a week on physical performance and injury rate. American Journal of Sports Medicine, v. 38, n. 9, p. 1752–1758, 2010.

ENOKA, R. M.; DUCHATEAU, J. Translating fatigue to human performance. Medicine and Science in Sports and Exercise, v. 48, n. 11, p. 2228, 2016.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. Journal of Sports Sciences, v. 30, n. 7, p. 625–631, 2012.

FAUDE, O.; RÖSSLER, R.; PETUSHEK, E. J.; ROTH, R.; ZAHNER, L.; DONATH, L. Neuromuscular adaptations to multimodal injury prevention programs in youth sports: a systematic review with meta-analysis of randomized controlled trials. Frontiers in Physiology, v. 8, p. 791, 2017.

FENG, Juan; RODRÍGUEZ FERNÁNDEZ, Alejandro *et al*. Impact of small-sided game formats on electromyographic responses in college students. Journal of Sports Science and Medicine, v. 24, n. 4, p. 729–738, 2025.

FERRINI, M.; ASIAN-CLEMENTE, J.; BAGATTINI, G.; SUAREZ-ARRONES, L. A combined 7-week strength and power training: effects on body composition, strength, speed, and agility in U14 and U16 youth elite soccer players. Applied Sciences, v. 15, n. 5, p. 2470, 2025.

FORTES, R. P.; MACHADO, C. L. F.; BARONI, B. M.; NAKAMURA, F. Y.; PINTO, R. S. Relationship between maximal strength and hamstring-to-quadriceps ratios in

balanced and unbalanced legs in futsal athletes. Sport Sciences for Health, v. 19, n. 4, p. 1169–1176, 2023.Fousekis, K., Tsepis, E., & Vagenas, G. (2010). Lower limb strength in professional soccer players: profile, asymmetry, and training age. *Journal of sports science & medicine*, *9*(3), 364.

GABBETT, T. J.; MULVEY, M. J. Time-motion analysis of small-sided training games and competition in elite women soccer players. Journal of Strength & Conditioning Research, v. 22, n. 2, p. 543–552, mar. 2008.

GABBETT, T. J.; WHYTE, D. G.; HARTWIG, T. B.; WESCOMBE, H.; NAUGHTON, G. A. The relationship between workloads, physical performance, injury and illness in adolescent male football players. Sports Medicine, v. 44, n. 7, p. 989–1003, 2014.

GIAVARINA, D. Understanding Bland Altman analysis. Biochemia Medica, v. 25, n. 2, p. 141–151, 2015.

GRAZIOLI, R.; INÁCIO, M.; LOPEZ, P.; FREITAS, S. R.; CUNHA, G. D. S.; MACHADO, C. L. F.; VEECK, F.; BARONI, B. M.; CADORE, E. L.; PINTO, R. S. Effects of eccentric-emphasized leg curl intervention on muscle strength imbalance markers in professional soccer players during pre-season. Journal of Bodywork and Movement Therapies, v. 35, p. 28–32, 2023.

HART, N. H.; NIMPHIUS, S.; WEBER, J.; SPITERI, T.; RANTALAINEN, T.; DOBBIN, M.; NEWTON, R. Musculoskeletal asymmetry in football athletes: a product of limb function over time. [S.l.: s.n.], 2016.Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: a systematic review. *Sports medicine*, *41*(3), 199-220.

HŮLKA, K.; STRNIŠTĚ, M. Fitness improvements of young soccer players after high volume or small sided games interventions. *Biology of Sport*, v. 38, n. 4, p. 573–578, 2021.

IACONO, A. D.; BEATO, M.; UNNITHAN, V. Effects of game profile–based training and small-sided games on physical performance of elite young soccer players. [S.l.: s.n.], 2019.

IBÁÑEZ, S. J.; FEU, S.; CAÑADAS, M. Sistema integral para el análisis de las tareas de entrenamiento, SIATE, en deportes de invasión. *E-balonmano.com: Revista de Ciencias del Deporte*, v. 12, n. 1, p. 3–30, 2016.

IBÁÑEZ, S. SIATE: Sistema de Información y Análisis de Entrenamiento Deportivo. Madrid: Editorial Paidotribo, 1997.

ISHIDA, A.; TRAVIS, S. K.; STONE, M. H. Associations of body composition, maximum strength, power characteristics with sprinting, jumping, and intermittent endurance performance in male intercollegiate soccer players. *Journal of Functional Morphology and Kinesiology*, [S.l.: s.n.], 2021.

JASTRZEBSKI, Z.; BARNAT, W.; DARGIEWICZ, R.; JASKULSKA, E.; SZWARC, A.; RADZIMIŃSKI, Ł. Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. *International Journal of Sports Science & Coaching*, v. 9, n. 5, p. 1169–1179, 2014.

JEONG, T. S.; REILLY, T.; MORTON, J.; BAE, S. W.; DRUST, B. Quantification of the physiological loading of one week of "pre-season" and one week of "in-season" training in professional soccer players. *Journal of Sports Sciences*, v. 29, n. 11, p. 1161–1166, 2011.

KAY, M. Tidybayes: tidy data and geoms for Bayesian models. Zenodo, 2023.

LEES, A.; NOLAN, L. The biomechanics of soccer: a review. Journal of Sports Sciences, v. 16, n. 3, p. 211–234, 1998.

LEHANCE, C.; BINET, J.; BURY, T.; CROISIER, J. L. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scandinavian Journal of Medicine & Science in Sports, v. 19, n. 2, p. 243–251, 2009.

MACHADO, C. L. F.; NAKAMURA, F. Y.; FORTES, R. P.; TRAPAGA, I. D.; BRUSCO, C. M.; PINTO, M. D.; PINTO, R. S. Changes in knee flexion-extension performance and hamstring-to-quadriceps ratio during a fatiguing isokinetic protocol in male professional futsal players. International Journal of Performance Analysis in Sport, v. 23, n. 4, p. 249–263, 2023.

MAFFIULETTI, N. A.; AAGAARD, P.; BLAZEVICH, A. J.; FOLLAND, J.; TILLIN, N.; DUCHATEAU, J. Rate of force development: physiological and methodological considerations. European Journal of Applied Physiology, v. 116, n. 6, p. 1091–1116, 2016.

MARSHALL, P. W.; LOVELL, R.; JEPPESEN, G. K.; ANDERSEN, K.; SIEGLER, J. C. Hamstring muscle fatigue and central motor output during a simulated soccer match. PLoS One, v. 9, n. 7, e102753, 2014.

MASUDA, K.; KIKUHARA, N.; DEMURA, S.; KATSUTA, S.; YAMANAKA, K. Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. Journal of Sports Medicine and Physical Fitness, v. 45, n. 1, p. 44, 2005.

MICHAILIDIS, Y.; FATOURES, I. G.; PRIMPA, E.; MICHAILIDIS, C.; AVLONITI, A.; CHATZINIKOLAOU, A.; KAMBAS, A. Plyometrics' trainability in preadolescent soccer athletes. Journal of Strength & Conditioning Research, v. 27, n. 1, p. 38–49, 2013.

MITCHELL, A., HOLDING, C., & GREIG, M. (2022). Factors influencing optimum countermovement jump performance and movement strategy in Championship professional football players: implications for player profiling. *Research in Sports Medicine*, *30*(1), 30-40.

MORIN, J. B.; GIMENEZ, P.; EDOUARD, P.; ARNAL, P.; JIMENEZ-REYES, P.; SAMOZINO, P.; MENDIGUCHIA, J. Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. Frontiers in Physiology, v. 6, dez. 2015.

NÉDÉLEC, M.; MCCALL, A.; CARLING, C.; LEGALL, F.; BERTHOIN, S.; DUPONT, G. Recovery in soccer: Part I – post-match fatigue and time course of recovery. Sports Medicine, v. 42, n. 12, p. 997–1015, 2012.

NEWMAN, M. A.; TARPENNING, K. M.; MARINO, F. E. Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players. Journal of Strength and Conditioning Research, v. 18, n. 4, p. 867–872, 2004.

OLIVA-LOZANO, J. M. *et al*. Acceleration and sprint profiles of professional male football players in relation to playing position. PLoS One, v. 15, n. 8, e0236959, 2020.

OSGNACH, C.; POSER, S.; BERNARDINI, R.; RINALDO, R.; DI PRAMPERO, P. E. Energy cost and metabolic power in elite soccer: a new match analysis approach. Medicine & Science in Sports & Exercise, v. 42, n. 1, p. 170–178, 2010.OTERO-

ESQUINA, C.; DE HOYO LORA, M.; GONZALO-SKOK, Ó.; DOMÍNGUEZ-COBO, S.; SÁNCHEZ, H. Is strength-training frequency a key factor to develop performance adaptations in young elite soccer players? European Journal of Sport Science, v. 17, n. 10, p. 1241–1251, 2017.

PIETRASZEWSKI, P.; MASZCZYK, A.; ZAJĄC, A.; GOŁAŚ, A. Muscle activity and biomechanics of sprinting: a meta-analysis review. Applied Sciences, v. 15, n. 9, p. 4959, 2025.

PINTO, M. D.; BLAZEVICH, A. J.; ANDERSEN, L. L.; MIL-HOMENS, P.; PINTO, R. S. Hamstring-to-quadriceps fatigue ratio offers new and different muscle function information than the conventional non-fatigued ratio. Scandinavian Journal of Medicine & Science in Sports, v. 28, n. 1, p. 282–293, 2018.

PONS, E. *et al*. A comparison of a GPS device and a multi-camera video technology during official football matches: agreement between systems. PLoS One, v. 14, n. 8, e0220729, 2019.

REILLY, T. *et al*. A multidisciplinary approach to talent identification in football. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

RODRÍGUEZ-FERNÁNDEZ, A.; RODRÍGUEZ-MARROYO, J. A.; CASAMICHANA, D.; VILLA, J. G. Effects of 5-week pre-season small-sided-game-based training on repeat sprint ability. The Journal of Sports Medicine and Physical Fitness, v. 57, n. 5, p. 529–536, 2016.

RUAS, C. V.; MINOZZO, F.; PINTO, M. D.; BROWN, L. E.; PINTO, R. S. Lower-extremity strength ratios of professional soccer players according to field position. Journal of Strength and Conditioning Research, v. 29, n. 5, p. 1220–1226, 2015.

SAHALY, R.; VANDEWALLE, H.; DRISS, T.; MONOD, H. Maximal voluntary force and rate of force development in humans – importance of instruction. European Journal of Applied Physiology, v. 85, p. 345–350, 2001.

SANGNIER, S.; TOURNY-CHOLLET, C. Study of the fatigue curve in quadriceps and hamstrings of soccer players during isokinetic endurance testing. Journal of Strength and Conditioning Research, v. 22, n. 5, p. 1458–1467, 2008.

SILVA, J. R. The soccer season: performance variations and evolutionary trends. PeerJ, v. 10, e14082, 2022.

SILVA, J. R.; NASSIS, G. P.; REBELO, A. Strength training in soccer with a specific focus on highly trained players. Sports Medicine-Open, v. 1, n. 1, p. 17, 2015.

STERN, D.; GONZALO-SKOK, O.; LOTURCO, I.; TURNER, A.; BISHOP, C. A comparison of bilateral vs. unilateral-biased strength and power training interventions on measures of physical performance in elite youth soccer players. The Journal of Strength & Conditioning Research, v. 34, n. 8, p. 2105–2111, 2020.

SUAREZ-ARRONES, L.; LARA-LOPEZ, P.; TORRENO, N.; SAEZ DE VILLARREAL, E.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Effects of strength training on body composition in young male professional soccer players. Sports, v. 7, n. 5, 104, 2019.

SUAREZ-ARRONES, L.; PETRI, C.; MALDONADO, R. A.; TORRENO, N.; MUNGUÍA-IZQUIERDO, D.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Body fat assessment in elite soccer players: cross-validation of different field methods. Science and Medicine in Football, v. 2, n. 3, p. 203–208, 2018.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. Pediatric Exercise Science, v. 24, p. 603–621, 2012.

VEECK, F.; LOPEZ, P.; GRAZIOLI, R.; MACHADO, C. L. F.; WILHELM, E. N.; CADORE, E. L.; PINTO, R. S. Dissociation between fatigued power output and traditional peak torque for isokinetic hamstring: quadriceps ratios in professional soccer players. Sport Sciences for Health, v. 18, n. 3, p. 967–973, 2022.

VEHTARI, A.; GELMAN, A.; SIMPSON, D.; CARPENTER, B.; BÜRKNER, P.-C. Rank-normalization, folding, and localization: an improved Ȓ for assessing convergence of MCMC (with discussion). Bayesian Analysis, v. 16, n. 2, p. 667–718, 2021.

WONG, P.-L.; CHAMARI, K.; CHAOUACHI, A.; MAO, D. W.; WISLØFF, U.; HONG, Y. Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. British Journal of Sports Medicine, v. 41, p. 84, 2007.

WORLD MEDICAL ASSOCIATION *et al*. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA, v. 310, n. 20, p. 2191–2194, 2013.

YOSHIKO, A., WATANABE, K., & AKIMA, H. (2023). Relative contribution of neuromuscular activation, muscle size, and muscle quality to maximum strength output of the thigh muscles in young individuals. *Physiological Reports*, *11*(1), e15563.

ZACHAROGIANNIS, E.; PARADISIS, G.; TZIORTZIS, S. An evaluation of tests of anaerobic power and capacity. Medicine & Science in Sports & Exercise, v. 36, supplement, S116, 2004.

ZAGATTO, A. M.; BECK, W. R.; GOBATTO, C. A. Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. Journal of Strength and Conditioning Research, v. 23, n. 6, p. 1820–1827, 2009.

ŽELEZNIK MEŽAN, L.; ŠKOF, B.; LESKOŠEK, B.; CECIĆ ERPIČ, S. Effects of cooperative learning in youth athletics' motivational climate, peer relationships and self-concept. Physical Education and Sport Pedagogy, v. 30, n. 4, p. 444–461, 2025.

ZHANG, Q.; LÉAM, A.; FOURÉ, A.; WONG, D. P.; HAUTIER, C. A. Relationship between explosive strength capacity of the knee muscles and deceleration performance in female professional soccer players. Frontiers in Physiology, v. 12, 723041, 2021.

6. CONSIDERAÇÕES FINAIS

A carreira de um atleta de futebol é um processo longo, seletivo e complexo (Malina *et al*., 2009; Reilly *et al*., 2000; Williams *et al*., 2020). A aptidão física constitui uma parte fundamental do desenvolvimento do jovem atleta, e seu aprimoramento ao longo do tempo é influenciado por múltiplos fatores que moldam as trajetórias de desenvolvimento em níveis individual e coletivo. Portanto, para compreender de forma mais completa o desenvolvimento da aptidão física em jovens atletas de futebol, é necessário considerar suas diferentes dimensões.

Neste contexto, a presente tese foi elaborada com o objetivo de descrever o desenvolvimento longitudinal da aptidão física de jovens atletas de futebol brasileiros, considerando a influência da idade cronológica, da maturação biológica, da exposição competitiva e da metodologia de treinamento.

A maturação é uma das dimensões que influencia diretamente as trajetórias de desenvolvimento. Ao se manifestar em momentos e ritmos distintos, variações significativas entre indivíduos são percebidas, resultando em trajetórias variadas (Malina *et al*., 2009). Essas variações reforçam a necessidade de abordagens que considerem a individualidade biológica no contexto do desenvolvimento esportivo. Neste contexto, o Artigo 1 – *Longitudinal development of physical fitness in young football players: a Bayesian analysis* – foi desenvolvido com o objetivo de descrever o desenvolvimento longitudinal do crescimento e da aptidão física em atletas masculinos de futebol de um clube brasileiro, considerando tanto a idade cronológica quanto a idade biológica.

Os resultados do estudo apresentam que as análises baseadas na idade cronológica apresentaram grandes diferenças entre os indivíduos em testes de sprint, salto, agilidade e resistência. Observou-se também que as taxas de evolução física são mais elevadas nas idades próximas ao pico de velocidade do crescimento. No entanto, ao alinhar os dados com base na maturação biológica verificaram-se padrões de desenvolvimento mais equilibrados entre os atletas, indicando que as variações observadas quando se utiliza apenas a idade cronológica refletem, em grande parte, diferenças nos ritmos maturacionais. Esses achados reforçam que a idade biológica constitui um referencial mais adequado para interpretar o desenvolvimento físico em contexto de formação.

Além da influência da dimensão biológica, o desenvolvimento da aptidão física de um jovem atleta de futebol também é modulado por fatores contextuais. As experiências competitivas distintas e as diferentes cargas físicas vivenciadas por atletas com diferentes status na equipe podem impactar significativamente seu progresso a longo prazo (Clemente *et al*., 2024). Sob essa perspectiva, o Artigo 2 – *Longitudinal effects of competition exposure on physical fitness development in youth football: a Bayesian analysis* – foi desenvolvido com o objetivo de analisar os efeitos longitudinais do status de exposição à competição sobre o desenvolvimento da aptidão física em jogadores de futebol masculinos de um clube brasileiro, considerando tanto a idade cronológica quanto a idade biológica.

Os resultados do estudo reforçam a tendência de desenvolvimento mais consistente da aptidão física observada nas análises alinhadas com base na maturação biológica entre titulares, reservas e atletas que não participaram dos jogos ao longo da temporada. Observou-se, ainda, que titulares e reservas apresentaram padrões semelhantes tanto nos valores absolutos quanto nos ritmos de evolução da aptidão física, enquanto os atletas sem participação em jogos demonstraram níveis e taxas de progresso inferiores. Esses resultados evidenciam o papel da exposição competitiva como um importante modulador do desenvolvimento da aptidão física à longo prazo.

Outro elemento contextual que influencia a evolução física de um atleta é a metodologia de treinamento. Os jogos reduzidos têm se mostrado uma ferramenta amplamente utilizada nos clubes de futebol, devido à sua capacidade de estimular simultaneamente componentes técnicos, táticos e físicos, integrando-os às demandas específicas da modalidade. No entanto, a literatura aponta que a variabilidade das respostas individuais pode gerar cargas distintas, dependendo da posição e da função desempenhada por cada atleta na equipe, resultando em taxas diferenciadas de evolução física entre jogadores (Iacono *et al*., 2017; Hill-Haas *et al*., 2011).

Diante dessa realidade, o Artigo 3 – *Effects of a 12-week in-season small-sided games training on neuromuscular function and lean mass in young football players* – foi desenvolvido com os objetivos de: (I) descrever as adaptações no desempenho neuromuscular e na composição corporal de jovens jogadores de futebol ao longo de 12 semanas durante uma fase competitiva, considerando exclusivamente treinamentos baseados em jogos reduzidos; (II) avaliar as respostas individuais dos atletas às

intervenções de treinamento, identificando variações entre os jogadores; e (III) investigar diferenças bilaterais no desempenho neuromuscular, comparando a perna dominante e a não dominante.

Os resultados indicaram que estratégias baseadas predominantemente em jogos reduzidos podem apresentar limitações no desenvolvimento de capacidades neuromusculares em atletas já maturados. Em consonância com a literatura prévia, observou-se que o treinamento centrado em jogos reduzidos não promove ganhos homogêneos entre os atletas, apresentando uma tendência de maior desenvolvimento da perna dominante, possivelmente associada à repetição de gestos técnicos unilaterais durante jogos e sessões de treino. Esses achados sugerem a necessidade de intervenções complementares para minimizar possíveis desequilíbrios musculares.

Integrando os achados dos três artigos inicialmente apresentados nesta tese, conclui-se que o desenvolvimento da aptidão física em jovens atletas de futebol é um fenômeno multifatorial, diretamente influenciado por fatores biológicos, como o crescimento e a maturação, modulados por aspectos genéticos, e por fatores contextuais, relacionados à exposição competitiva e às metodologias de treinamento adotadas pelas comissões técnicas.

Não é possível influenciar o ritmo de desenvolvimento maturacional de um jovem atleta. No entanto, a compreensão dos fatores que influenciam as diferentes trajetórias de desenvolvimento possibilita a elaboração de estratégias pedagógicas capazes de equilibrar o progresso daqueles que maturam mais tardiamente e/ou que possuem menor exposição competitiva, ao mesmo tempo em que potencializa o desempenho dos que maturam precocemente e/ou já se destacam em posições de titularidade.

Os achados evidenciam a importância de identificar o estágio de maturação de cada atleta. Ter consciência do estágio que o atleta se encontra possibilita compreender as respostas do treinamento, planejar estratégias de desenvolvimento e criar expectativas coerentes sobre o potencial do atleta. Além disso, identificar atletas que vivenciam a maturação tardiamente, permite o desenvolvimento de estratégias para que também sejam expostos a experiências competitivas e cargas suficientes para seu desenvolvimento contribui para um processo mais justo e consistente. Portanto, reconhecer que os períodos de ganho acelerado na aptidão física ocorrem em momentos distintos para cada atleta, e

que uma menor exposição à competição está associada a ritmos reduzidos de evolução física, reforça a relevância de estratégias pedagógicas longitudinais voltadas ao desenvolvimento consistente e equilibrado do grupo, em vez de resultados imediatos e pontuais.

Além disso, os resultados evidenciam que metodologias de treinamento baseadas predominantemente em jogos reduzidos, embora indicadas pela literatura como eficazes para integrar aspectos técnicos, táticos e físicos, geram respostas neuromusculares heterogêneas entre os atletas. Essa variabilidade interindividual pode estar associada não apenas a diferenças nos ritmos maturacionais e nas oportunidades competitivas, destacadas nos estudos anteriores, mas também à influência de fatores como posição, função tática e nível de envolvimento nas tarefas de treino, elementos que podem ser considerados por futuros estudos. Nesse sentido, sugere-se a adoção de estratégias de controle individual da carga de treinamento ao longo de todas as fases da maturação, bem como a implementação de intervenções complementares que minimizem desequilíbrios entre os membros dominante e não dominante e entre os grupos musculares flexores e extensores do joelho. Tais medidas podem favorecer um desenvolvimento físico mais equilibrado, sustentável e ajustado às necessidades específicas de cada atleta.

Tradicionalmente, a avaliação do desenvolvimento da aptidão física de jovens atletas tem sido baseada em avaliações das capacidades físicas máximas (Philliparts *et al*. 2006; Carvalho *et al*., 2017). No Artigo 4 - *Are neuromuscular performance tests related to the fatigue index in young football players?* - foi investigada a relação entre as avaliações das capacidades máximas de sprint, salto e pico de torque de extensores e flexores de joelho e diferentes avaliações da fadiga neuromuscular. Os resultados sugerem que os mecanismos responsáveis pela produção máxima de velocidade, potência e torque não refletem diretamente uma maior capacidade de resistência, evidenciando a natureza multifatorial e complexa dos processos fisiológicos de cada teste.

Esses resultados reforçam a importância da inclusão de avaliações complementares da fadiga neuromuscular no monitoramento do desenvolvimento físico. Embora a capacidade neuromuscular máxima seja um importante indicador de desempenho, a análise complementar da fadiga neuromuscular permite uma compreensão mais abrangente das habilidades funcionais dos atletas e de sua capacidade de sustentar

esforços prolongados, fornecendo informações adicionais relevantes para o planejamento do treinamento e acompanhamento do desenvolvimento físico.

Diante das tendências atuais do futebol de aumento da intensidade do jogo (Barnes *et al*., 2014), sugere-se que futuros estudos acompanhem o desenvolvimento longitudinal da performance de jovens atletas, utilizando não apenas avaliações das capacidades máximas, mas também mediadas que avaliem como as capacidades neuromusculares de sustentar a força, velocidade, e potência em situações de esforço máximo interagem com as fases do processo maturacional

Portanto, defendemos a tese de que o desenvolvimento físico de jovens atletas de futebol é fortemente determinado pela maturação biológica e diretamente influenciado tanto pelo nível de exposição competitiva quanto pela variabilidade individual de resposta aos estímulos de treinamento. Neste sentido, os achados reforçam que o crescimento e a maturação, enquanto processos biológicos inerentes ao indivíduo, modulam tanto as diferenças de desempenho quanto os ritmos de evolução física entre atletas, ao passo que fatores contextuais, como a participação em jogos e as metodologias de treino, condicionam as oportunidades de estímulo e a qualidade das adaptações ao longo do processo formativo.

Com base nesses resultados, sugere-se que, para promover um desenvolvimento mais eficiente e equitativo, os profissionais do esporte devem reconhecer e compreender os mecanismos biológicos e contextuais que moldam as trajetórias individuais de desenvolvimento, de modo a planejar intervenções coerentes e ajustadas às necessidades específicas de cada atleta. Adicionalmente, recomenda-se que, para uma compreensão mais aprofundada do processo de desenvolvimento, futuros estudos longitudinais incorporem avaliações da fadiga neuromuscular, contribuindo para análises cada vez mais precisa e alinhada às demandas reais impostas pelo jogo.

REFÊRENCIAS

AAGAARD, P, SIMONSEN, EB, MAGNUSSON, SP, LARSSON, B, AND DYHRE POULSEN, P. A new concept for isokinetic hamstring: Quadriceps muscle strength ratio. Am J Sports Med 26: 231–237, 1998.

ABARGHOUEINEJAD, M. *et al*. Motor performance in male youth soccer players: a systematic review of longitudinal studies. Sports, v. 9, n. 4, p. 1–16, 2021.

AKTUĞ, Z. B.; HARBILI, E.; HARBILI, S. Comparison of isokinetic knee strength between the dominant and non-dominant legs and relationships among isokinetic strength, vertical jump, and speed performance in soccer players. Turkiye Klinikleri Journal of Sports Sciences, v. 8, n. 1, p. 8-14, jan. 2016.

ALBALADEJO-SAURA, M. *et al*. Relationship between biological maturation, physical fitness, and kinanthropometric variables of young athletes: a systematic review and meta-analysis. International Journal of Environmental Research and Public Health, v. 18, n. 1, p. 1–20, 2021.

ALBUQUERQUE, M. R. *et al*. Relative age effect and ACTN3 R577X and ACE I/D polymorphisms in Brazilian football players: an association genetic study. Research Quarterly for Exercise and Sport, p. 1-11, 2024.

ALLEN, D. G.; LAMB, G. D.; WESTERBLAD, H. Skeletal muscle fatigue: cellular mechanisms. Physiological Reviews, v. 88, n. 1, p. 287-332, jan. 2008.

ALVARES, D. A. R. J. B.; RODRIGUES, R.; DE AZEVEDO FRANKE, R.; SILVA, B. G. C.; PINTO, R. S.; VAZ, M. A.; BARONI, B. M. Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. Physical Therapy in Sport, v. 16, p. 59–65, 2015.

AMSTRONG, N. Development of the youth athlete. Abingdon: Routledge, 2019.

ANDERSON, L.; ORME, P.; DI MICHELE, R.; CLOSE, G. L.; MILSOM, J.; MORGANS, R.; DRUST, B.; MORTON, J. P. Quantification of seasonal-long physical load in soccer players with different starting status from the English Premier League: implications for maintaining squad physical fitness. International Journal of Sports Physiology and Performance, v. 11, p. 1038–1046, 2016.

ARMADA-CORTÉS, E.; BENÍTEZ-MUÑOZ, J. A.; SAN JUAN, A. F.; SÁNCHEZ-SÁNCHEZ, J. Evaluation of neuromuscular fatigue in a repeat sprint ability, countermovement jump and hamstring test in elite female soccer players. International Journal of Environmental Research and Public Health, v. 19, n. 22, p. 15069, 16 nov. 2022.

ARMSTRONG, N. Development of the youth athlete. Routledge, 2019.

BALAGUÉ, N.; HRISTOVSKI, R.; POL, R.; BORRALO, A.; GARCÍA-RETORTILLO, S. Preventing or promoting muscle injuries? Strength training as a risk factor in professional football. Apunts Sports Medicine, v. 59, n. 224, 2024.

BANGSBO, J. Fitness training in football – a scientific approach. Bangsvaerd: HO Storm, 1994.

BANGSBO, J.; MOHR, M.; KRUSTRUP, P. Physical and metabolic demands of training and match-play in the elite football player. Journal of Sports Sciences, v. 24, n. 7, p. 665–674, 2006.

BARNES, C. *et al*. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BARNES, C.; ARCHER, D. T.; HOGG, B.; BUSH, M.; BRADLEY, P. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine, v. 35, n. 13, p. 1095–1100, 2014.

BARONI, B. M.; RUAS, C. V.; RIBEIRO-ALVARES, J. B.; PINTO, R. S. Hamstring-to-quadriceps torque ratios of professional male soccer players: A systematic review. The Journal of Strength & Conditioning Research, v. 34, n. 1, p. 281–293, 2020.

BARREIRA, J.; NAKAMURA, F. Y.; FERREIRA, R.; PEREIRA, J.; AQUINO, R.; FIGUEIREDO, P. Season match loads of a Portuguese under-23 soccer team: differences between different starting statuses throughout the season and specific periods within the season using global positioning systems. Sensors (Basel), v. 22, n. 17, p. 6379, 24 ago. 2022.

BEDOYA, A. A.; MILTENBERGER, M. R.; LOPEZ, R. M. Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. Journal of Strength & Conditioning Research, v. 29, n. 8, p. 2351–2360, 2015.

BEKRIS, E.; BOURDAS, D. I.; MYLONIS, E.; ISPIRLIDIS, I.; ZACHARAKIS, E. D.; KATIS, A. Effect of 3 vs. 3 soccer small-sided game on various performance, inflammatory, muscle damage and hormonal indicators in semi-professional players. Sports, v. 10, n. 7, p. 102, 2022.

BERGER, A.; CARVALHO, H.; CARDOSO, M.; OLIVEIRA, J.; DELAVALD, V.; PINTO, R.; LEONARDI, T. Longitudinal development of physical fitness in young football players: a Bayesian analysis. Research Quarterly for Exercise and Sport, v. 18, p. 1–10, 2025.

BEUNEN, G.; MALINA, R. M. Growth and biologic maturation: relevance to athletic performance. The Young Athlete, v. 1, p. 3–17, 2008.

BIDAURRAZAGA-LETONA, I. *et al*. Longitudinal field test assessment in a Basque football youth academy: A multilevel modeling framework to partition effects of maturation. International Journal of Sports Medicine, v. 36, n. 3, p. 234–240, 2015.

BIDAURRAZAGA-LETONA, I. *et al*. Progression in youth football: Selection and identification in youth football players aged 13–15 years. Journal of Strength & Conditioning Research, v. 33, n. 9, p. 2548–2558, 2017.

BOLANOWSKI, M.; NILSSON, B. E. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. Medical Science Monitor, v. 7, n. 5, p. 1029–1033, 2001.

BOSCO, C.; LUHTANEN, P.; KOMI, P. V. A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology and Occupational Physiology, v. 50, p. 273–282, 1983.

BRANQUINHO, L.; DE FRANÇA, E.; TEIXEIRA, J. E.; TITTON, A.; LEITE DE BARROS, L. F.; CAMPOS, P.; MARINHO, D. A.; FORTE, P.; CAPERUTO, E. C.; THOMATIELI DOS SANTOS, R. V.; FERRAZ, R. Identifying the ideal weekly training load for in-game performance in an elite Brazilian soccer team. Frontiers in Physiology, v. 15, p. 1341791, 2024.

BUCHHEIT, M.; SAMOZINO, P.; GLYNN, J. A.; SIMPSON, B.; AL HADDAD, H.; MENDEZ-VILLANUEVA, A.; MORIN, J. B. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. Journal of Sports Sciences, v. 32, n. 20, p. 1906–1913, 2014.

BUJALANCE-MORENO, P.; LATORRE-ROMÁN, P. Á.; GARCÍA-PINILLOS, F. A systematic review on small-sided games in football players: acute and chronic adaptations. Journal of Sports Sciences, v. 37, n. 8, p. 921–949, 2019.

BÜRKNER, P. Brms: An R package for Bayesian multilevel models using Stan. Journal of Statistical Software, v. 80, n. 1, p. 1–28, 2017

CARLING, C.; LE GALL, F.; MALINA, R. M. Body size, skeletal maturity, and functional characteristics of elite academy football players on entry between 1992 and 2003. Journal of Sports Sciences, v. 30, p. 1683–1693, 2012.

CARVALHO, H. M. *et al*. Growth, functional capacities and motivation for achievement and competitiveness in youth basketball: an interdisciplinary approach. Journal of Sports Science, p. 1–7, 2017a.

CARVALHO, H. M. *et al*. Influence of coaches on sources of enjoyment in youth basketball. Revista de Psicologia del Deporte, v. 26, p. 143–148, 2017b.

CARVALHO, H. M. *et al*. Longitudinal changes of functional capacities among adolescent female basketball players. Frontiers in Physiology, v. 10, p. 339, 2019.

CARVALHO, H. M. *et al*. Pubertal development of body size and football-specific functional capacities in adolescent players. Research in Sports Medicine, v. 25, n. 4, p. 421–436, 2017.

CARVALHO, H. M.; GONÇALVES, C. E. Mismatches in youth sports talent development. Frontiers in Sports and Active Living, v. 5, p. 1189355, 2023.

CASTILLO-RODRÍGUEZ, A.; GONZÁLEZ-TÉLLEZ, J. L.; FIGUEIREDO, A.; CHINCHILLA-MINGUET, J. L.; ONETTI-ONETTI, W. Starters and non-starters soccer players in competition: is physical performance increased by the substitutions?. BMC Sports Science, Medicine and Rehabilitation, v. 15, n. 1, p. 33, 2023.

CEZARINO, L. G.; DA SILVA GRÜNINGER, B. L.; SILVA, R. S. Injury profile in a Brazilian first-division youth soccer team: a prospective study. Journal of Athletic Training, v. 55, n. 3, p. 295–302, 2020.

CLEMENTE, F.; PILLITTERI, G.; VIEIRA, L. H. P.; RABBANI, A.; ZMIJEWSKI, P.; BEATO, M. Balancing the load: a narrative review with methodological implications of compensatory training strategies for non-starting soccer players. Biology of Sport, v. 41, n. 4, p. 173–185, 2024.

COELHO E SILVA, M. J. *et al*. Growth, maturation, functional capacities and sport-specific skills in 12–13 year-old basketball players. Journal of Sports Medicine and Physical Fitness, v. 50, n. 2, p. 174–181, 2010.

COMETTI, G.; MAFFIULETTI, N. A.; POUSSON, M.; CHATARD, J. C.; MAFFULLI, N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. International Journal of Sports Medicine, v. 22, n. 1, p. 45–51, 2001.

CUMMING, S. P.; HILL, M.; JOHNSON, D.; PARR, J.; TEUNNISEN, J. W.; MALINA, R. M. Growth and maturation. In: Science and Soccer. Abingdon: Routledge, 2023. p. 329–345.

DE HOYO, M.; GONZALO-SKOK, O.; SAÑUDO, B.; CARRASCAL, C.; PLAZA-ARMAS, J. R.; CAMACHO-CANDIL, F.; OTERO-ESQUINA, C. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. The Journal of Strength & Conditioning Research, v. 30, n. 2, p. 368–377, 2016.

DE HOYO, M.; POZZO, M.; SAÑUDO, B.; CARRASCO, L.; GONZALO-SKOK, O.; DOMÍNGUEZ-COBO, S.; MORÁN-CAMACHO, E. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. International Journal of Sports Physiology and Performance, v. 10, n. 1, p. 46–52, 2015.

DELANG, M. D.; SALAMH, P. A.; FAROOQ, A.; TABBEN, M.; WHITELEY, R.; VAN DYK, N.; CHAMARI, K. The dominant leg is more likely to get injured in soccer players: systematic review and meta-analysis. Biology of Sport, v. 38, n. 3, p. 397–435, 2021.

DELLAL, A.; OWEN, A.; WONG, D. P.; KRUSTRUP, P.; VAN EXSEL, M.; MALLO, J. Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. Human Movement Science, v. 31, n. 4, p. 957–969, 2012.

DEPREZ, D.; COUTTS, A. J.; FRANSEN, J.; DECONINCK, F. J. A.; LENOIR, M.; VAEYENS, R.; PHILIPPAERTS, R. Relative Age, Biological Maturation and Anaerobic Characteristics in Elite Youth Soccer Players. International Journal of Sports Medicine, 2013.

DEPREZ, D.; FRANSEN, J.; LENOIR, M.; PHILIPPAERTS, R.; VAEYENS, R. Characteristics of high-level youth football players: Variation by playing position. Journal of Sports Sciences, v. 33, n. 3, p. 243–254, 2015.

DEPREZ, D.; VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; LENOIR, M.; PHILIPPAERTS, R.; VAEYENS, R. Longitudinal development of explosive leg power from childhood to adulthood in football players. International Journal of Sports Medicine, v. 36, p. 672–679, 2015.

DORE, E.; MARTIN, R.; RATEL, S. *et al*. Gender differences in peak muscle performance during growth. International Journal of Sports Medicine, v. 26, p. 274–280, 2005.

DOWSON, M. N.; NEVILL, M. E.; LAKOMY, H. K.; NEVILL, A. M.; HAZELDINE, R. J. Modelling the relationship between isokinetic muscle strength and sprint running performance. Journal of Sports Sciences, v. 16, n. 3, p. 257–265, 1998.

DUPONT, G.; NEDELEC, M.; MCCALL, A.; MCCORMACK, D.; BERTHOIN, S.; WISLØFF, U. Effect of 2 soccer matches in a week on physical performance and injury rate. American Journal of Sports Medicine, v. 38, n. 9, p. 1752–1758, 2010.

EKSTRAND, J.; WALDÉN, M.; HÄGGLUND, M. Hamstring injuries have increased 4% annually in men's professional football since 2001: A 13-year longitudinal analysis of the UEFA elite club injury study. British Journal of Sports Medicine, v. 50, n. 12, p. 731–737, 2016.

ENOKA, R. M.; DUCHATEAU, J. Translating fatigue to human performance. Medicine and Science in Sports and Exercise, v. 48, n. 11, p. 2228, 2016.

ESKANDARIFARD, E.; SILVA, R.; NOBARI, H.; CLEMENTE, F. M.; PÉREZ-GÓMEZ, J.; FIGUEIREDO, A. J. Maturational effect on physical capacities and anabolic hormones in under-16 elite footballers: a cross-sectional study. Sport Sciences for Health, v. 18, n. 2, p. 297–305, 2022.

FAUDE, O.; KOCH, T.; MEYER, T. Straight sprinting is the most frequent action in goal situations in professional football. Journal of Sports Sciences, v. 30, n. 7, p. 625–631, 2012.

FAUDE, O.; RÖSSLER, R.; PETUSHEK, E. J.; ROTH, R.; ZAHNER, L.; DONATH, L. Neuromuscular adaptations to multimodal injury prevention programs in youth sports: a systematic review with meta-analysis of randomized controlled trials. Frontiers in Physiology, v. 8, p. 791, 2017.

FENG, J.; RODRÍGUEZ FERNÁNDEZ, A., *et al*. Impact of small-sided game formats on electromyographic responses in college students. Journal of Sports Science and medicine, v. 24, n. 4, p. 729–738, 2025.

FIGUEIREDO, A. J. *et al*. Characteristics of youth football players who drop out, persist, or move up. Journal of Sports Sciences, v. 27, n. 9, p. 883–891, 2009.

FIGUEIREDO, A. J. *et al*. Youth soccer players, 11–14 years: maturity, size, function, skill and goal orientation. Annals of Human Biology, v. 36, n. 1, p. 60–73, 2009b.

FORTES, R. P.; MACHADO, C. L. F.; BARONI, B. M.; NAKAMURA, F. Y.; PINTO, R. S. Relationship between maximal strength and hamstring-to-quadriceps ratios in balanced and unbalanced legs in futsal athletes. Sport Sciences for Health, v. 19, n. 4, p. 1169–1176, 2023.

FRANCIONI, F. M.; FIGUEIREDO, A. J.; LUPO, C.; TERRIBILI, M.; CONDELLO, G.; TESSITORE, A. Intra-seasonal variation of anthropometrical, conditional, and technical tests in U14 football players. RICYDE. Revista Internacional de Ciencias del Deporte, v. 14, n. 53, p. 219–232, 2018.

GABBETT, T. J.; MULVEY, M. J. Time-motion analysis of small-sided training games and competition in elite women soccer players. Journal of Strength & Conditioning Research, v. 22, n. 2, p. 543–552, mar. 2008.

GABBETT, T. J.; WHYTE, D. G.; HARTWIG, T. B.; WESCOMBE, H.; NAUGHTON, G. A. The relationship between workloads, physical performance, injury and illness in adolescent male football players. Sports Medicine, 2014.

GABRY, J.; SIMPSON, D.; VEHTARI, A. *et al*. Visualization in Bayesian workflow. Journal of the Royal Statistical Society: Series A (Statistics in Society), v. 182, p. 389–402, 2019.

GAITANOS, G. C.; WILLIAMS, C.; BOOBIS, L. H.; BROOKS, S. Human muscle metabolism during intermittent maximal exercise. Journal of Applied Physiology, v. 75, n. 2, p. 712–719, 1993.

GANDEVIA, S. C. Spinal and supraspinal factors in human muscle fatigue. Physiological Reviews, v. 81, n. 4, p. 1725–1789, 2001.

GELMAN, A.; HILL, J. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, 2007.

GIMÉNEZ, J. V.; LEICHT, A. S.; GOMEZ, M. A. Physical performance differences between starter and non-starter players during professional soccer friendly matches. Journal of Human Kinetics, v. 69, p. 283–291, 2019.

GLAISTER, M. Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. Sports Medicine, v. 35, n. 9, p. 757–777, 2005.

GOLDSTEIN, H. Efficient statistical modelling of longitudinal data. Annals of Human Biology, v. 13, p. 129–141, 1986.

GONÇALVES, L. G.; NOBARI, H.; RITES, A. A.; NAKAMURA, F. Y.; GARCIA, G. R.; AQUINO, R. Influence of contextual factors on match running performance of starters and non-starters in elite youth male soccer players. Science Progress, v. 107, n. 2, Art. 368504241239187, 2024.

GRAZIOLI, R.; INÁCIO, M.; LOPEZ, P.; FREITAS, S. R.; CUNHA, G. D. S.; MACHADO, C. L. F.; VEECK, F.; BARONI, B. M.; CADORE, E. L.; PINTO, R. S. Effects of eccentric-emphasized leg curl intervention on muscle strength imbalance markers in professional soccer players during pre-season. Journal of Bodywork and Movement Therapies, v. 35, p. 28–32, 2023.

HAMMAMI, A. *et al*. Blood pressure, heart rate and perceived enjoyment after small-sided soccer games and repeated sprint in untrained healthy adolescents. Biology of Sport, v. 34, n. 3, p. 219, 2017.

HART, N. H.; NIMPHIUS, S.; WEBER, J.; SPITERI, T.; RANTALAINEN, T.; DOBBIN, M.; NEWTON, R. Musculoskeletal asymmetry in football athletes: a product of limb function over time. 2016.

HAUGEN, T. A.; TØNNESSEN, E.; SEILER, S. Anaerobic performance testing of professional soccer players 1995–2010. International Journal of Sports Physiology and Performance, v. 8, n. 2, p. 148–156, 2013.

HILL-HAAS, S. V.; DAWSON, B.; IMPELLIZZERI, F. M.; COUTTS, A. J. Physiology of small-sided games training in football: a systematic review. Sports Medicine, v. 41, n. 3, p. 199–220, 2011.

HOPKINS, W. G. Measures of reliability in sports medicine and science. Sports Medicine, v. 30, n. 1, p. 1–15, 2000.

HUIJGEN, B. C. H. *et al*. Development of dribbling in talented youth football players aged 12–19 years: a longitudinal study. Journal of Sports Sciences, v. 28, n. 7, p. 689–698, 2010.

HUIJGEN, B. C. H. *et al*. Multidimensional performance characteristics in selected and deselected talented football players. European Journal of Sport Science, v. 14, n. 1, p. 2–10, 2014.

HŮLKA, K.; STRNIŠTĚ, M. Fitness improvements of young soccer players after high volume or small sided games interventions. Biology of Sport, v. 38, n. 4, p. 573–578, 2021.

IACONO, A. D.; BEATO, M.; UNNITHAN, V. Effects of game profile–based training and small-sided games on physical performance of elite young soccer players. The Journal of Strength & Conditioning Research, [s. l.], 2019.

IACONO, A. D.; MARTONE, D.; CULAR, D.; MILIC, M.; PADULO, J. Game profile–based training in soccer: A new field approach. The Journal of Strength & Conditioning Research, v. 31, n. 12, p. 3333–3342, 2017.

IBÁÑEZ, S. J.; FEU, S.; CAÑADAS, M. Sistema integral para el análisis de las tareas de entrenamiento, SIATE, en deportes de invasión. E-balonmano.com: Revista de Ciencias del Deporte, v. 12, n. 1, p. 3–30, 2016.

ISHIDA, A.; TRAVIS, S. K.; STONE, M. H. Associations of body composition, maximum strength, power characteristics with sprinting, jumping, and intermittent endurance performance in male intercollegiate soccer players. Journal of Functional Morphology and Kinesiology, 2021.

JANUSIAK, M.; SILVA, A. F.; SILVA, R.; KOSENDIAK, A.; BOGDAŃSKI, B.; SMOTER, M.; PRAÇA, G.; CLEMENTE, F. M. Testing variations between starters and substitute players in terms of total distance, high-speed running, and sprinting distance: a descriptive study on professional male soccer players. Biology of Sport, v. 41, n. 2, p. 95–103, 2024.

JASTRZEBSKI, Z.; BARNAT, W.; DARGIEWICZ, R.; JASKULSKA, E.; SZWARC, A.; RADZIMIŃSKI, Ł. Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. International Journal of Sports Science & Coaching, v. 9, n. 5, p. 1169–1179, 2014.

JEFFREYS, I. The use of small-sided games in the metabolic training of high school soccer players. Strength and Conditioning Journal, v. 26, n. 5, p. 77–78, 2004.

JIMÉNEZ-REYES, P.; PAREJA-BLANCO, F.; CUADRADO-PEÑAFIEL, V.; MORCILLO, J. A.; PÁRRAGA, J. A.; GONZÁLEZ-BADILLO, J. J. Mechanical, metabolic and perceptual response during sprint training. International Journal of Sports Medicine, v. 37, n. 10, p. 807–812, 2016.

JULLIEN, H.; BISCH, C.; LARGOUËT, N.; MANOUVRIER, C.; CARLING, C. J.; AMIARD, V. Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players? Journal of Strength & Conditioning Research, v. 22, n. 2, p. 404–411, 2008.

KAY, M. Tidybayes: Tidy data and geoms for Bayesian models. Zenodo, 2023.

KEINER, M.; SANDER, A.; WIRTH, K.; HARTMANN, H.; YAGHOBI, D. Correlations between maximal strength tests at different squat depths and sprint performance in adolescent soccer players. American Journal of Sports Science, v. 2, n. 1, p. 1–7, 2014.

KELLY, A. L.; WILLIAMS, C. A. Physical characteristics and the talent identification and development processes in male youth football: A narrative review. Strength & Conditioning Journal, v. 42, n. 6, p. 15–34, 2020

LEHANCE, C.; BINET, J.; BURY, T.; CROISIER, J. L. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scandinavian Journal of Medicine & Science in Sports, v. 19, n. 2, p. 243–251, 2009.

LEONARDI, T. J. *et al*. Biological maturation, training experience, body size and functional capacity of adolescent female basketball players: A Bayesian analysis. International Journal of Sports Science and Coaching, v. 13, n. 5, p. 713–722, 2018.

LIMA, A. B.; QUINAUD, R. T.; GONÇALVES, C. E.; CARVALHO, H. M. Peak height velocity in young athletes: A longitudinal meta-analysis. Journal of Sports Sciences, v. 41, n. 2, p. 151–163, 2023.

LLOYD, R. S.; OLIVER, J. L. The youth physical development model: A new approach to long-term athletic development. Strength & Conditioning Journal, v. 34, n. 3, p. 61–72, 2012.

LOHMAN, T. G.; ROCHE, A. F.; MARTORELL, R. Anthropometric standardization reference manual. Human Kinetics, 1988.

LOTURCO, I. *et al*. Maximum acceleration performance of professional football players in linear sprints: Is there a direct connection with change-of-direction ability? PloS One, v. 14, n. 5, e0216806, 2019.

MACHADO, C. L.; NAKAMURA, F. Y.; DE ANDRADE, M. X.; DOS SANTOS, G. C.; CARLET, R.; BRUSCO, C. M.; REISCHAK-OLIVEIRA, A.; VOSER, R. D. C.; PINTO, R. S. Total and regional body composition are related with aerobic fitness performance in elite futsal players. Journal of Bodywork and Movement Therapies, v. 35, p. 164–168, 2023.

MAFFIULETTI, N. A.; AAGAARD, P.; BLAZEVICH, A. J.; FOLLAND, J.; TILLIN, N.; DUCHATEAU, J. Rate of force development: physiological and methodological considerations. European Journal of Applied Physiology, v. 116, n. 6, p. 1091–1116, 2016.

MAKAR, P.; SILVA, A.; KAWCZYŃSKI, A.; AKYILDIZ, Z.; YILDIZ, M.; PRAÇA, G.; CLEMENTE, F. Variability of peak speed and sprinting actions during the same small-sided games: within- and between-player variations inspected over four consecutive weeks. Biology of Sport, v. 40, n. 4, p. 959–965, 2023.

MALINA, R. M. *et al*. Height, mass and skeletal maturity of elite Portuguese football players aged 11–16 years. Journal of Sports Sciences, v. 18, n. 9, p. 685–693, 2000.

MALINA, R. M. *et al*. Maturity-associated variation in the growth and functional capacities of youth football (football) players 13–15 years. European Journal of Applied Physiology, v. 91, p. 555–562, 2004.

MALINA, R. M. *et al*. Observed and predicted ages at peak height velocity in soccer players. PloS One, v. 16, n. 7, e0254659, 2021.

MALINA, R. M. Physical growth and biological maturation of young athletes. Exercise and Sport Sciences Reviews, v. 22, n. 1, p. 280–284, 1994.

MALINA, R. M.; BOUCHARD, C.; BAR-OR, O. Growth, maturation, and physical activity. Champaign: Human Kinetics, 2009.

MARFELL-JONES, S. International standards for anthropometric assessment. 2012.

MARKOVIC, G.; DIZDAR, D.; JUKIC, I.; CARDINALE, M. Reliability and factorial validity of squat and countermovement jump tests. The Journal of Strength & Conditioning Research, v. 18, n. 3, p. 551–555, 2004.

MENDES, F. G.; NASCIMENTO, J. V.; SOUZA, E. R.; *et al*. Retrospective analysis of accumulated structured practice: A Bayesian multilevel analysis of elite Brazilian volleyball players. High Ability Studies, v. 29, p. 255–269, 2018.

MEYLAN, C.; *et al*. Talent identification in football: The role of maturity status on physical, physiological and technical characteristics. International Journal of Sports Science & Coaching, v. 5, n. 4, p. 571–592, 2010.

MICHAILIDIS, Y.; FATOURES, I. G.; PRIMPA, E.; MICHAILIDIS, C.; AVLONITI, A.; CHATZINIKOLAOU, A.; KAMBAS, A. Plyometrics' trainability in preadolescent soccer athletes. Journal of Strength & Conditioning Research, v. 27, n. 1, p. 38–49, 2013.

MIGUEL, C. G.; SOARES, A. L.; LIMA, A. B.; KARASIAK, F. C.; GALVÃO, L. G.; LEONARDI, T. J.; FOSTER, C.; GONÇALVES, C. E.; CARVALHO, H. M. Developmental changes in the physical fitness of young female and male basketball players: a Bayesian analysis. Journal of Sports Medicine and Physical Fitness, v. 65, n. 10, p. 1296–1305, 2025.

MOHR, M.; KRUSTRUP, P.; BANGSBO, J. Fatigue in soccer: a brief review. Journal of Sports Sciences, v. 23, n. 6, p. 593–599, 2005.

MOHR, M.; KRUSTRUP, P.; BANGSBO, J. Match performance of high-standard soccer players with special reference to development of fatigue. Journal of Sports Sciences, v. 21, n. 7, p. 519–528, 2003.

MORAES, A. M.; QUINAUD, R. T.; FERREIRA, G. O. C.; *et al*. Age-, sex-, and maturity-associated variation in the phase angle after adjusting for size in adolescents. Frontiers in Nutrition, v. 9, 939714, 2022.

MORIN, J. B.; GIMENEZ, P.; EDOUARD, P.; ARNAL, P.; JIMENEZ-REYES, P.; SAMOZINO, P.; ... MENDIGUCHIA, J. Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. Frontiers in Physiology, v. 6, dec. 2015. doi:10.3389/fphys.2015.00404

NÉDÉLEC, M.; MCCALL, A.; CARLING, C.; LEGALL, F.; BERTHOIN, S.; DUPONT, G. Recovery in soccer: Part I – post-match fatigue and time course of recovery. Sports Medicine, v. 42, n. 12, p. 997–1015, 2012.

NEWMANN, M. A.; TARPENNING, K. M.; MARINO, F. E. Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players. Journal of Strength and Conditioning Research, v. 18, n. 4, p. 867–872, 2004.

OLIVA-LOZANO, J. M. *et al*. Acceleration and sprint profiles of professional male football players in relation to playing position. PloS One, v. 15, n. 8, e0236959, 2020.

OLIVA-LOZANO, J. M.; FORTES, V.; KRUSTRUP, P.; MUYOR, J. M. Acceleration and sprint profiles of professional male football players in relation to playing position. PLoS One, v. 15, n. 8, e0236959, 2020.

OSGNACH, C.; POSER, S.; BERNARDINI, R.; RINALDO, R.; DI PRAMPERO, P. E. Energy cost and metabolic power in elite soccer: a new match analysis approach. Medicine & Science in Sports & Exercise, v. 42, n. 1, p. 170–178, 2010.

OTERO-ESQUINA, C.; DE HOYO LORA, M.; GONZALO-SKOK, Ó.; DOMÍNGUEZ-COBO, S.; SÁNCHEZ, H. Is strength-training frequency a key factor to develop performance adaptations in young elite soccer players? European Journal of Sport Science, v. 17, n. 10, p. 1241–1251, 2017.

PEÑA-GONZÁLEZ, I.; FERNÁNDEZ-FERNÁNDEZ, J.; MOYA-RAMÓN, M.; CERVELLÓ, E. Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. Research Quarterly for Exercise and Sport, v. 89, n. 3, p. 373–379, 2018.

PEÑA-GONZÁLEZ, I.; JAVALOYES, A.; CERVELLÓ, E.; MOYA-RAMÓN, M. The maturity status but not the relative age influences elite young football players' physical performance. Science and Medicine in Football, v. 6, n. 3, p. 309–316, 2022.

PEREIRA, G.; MORSE, C.; UGRINOWITSCH, C.; RODACKI, A.; KOKUBUN, E.; FOWLER, N. Manipulation of rest period length induces different causes of fatigue in vertical jumping. International Journal of Sports Medicine, v. 30, n. 5, p. 325–330, 2009.

PHILIPPAERTS, R. M.; *et al*. The relationship between peak height velocity and physical performance in youth football players. Journal of Sports Sciences, v. 24, n. 3, p. 221–230, 2006.

PIETRASZEWSKI, P.; MASZCZYK, A.; ZAJĄC, A.; GOŁAŚ, A. Muscle activity and biomechanics of sprinting: a meta-analysis review. Applied Sciences, v. 15, n. 9, p. 4959, 2025.

PINTO, M. D.; BLAZEVICH, A. J.; ANDERSEN, L. L.; MIL-HOMENS, P.; PINTO, R. S. Hamstring-to-quadriceps fatigue ratio offers new and different muscle function information than the conventional non-fatigued ratio. Scandinavian Journal of Medicine & Science in Sports, v. 28, n. 1, p. 282–293, 2018.

PONS, E.; GARCÍA-CALVO, T.; RESTA, R.; BLANCO, H.; LÓPEZ DEL CAMPO, R.; DÍAZ GARCÍA, J.; PULIDO, J. J. A comparison of a GPS device and a multi-camera

video technology during official football matches: agreement between systems. PLOS ONE, v. 14, n. 8, e0220729, 2019. https://doi.org/10.1371/journal.pone.0220729

PRAAGH, E. V.; DORE, E. Short-term muscle power during growth and maturation. Sports Medicine, v. 32, p. 701–728, 2002.

REILLY, T. *et al*. A multidisciplinary approach to talent identification in football. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

REILLY, T.; BANGSBO, J.; FRANKS, A. Anthropometric and physiological predispositions for elite football. Journal of Sports Sciences, v. 18, n. 9, p. 669–683, 2000.

REILLY, T.; *et al*. A multidisciplinary approach to talent identification in football. Journal of Sports Sciences, v. 18, n. 9, p. 695–702, 2000.

REYNOLDS, J.; CONNOR, M.; JAMIL, M.; BEATO, M. Quantifying and comparing the match demands of U18, U23, and 1ST team English professional soccer players. Frontiers in Physiology, v. 12, p. 706451, 2021.

RODRÍGUEZ-FERNÁNDEZ, A.; RODRÍGUEZ-MARROYO, J. A.; CASAMICHANA, D.; VILLA, J. G. Effects of 5-week pre-season small-sided-game-based training on repeat sprint ability. The Journal of Sports Medicine and Physical Fitness, v. 57, n. 5, p. 529–536, 2016.

ROESCHER, C. R.; ELFERINK-GEMSER, M. T.; HUIJGEN, B. C. H.; VISSCHER, C. Soccer endurance development in professionals. International Journal of Sports Medicine, v. 31, n. 3, p. 174–179, 2010.

RUAS, C. V.; MINOZZO, F.; PINTO, M. D.; BROWN, L. E.; PINTO, R. S. Lower-extremity strength ratios of professional soccer players according to field position. Journal of Strength and Conditioning Research, v. 29, n. 5, p. 1220–1226, 2015.

SAEZ, E. de VILLAREAL; GONZÁLEZ-BADILLO, J. J.; IZQUIERDO, M. Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. The Journal of Strength & Conditioning Research, v. 22, n. 3, p. 715–725, 2008.

SAHALY, R.; VANDEWALLE, H.; DRISS, T.; MONOD, H. Maximal voluntary force and rate of force development in humans–importance of instruction. European Journal of Applied Physiology, v. 85, p. 345–350, 2001.

SANCHEZ-SANCHEZ, *et al*. Heart rate variability and physical demands of in-season youth elite soccer players. International Journal of Environmental Research and Public Health, v. 18, n. 4, 1391, 2021.

SANGNIER, S.; TOURNY-CHOLLET, C. Study of the fatigue curve in quadriceps and hamstrings of soccer players during isokinetic endurance testing. Journal of Strength and Conditioning Research, v. 22, n. 5, p. 1458–1467, 2008.

SILVA, J. R.; MAGALHÃES, J. F.; ASCENSÃO, A. A.; OLIVEIRA, E. M.; SEABRA, A. F.; REBELO, A. N. Individual match playing time during the season affects fitness-related parameters of male professional soccer players. The Journal of Strength & Conditioning Research, v. 25, n. 10, p. 2729–2739, 2011.

SLIMANI, M.; CHAMARI, K.; MIARKA, B.; DEL VECCHIO, F. B.; CHEOUR, F. Effects of plyometric training on physical fitness in team sport athletes: a systematic review. Journal of Human Kinetics, v. 53, p. 231, 2016.

SOARES, A. L.; LIMA, A. B.; MIGUEL, C. G. *et al*. Does early specialization provide an advantage in physical fitness development in youth basketball? Frontiers in Sports and Active Living, v. 4, p. 1042494, 2023.

STAN DEVELOPMENT TEAM. Stan modeling language user's guide and reference manual (version 2.19.2). Interaction Flow Modeling Language, 2020.

STERN, D.; GONZALO-SKOK, O.; LOTURCO, I.; TURNER, A.; BISHOP, C. A comparison of bilateral vs. unilateral-biased strength and power training interventions on measures of physical performance in elite youth soccer players. The Journal of Strength & Conditioning Research, v. 34, n. 8, p. 2105–2111, 2020.

STØLEN, T.; CHAMARI, K.; CASTAGNA, C.; WISLØFF, U. Physiology of soccer: an update. Sports Medicine, v. 35, n. 6, p. 501–536, 2005.

SUAREZ-ARRONES, L.; LARA-LOPEZ, P.; TORRENO, N.; SAEZ DE VILLARREAL, E.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Effects of strength training on body composition in young male professional soccer players. Sports, v. 7, n. 5, p. 104, 2019.

SUAREZ-ARRONES, L.; PETRI, C.; MALDONADO, R. A.; TORRENO, N.; MUNGUÍA-IZQUIERDO, D.; DI SALVO, V.; MENDEZ-VILLANUEVA, A. Body fat assessment in elite soccer players: cross-validation of different field methods. Science and Medicine in Football, v. 2, n. 3, p. 203–208, 2018.

VAEYENS, R. *et al*. A multidisciplinary selection model for youth football: The Ghent Youth Football Project. British Journal of Sports Medicine, v. 40, n. 11, p. 928–934, 2006.

VAEYENS, R.; LENOIR, M.; WILLIAMS, A. M.; PHILIPPAERTS, R. M. Talent identification and development programmes in sport: current models and future directions. Sports Medicine, v. 38, n. 9, p. 703–714, 2008.

VALENTE-DOS-SANTOS, J.; COELHO-E-SILVA, M. J.; SIMOES, F.; FIGUEIREDO, A. J.; LEITE, N.; ELFERINK-GEMSER, M. T.; MALINA, R. M.; SHERAR, L. Modeling developmental changes in functional capacities and football-specific skills in male players aged 11–17 years. Pediatric Exercise Science, v. 24, p. 603–621, 2012.

VARJAN, M.; HANK, M.; KALATA, M.; CHMURA, P.; MALA, L.; ZAHALKA, F. Weekly training load differences between starting and non-starting soccer players. Journal of Human Kinetics, v. 90, p. 125, 2023.

VEHTARI, A.; GELMAN, A.; GABRY, J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Statistics and Computing, v. 27, p. 1413–1432, 2017.

VEHTARI, A.; GELMAN, A.; SIMPSON, D.; CARPENTER, B.; BÜRKNER, P.-C. Rank-normalization, folding, and localization: an improved R for assessing convergence of MCMC (with discussion). Bayesian Analysis, v. 16, n. 2, p. 667–718, 2021.

VIGNE, G.; *et al*. Activity profile in elite Italian football team. International Journal of Sports Medicine, v. 31, n. 5, p. 304–310, 2010.

YOSHIKO, A., WATANABE, K., & AKIMA, H. (2023). Relative contribution of neuromuscular activation, muscle size, and muscle quality to maximum strength output of the thigh muscles in young individuals. *Physiological Reports*, *11*(1), e15563.

WICKHAM, H. Ggplot2: Elegant graphics for data analysis. Springer, 2016. Disponível em: https://ggplot2.tidyverse.org.

WILLIAMS, A. M.; FORD, P. R.; DRUST, B. Talent identification and development in soccer since the millennium. In: Science and football, p. 3–14, 2023.

WILLIAMS, M.; FORD, P.; DRUST, B. Talent identification and development in soccer since the millennium. Journal of Sports Sciences, v. 38, n. 11–12, p. 1199–1210, 2020.

WING, C. E.; TURNER, A. N.; BISHOP, C. J. Importance of strength and power on key performance indicators in elite youth soccer. Journal of Strength and Conditioning Research, v. 34, n. 7, p. 2006–2014, 2020.

WONG, P.-L.; CHAMARI, K.; CHAOUACHI, A.; MAO, D. W.; WISLØFF, U.; HONG, Y. Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. British Journal of Sports Medicine, v. 41, p. 84, 2007.

WORLD MEDICAL ASSOCIATION *et al*. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA, v. 310, n. 20, p. 2191–2194, 2013.

ZHANG, Q.; LÉAM, A.; FOURÉ, A.; WONG, D. P.; HAUTIER, C. A. Relationship between explosive strength capacity of the knee muscles and deceleration performance in female professional soccer players. Frontiers in Physiology, v. 12, p. 723041, 2021

APÊNDICE A – TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE) - TREINADORES

Título da Pesquisa: Percursos de desenvolvimento do jovem esportista: análise multidimensional

Nome do Pesquisador Principal: Prof. Dr. Thiago José Leonardi

Você está sendo convidado(a) a participar como voluntário (a) de um estudo que terá duração de três anos. Este documento, chamado Termo de Consentimento Livre e Esclarecido (TCLE), visa assegurar seus direitos como participante e é elaborado em duas vias, uma que deverá ficar com você e outra com o pesquisador.

Por favor, leia com atenção e calma, aproveitando para esclarecer suas dúvidas. Se houver perguntas antes ou mesmo depois de assiná-lo, você poderá esclarecê-las com o pesquisador. Se preferir, pode levar para casa e consultar seus familiares ou outras pessoas antes de decidir sobre sua participação. Se você não quiser participar ou decidir retirar sua autorização, a qualquer momento, não haverá nenhum tipo de penalização ou prejuízo.

Justificativa e objetivos: A pesquisa dedica-se ao estudo do estado de crescimento, maturação biológica e aptidão física no jovem atleta. De uma forma resumida, pretende-se caracterizar o quanto os jovens atletas estão aptos para aquilo que são hoje as exigências de formação esportiva, em particular do volume de treino e competição. Para alcançar esse objetivo, entendemos que sua poderá trazer importante contribuição.

Procedimentos: Participando do estudo você será convidado (a) a: participar de reuniões mensais com a equipe de pesquisadores a fim de refletir sua prática profissional e a disponibilizar seu caderno de treino para que os pesquisadores possam conhecer os conteúdos de treino ministrados. As reuniões mensais terão duração de 1 (uma) hora e serão marcadas em horário a ser combinado com a equipe de pesquisadores. Nessas reuniões será solicitado que você entregue o caderno de treinos do período referente ao mês anterior. Nos meses em que houver avaliação dos atletas, você será convidado(a) a participar de uma entrevista semi-estruturada a fim de verificar a sua percepção quanto ao seu desenvolvimento como profissional, a partir das reuniões e reflexões.

Desconfortos e riscos: Você não deve participar deste estudo se achar que não foi devidamente esclarecido quanto aos objetivos e à forma em que irá participar. As reuniões e as entrevistas podem gerar algum grau de desconforto ao fazê-lo (a) refletir sobre as práticas que vem desenvolvendo. Adicionalmente, na ocorrência de qualquer desconforto que não tenha sido previsto nesse documento, serão adotadas providências para minimizá-los. A não autorização de sua participação neste estudo em nada afetará a sua relação com o clube.

Benefícios: O estudo produzirá informações acerca do processo de treino e sobre o estado de crescimento e desempenho dos atletas, dados estes que serão devolvidas ao professor/treinador da equipe. Você e todos os demais participantes terão acesso aos resultados e ao conhecimento gerado a partir do estudo por meio da devolutiva dos resultados obtidos nas diferentes avaliações.

Sigilo e privacidade: Você tem a garantia de que a sua identidade será mantida em sigilo e nenhuma informação será dada a outras pessoas que não façam parte da equipe de pesquisadores. Na divulgação dos resultados desse estudo, seu nome não será citado.

Ressarcimento: Não será oferecido nenhum tipo de ressarcimento de despesas (transporte, alimentação, hospedagem, dentre outros) para participação no estudo.

Contato: Em caso de dúvidas sobre o estudo, você poderá entrar em contato com o pesquisador Thiago José Leonardi (Pesquisador Responsável) através dos seguintes contatos: Escola Superior de Educação Física, Fisioterapia e Dança, Universidade Federal do Rio Grande do Sul – Rua Felizardo, 750, Jardim Botânico, CEP 90690-020, Porto Alegre, RS; Telefone: 51-3308-585; E-mail: thiago.leonardi@ufrgs.br. Em caso de denúncias ou reclamações sobre sua participação e sobre questões éticas do estudo, você pode entrar em contato com o Comitê de Ética em Pesquisa (CEP) da UFRGS: Av. Paulo Gama, n. 110, Sala 321, Prédio Anexo 01 da Reitoria, Campus Centro, Porto Alegre/RS; Telefone: (51) 3308 3738; E-mail: etica@propesq.ufrgs.br.

Consentimento livre e esclarecido:

Após ler este documento sobre a participação no estudo, ter sido esclarecido sobre a natureza da pesquisa, seus objetivos, métodos, benefícios previstos, potenciais riscos e o incômodo que esta possa acarretar, eu, _____ manifesto meu consentimento livre e esclarecido em participar da presente pesquisa.

_____

(Assinatura do(a) participante)

Data: ____/_____/_____.

Responsabilidade do Pesquisador:

Asseguro ter cumprido as exigências da resolução 466/2012 CNS/MS e complementares na elaboração do protocolo e na obtenção deste Termo de Consentimento Livre e Esclarecido. Asseguro, também, ter explicado e fornecido uma cópia deste documento ao participante. Informo que o estudo foi aprovado pelo CEP perante o qual o projeto foi apresentado e pela CONEP, quando pertinente. Comprometo-me a utilizar o material e os dados obtidos nesta pesquisa exclusivamente para as finalidades previstas neste documento ou conforme o consentimento dado pelo participante.

Data: ____/_____/_____.

_____

Prof. Dr. Thiago José Leonardi – Responsável pela pesquisa.

APÊNDICE B – TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE) – PAIS E/OU RESPONSÁVEIS

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)

Título da Pesquisa: Percursos de desenvolvimento do jovem esportista: análise multidimensional

Nome do Pesquisador Principal: Prof. Dr. Thiago José Leonardi

O (a) seu (a) filho (a), através de você, como responsável legal, está sendo convidado(a) a participar como voluntário (a) de um estudo que terá duração de três anos. Este documento, chamado Termo de Consentimento Livre e Esclarecido (TCLE), visa assegurar seus direitos e do (a) seu (a) filho (a) como participante e é elaborado em duas vias, uma que deverá ficar com você e outra com o pesquisador.

Por favor, leia com atenção e calma, aproveitando para esclarecer suas dúvidas. Se houver perguntas antes ou mesmo depois de assiná-lo, você poderá esclarecê-las com o pesquisador. Se preferir, pode levar para casa e consultar seus familiares ou outras pessoas antes de decidir sobre a participação do (a) seu (a) filho (a). Se você não quiser que seu (a) filho (a) participe ou retirar sua autorização, a qualquer momento, não haverá nenhum tipo de penalização ou prejuízo.

Justificativa e objetivos: A pesquisa dedica-se ao estudo do estado de crescimento, maturação biológica, aptidão física e performance tático-técnica no jovem atleta. De uma forma resumida, pretende-se caracterizar o quanto os jovens atletas estão aptos para aquilo que são hoje as exigências de formação esportiva, em particular do volume de treino e competição. Para alcançar esse objetivo, entendemos que a participação do (a) seu (a) filho (a) poderá trazer importante contribuição.

Procedimentos: As coletas deste estudo ocorrerão três vezes ao ano (início, meio e final da temporada esportiva), durante dois anos, com duração de três sessões de treino a cada avaliação. Participando do estudo o (a) seu (a) filho (a) está sendo convidado (a) a: responder questionários com questões acerca da importância da prática do esporte no seu dia a dia. Os questionários serão respondidos durante o horário de treinamento, sendo acompanhado (a) pelos professores/treinadores do Clube e pelo pesquisador. Cada questionário será respondido apenas uma (1) vez por etapa de coleta de dados, com duração estimada de 15 minutos cada. O (a) seu (a) filho (a) poderá, a qualquer momento, decidir não responder alguma questão ou desistir de participar em qualquer momento da pesquisa. Entre as variáveis em estudo, interessa-nos discriminar as características antropométricas dos (as) atletas participantes e, para tanto, participarão de medidas e composição corporal (será medida estatura, massa corporal, dobras cutâneas, diâmetro ósseo, perímetro de braço e coxa, além de avaliações em densitômetro por absorção de raios-X de dupla energia, conhecido como DXA, e ultrassom, os quais não apresentam riscos à saúde de seu filho). Outro conjunto de informações serão coletadas para determinar a aptidão anaeróbia e aeróbia, as quais serão determinadas através de teste de velocidade de 20 metros, teste de agilidade em zig-zag, uma prova de seis corridas de 35m com 10 segundos de intervalo, corrida vai-e-vem de 20 metros com e sem intervalos

de recuperação. Haverá, também, convite para avaliações neuromusculares, como saltos, avaliação de força, potência, taxa de produção de força, em membros inferiores, com movimentos em cadeira extensora, flexora e agachamento e avaliação eletromiográfica. O(a) seu (a) filho (a) também será convidado (a) a participar de uma avaliação técnica e tática caracterizada por um jogo em campo reduzido com duração de 10 minutos, o qual será filmado para posterior análise. Haverá, também, convite para avaliações nutricionais, em que seu filho (a) será convidado (a) a descrever os alimentos ingeridos em um dia típico de treino, um dia atípico (final de semana) e dia de jogo, e aplicação de questionários. Por fim, para que possamos compreender o processo de treino em que seu filho(a) está inserido, faremos controle dos conteúdos e da carga do treino, sendo este último realizado por meio de dispositivos GPS.

Desconfortos e riscos: Você e seu (a) filho (a)não devem participar deste estudo se achar que não foram devidamente esclarecidos quanto aos objetivos e da forma em que irá participar. As provas de aptidão física poderão provocar exaustão e fadiga aguda transiente aos participantes, similar aos momentos mais intensos que os participantes vivenciam no treinamento ou jogo. A fim de minimizar esse desconforto, para as instruções preparatórias dos testes serão utilizados aquecimentos prévios de articulações e musculaturas envolvidas nas provas e instruções claras sobre protocolos de execução; durante a realização dos testes ocorrerá a supervisão de execução dos movimentos, com orientação a fim de evitar movimentos que possam ocasionar lesão; e após os testes que envolvem esforço físico, os atletas realizarão recuperação ativa (em movimento) antecedendo a recuperação passiva (pausa). No caso de ocorrer algum agravo de saúde ou lesão em decorrência da realização dos testes, será acionado atendimento emergencial. Adicionalmente, na ocorrência de qualquer desconforto que não tenha sido previsto nesse documento, serão adotadas providências para minimizá-los. A não autorização em nada afetará a relação do atleta com o clube.

Benefícios: O estudo produzirá informação sobre o estado de crescimento, questões comportamentais, nutricionais e desempenhos físico, técnico e tático (vantagens). Você, seu (a) filho (a) e todos os demais participantes, terão acesso aos resultados e ao conhecimento gerado a partir do estudo por meio da devolutiva dos resultados obtidos pelo (a) seu (a) filho (a) nas diferentes avaliações. Não haverá custos para a participação de seu (a) filho (a) neste estudo.

Sigilo e privacidade: Você e seu (a) filho (a) tem a garantia de que a identidade será mantida em sigilo e nenhuma informação será dada a outras pessoas que não façam parte da equipe de pesquisadores. Na divulgação dos resultados desse estudo, seu nome e do (a) seu (a) filho (a) não serão citados. As informações coletadas serão guardadas na instituição sede da presente pesquisa, sob cuidados do pesquisador principal, pelo período de cinco anos.

Contato: Em caso de dúvidas sobre o estudo, você poderá entrar em contato com o pesquisador Thiago José Leonardi (Pesquisador Responsável) através dos seguintes contatos: Escola Superior de Educação Física, Fisioterapia e Dança, Universidade Federal do Rio Grande do Sul – Rua Felizardo, 750, Jardim Botânico, CEP 90690-020, Porto Alegre, RS; Telefone: 51-3308-5858; E-mail: thiago.leonardi@ufrgs.br. Em caso de denúncias ou reclamações sobre sua participação e sobre questões éticas do estudo, você pode entrar em contato com o Comitê de Ética em Pesquisa (CEP) da UFRGS: Av. Paulo

Gama, n. 110, Sala 321, Prédio Anexo 01 da Reitoria, Campus Centro, Porto Alegre/RS; Telefone: (51) 3308 3738; E-mail: etica@propesq.ufrgs.br.

Consentimento livre e esclarecido:

Após discutir com meu (minha) filho (a) sobre a participação no estudo, ter sido esclarecido sobre a natureza da pesquisa, seus objetivos, métodos, benefícios previstos, potenciais riscos e o incômodo que esta possa acarretar, autorizo a participação:

Nome do(a) participante: _____

Nome do Responsável:_____

_____

(Assinatura do(a) responsável)

Data: ____/_____/_____.

Responsabilidade do Pesquisador:

Asseguro ter cumprido as exigências da resolução 466/2012 CNS/MS e complementares na elaboração do protocolo e na obtenção deste Termo de Consentimento Livre e Esclarecido. Asseguro, também, ter explicado e fornecido uma cópia deste documento ao participante. Informo que o estudo foi aprovado pelo CEP perante o qual o projeto foi apresentado e pela CONEP, quando pertinente. Comprometo-me a utilizar o material e os dados obtidos nesta pesquisa exclusivamente para as finalidades previstas neste documento ou conforme o consentimento dado pelo participante.

Data: ____/_____/_____.

_____

Prof. Dr. Thiago José Leonardi – Responsável pela pesquisa.

APÊNDICE C – TERMO DE ASSENTIMENTO LIVRE E ESCLARECIDO (TALE)

TERMO DE ASSENTIMENTO LIVRE E ESCLARECIDO (TALE)

Você está sendo convidado(a) a participar de uma pesquisa intitulada "Percursos de desenvolvimento do jovem esportista: análise multidimensional", a qual terá duração de dois anos, sob a responsabilidade de Thiago José Leonardi, professor da Escola de Educação Física, Fisioterapia e Dança (ESEFID) da Universidade Federal do Rio Grande do Sul (UFRGS). Dessa forma, pedimos que você leia (ou escute a leitura) este documento e esclareça suas dúvidas antes de consentir, com a sua assinatura ou oralmente, a participação neste estudo. Se você aceitar, receberá uma via deste Termo para que possa questionar sobre eventuais dúvidas que venham a surgir, a qualquer momento, se assim desejar.

Este estudo tem o objetivo, de maneira resumida, de caracterizar o quanto os jovens atletas estão aptos para aquilo que são hoje as exigências de formação esportiva, em particular do volume de treino e competição. O estudo produzirá informação sobre o estado de crescimento, informações psicológicas, nutricionais e desempenho físico e técnico-tático (vantagens) que serão devolvidas ao professor/treinador da equipe. Você e todos os demais participantes terão acesso aos resultados e ao conhecimento gerado a partir do estudo por meio da devolutiva dos resultados obtidos nas diferentes avaliações. As coletas deste estudo ocorrerão três vezes ao ano (início, meio e final da temporada esportiva), durante dois anos, com duração de três sessões de treino a cada avaliação. O procedimento que pretendemos realizar serão avaliações antropométricas (estatura, massa corporal, dobras cutâneas, diâmetro ósseo, perímetro de braço e coxa, além de avaliações em densitômetro por absorção de raios-X de dupla energia, conhecido como DXA, e ultrassom, os quais não apresentam riscos à sua saúde), avaliações de desempenho físico (teste de velocidade de 20 metros, teste de agilidade em zig-zag, uma prova de seis corridas de 35m com 10 segundos de intervalo, corrida vai-e-vem de 20 metros com e sem intervalos de recuperação, saltos, avaliação de força, potência, taxa de produção de força, em membros inferiores, com movimentos em cadeira extensora, flexora e agachamento e avaliação eletromiográfica), avaliação tático-técnica (jogo em campo reduzido com duração de 10 minutos, o qual será filmado para posterior análise), nutricionais (descrição dos alimentos ingeridos em um dia típico de treino, um dia atípico (final de semana) e dia de jogo) e aplicação de questionários. Por fim, para que possamos compreender o seu processo de treino, faremos controle dos conteúdos e da carga do treino, sendo este último realizado por meio de dispositivos GPS.

Você tem a garantia de que a sua identidade será mantida em sigilo e nenhuma informação será dada a outras pessoas que não façam parte da equipe de pesquisadores. Na divulgação dos resultados desse estudo, seu nome não será citado. As informações coletadas serão guardadas na instituição sede da presente pesquisa, sob cuidados do pesquisador principal, pelo período de cinco anos. Não haverá custos para tua participação neste estudo

Em caso de dúvidas sobre o estudo, você poderá entrar em contato com o pesquisador Thiago José Leonardi (Pesquisador Responsável) através dos seguintes contatos: Escola

Superior de Educação Física, Fisioterapia e Dança, Universidade Federal do Rio Grande do Sul – Rua Felizardo, 750, Jardim Botânico, CEP 90690-020, Porto Alegre, RS; Telefone: 51-3308-5858; E-mail: thiago.leonardi@ufrgs.br. Em caso de denúncias ou reclamações sobre sua participação e sobre questões éticas do estudo, você pode entrar em contato com o Comitê de Ética em Pesquisa (CEP) da UFRGS: Av. Paulo Gama, n. 110, Sala 321, Prédio Anexo 01 da Reitoria, Campus Centro, Porto Alegre/RS; Telefone: (51) 3308 3738; E-mail: etica@propesq.ufrgs.br.

Termo de autorização para o estudo

Tendo em vista os itens acima apresentados, eu, _____, de forma livre e esclarecida, manifesto meu assentimento em participar da pesquisa. Declaro que recebi cópia deste termo de consentimento, e autorizo a realização da pesquisa e a divulgação dos dados obtidos neste estudo.

_____

Assinatura do Participante da Pesquisa

Responsabilidade do Pesquisador:

Asseguro ter cumprido as exigências da resolução 466/2012 CNS/MS e complementares na elaboração do protocolo e na obtenção deste Termo de Assentimento Livre e Esclarecido. Asseguro, também, ter explicado e fornecido uma cópia deste documento ao participante. Informo que o estudo foi aprovado pelo CEP perante o qual o projeto foi apresentado e pela CONEP, quando pertinente. Comprometo-me a utilizar o material e os dados obtidos nesta pesquisa exclusivamente para as finalidades previstas neste documento ou conforme o consentimento dado pelo participante.

Data: ____/_____/_____.

_____

Prof. Dr. Thiago José Leonardi – Responsável pela pesquisa.

APÊNDICE D - ANAMNESE

Anamnese Clínica

Número do Participante Data da Avaliação: _____

Data de Nascimento:_____ Idade:_____ Sexo: ( )M ( )F

Profissão:_____ _____

Peso (kg):_____ Altura (cm):_____ IMC (peso/altura²): Classificação: _____

Profisssão:_____ ____

Esporte:_____ ____Posição:_____ _____Membro superior dominante: ( ) Direito ( ) Esquerdo;

Membro inferior dominante: ( ) Direito ( ) Esquerdo.

Questões Relacionadas à Saúde

Apresenta problema de saúde? Se sim, qual? (Descreva):

( ) Sim ( ) Não

_____ _____-

Fatores de risco:

Possui alguma destas condições?

( ) Doença cardiovascular ( ) Hipertensão arterial ( ) Diabetes ( ) Varizes ( ) Estresse ( ) Colesterol (LDL elevado; HDL baixo) ( ) Sobrepeso/obesidade ( ) Alcoolismo ( ) Tabagismo ( ) Outra:_____

Fatores Hereditários:

( ) Doença Cardiovascular: ( ) Parente (s) c/ menos de 60 nº: _____

( ) Hipertensão Arterial: ( ) Parente (s) c/ menos de 60 nº: _____

( ) Acidente Vascular Cerebral: ( ) Parente (s) c/ menos de 60 nº: _____

( ) Obesidade: ( ) Parente (s) c/ menos de 60 nº: _____

( ) Diabetes – ( )I, ( )II: ( ) Parente (s) c/ menos de 60 nº: _____

( ) Câncer: _____ ( ) Parente (s) c/ menos de 60 nº: _____

Utiliza medicação de uso contínuo? Se sim, qual? (Descreva)

( ) Sim ( ) Não

_____

_____

NÍVEL DE ATIVIDADE FÍSICA ESPORTIVA:

Frequência semanal:

( ) 0-1x ( ) 1-2x ( ) 2-3x
( ) 3-4x
( ) 4-5x ( )5-6x ( ) 6-7x

Duração semanal? (média de horas/semana)

( ) Nunca ( ) até 1h ( ) 1h-1h30min ( ) 1h30min a 2h ( ) 2h a 2h30min
( ) 2h30 a 3h ( ) 3h a 3h30min ( ) 3h30min a 4h ( ) 4h a 4h30min

( ) 4h30 a 5h ( ) Mais que 5h

Duração diária? (média de horas/dia)

( ) até 1h ( ) 1h-1h30min ( ) 1h30min a 2h ( ) 2h a 2h30min
( ) 2h30 a 3h ( ) 3h a 3h30min ( ) 3h30min a 4h ( ) 4h a 4h30
( ) 4h30 a 5h ( ) Mais que 5h

Intensidade?

( ) Leve ( ) Leve a moderada ( ) Moderada ( ) Moderada a intensa ( ) Intensa

Tempo de prática esportiva (anos):

( ) 0-1 ( ) 1-2 ( ) 2-3 ( ) 3-4 ( ) 4-5 ( ) 5-6

( ) 6-7 ( ) 7-8 ( ) 8-9 ( ) 9-10 ( ) Mais que 10 anos

Quantidade de campeonatos disputados (anualmente):

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7 ( ) 8

Municipal:___ Estadual:___ Nacional:___ Internacional:___

Tempo/duração de prática esportiva (anualmente):

( ) 0-1 meses ( ) 1-2 meses ( ) 2-3 meses ( ) 3-4 meses ( ) 4-5 meses ( ) 5-6 meses

( ) 6-7 meses ( ) 7-8 meses ( ) 8-9 meses ( ) 9-10 meses ( ) Mais que 10 meses

Realizam pré-temporada (duração em semanas)? ( ) Sim ( ) Não

( ) 0-1 ( ) 1-2 ( ) 2-3 ( ) 3-4 ( ) 4-5 ( ) 5-6 ( ) 6-7 ( ) 7-8 ( ) 8-9 ( ) 9-10

( ) 10-11 ( ) 11-12 ( ) Mais que 12 semanas ( ) Entre 12-16 semanas ( ) Mais que 16

Realiza aquecimento antes das partidas?

( ) Sim ( ) Não

Descreva brevemente:_____

_____

Realiza alongamento/relaxamento antes e/ou depois das partidas?

( ) Sim ( ) Não

Descreva brevemente:_____

Tipo de atividade realizada ao longo dos treinamentos (descreva):

( ) Atividade aeróbia:

_____

( ) Atividades de força muscular:

_____

( ) Atividade específica esportiva:

_____

( ) Atividade técnica/táctica:

_____

( ) Realiza atividades/exercícios físicos além da prática esportivas? Quais? Descreva:

_____
_____
_____

Frequência semanal:

( ) 0-1x ( ) 1-2x ( ) 2-3x
( ) 3-4x
( ) 4-5x ( )5-6x ( ) 6-7x

Duração diária? (horas/dias)

( ) até 1h ( ) 1h-1h30min ( ) 1h30min a 2h ( ) 2h a 2h30min
( ) 2h30 a 3h ( ) 3h a 3h30min ( ) 3h30min a 4h ( ) 4h a 4h30

Intensidade?

( ) Leve ( ) Leve a moderada ( ) Moderada ( ) Moderada a intensa ( ) Intensa

SISTEMA MÚSCULO-ESQUELÉTICO

Apresenta dores musculares atualmente? Se sim, onde? (Descreva) ( ) Não

_____
_____

_____
_____

Dores na coluna? Se sim, qual(is) da(s) opção(ões) abaixo? ( ) Não**;**

( ) Lombar ( ) Torácica ( ) Cervical

_____
_____

Dores nas articulações? Se sim, qual(is)? ( ) Não;

_____
_____

_____
_____

Histórico de lesão musculoesquelética:

Recente (últimos 24 meses/ 2 anos):

Coluna: ( ) Cervical ( ) Lombar ( ) Torácica ( ) Hérnia de disco

Muscular? ( ) Sim ( ) Não

Região:_____
_____

M. Inferior: ( ) Quadril ( ) Joelho ( ) Tornozelo ( ) Cabeça

Muscular? ( ) Sim ( ) Não

Região:_____
_____

M. Superior: ( ) Ombros ( ) Braço ( ) Cotovelo ( ) Antebraço ( ) Mãos/punhos

Muscular? ( ) Sim ( ) Não

Região:_____
_____

Tronco: ( ) Peitoral ( ) Abdominal

Muscular? ( ) Sim ( ) Não

Região:_____
_____

( ) **Outra região**:_____

Muscular?
Região:_____

Muscular?
Região:_____

Condição da lesão (ex: contato, sem contato, corrida, sprint, troca de direção, arremesso, chute, passe, golpe etc) (descreva para cada lesão):

_____
_____
_____
_____

_____

_____

Momento das lesões (ex: aquecimento, jogo, treino, competição, pré-jogo, pós-jogo, sem razão aparente, outro) (descreva para cada lesão):

_____
_____
_____

_____
_____

_____
_____

_____
_____

Estrutura (s) afetada (s):

( ) Músculos ( ) Tendões ( ) Articulação

( ) Ligamentos ( ) Meniscos ( ) Cartilagens

( ) Estrutura nervosa ( ) Pele ( ) Ossos ( ) Outra (s):_____

Necessidade de cirurgia? ( ) Sim ( ) Não

Região:_____
_____

Região:_____
_____

Região:_____
_____

Região:_____
_____

Período da cirurgia:

( ) Últimos 24 meses ( ) 18 meses ( ) 12 meses ( ) 6 meses ( ) 3 meses

Observações:_____
____

_____
_____

_____
_____

Tempo de inatividade física causada pela lesão (dias e/ou meses):

( ) 1-3 dias ( ) 3-7 ( ) 7-10 ( ) 10-15 ( ) 15-20 ( ) 20-25 ( ) 25-30 dias
( ) 1 a 1,5 meses ( ) 1,5 a 2 meses ( ) 2 a 2,5 meses ( ) 2,5 a 3 meses

( ) Entre 3 e 4 meses ( ) Entre 4 e 5 meses ( ) 5 a 6 meses ( ) Entre 6 e 9 meses

( ) Entre 8 e 10 meses ( ) Entre 10 e 12 meses

Histórico de lesão musculoesquelética (**período MAIOR que** 24 meses/ 2 anos):

Coluna: ( ) Cervical ( ) Lombar ( ) Torácica ( ) Hérnia de disco

Muscular? ( ) Sim ( ) Não

Região:_____
_____

M. Inferior: ( ) Quadril ( ) Joelho ( ) Tornozelo ( ) Cabeça

Muscular? ( ) Sim ( ) Não

Região:_____
_____

M. Superior: ( ) Ombros ( ) Braço ( ) Cotovelo ( ) Antebraço ( ) Mãos/punhos

Muscular? ( ) Sim ( ) Não

Região:_____
_____

Tronco: ( ) Peitoral ( ) Abdominal

Muscular? ( ) Sim ( ) Não

Região:_____
_____

( ) **Outra região**:_____

Muscular?
Região:_____

Muscular?
Região:_____

Condição da lesão (ex: contato, sem contato, corrida, sprint, arremesso, chute, golpe etc)

(descreva para cada lesão):

_____
_____
_____
_____

_____
_____

_____
_____

Momento das lesões (ex: aquecimento, jogo, treino, competição, pré-jogo, pós-jogo, sem razão aparente, outro) (descreva para cada lesão):

_____
_____
_____

_____
_____

_____
_____

_____
_____

Estrutura (s) afetada (s):

( ) Músculos ( ) Tendões ( ) Articulação

( ) Ligamentos ( ) Meniscos ( ) Cartilagens

( ) Estrutura nervosa ( ) Pele ( ) Ossos ( ) Outra (s):_____

Necessidade de cirurgia? ( ) Sim ( ) Não

Região:_____
_____

Região:_____
_____

Região:_____
_____

Região:_____
_____

Período da cirurgia:

( ) Últimos 24 meses ( ) 18 meses ( ) 12 meses ( ) 6 meses ( ) 3 meses

Observações:_____
____

_____
_____

_____
_____

HÁBITOS ALIMENTARES:

Café da manhã?

( ) Nunca ( ) Às vezes ( ) Sempre

Número de refeições diárias?

( ) 1 refeição ( ) 2 refeições ( ) 3 refeições ( ) 4 refeições ( ) 5 refeições

( ) 6 refeições ( ) 7 refeições ( ) 8 ou mais refeições

Consumo de álcool durante a semana?

( ) Nunca ( ) 1x/semana ( ) 2-3x/semana ( ) 4-7x/semana

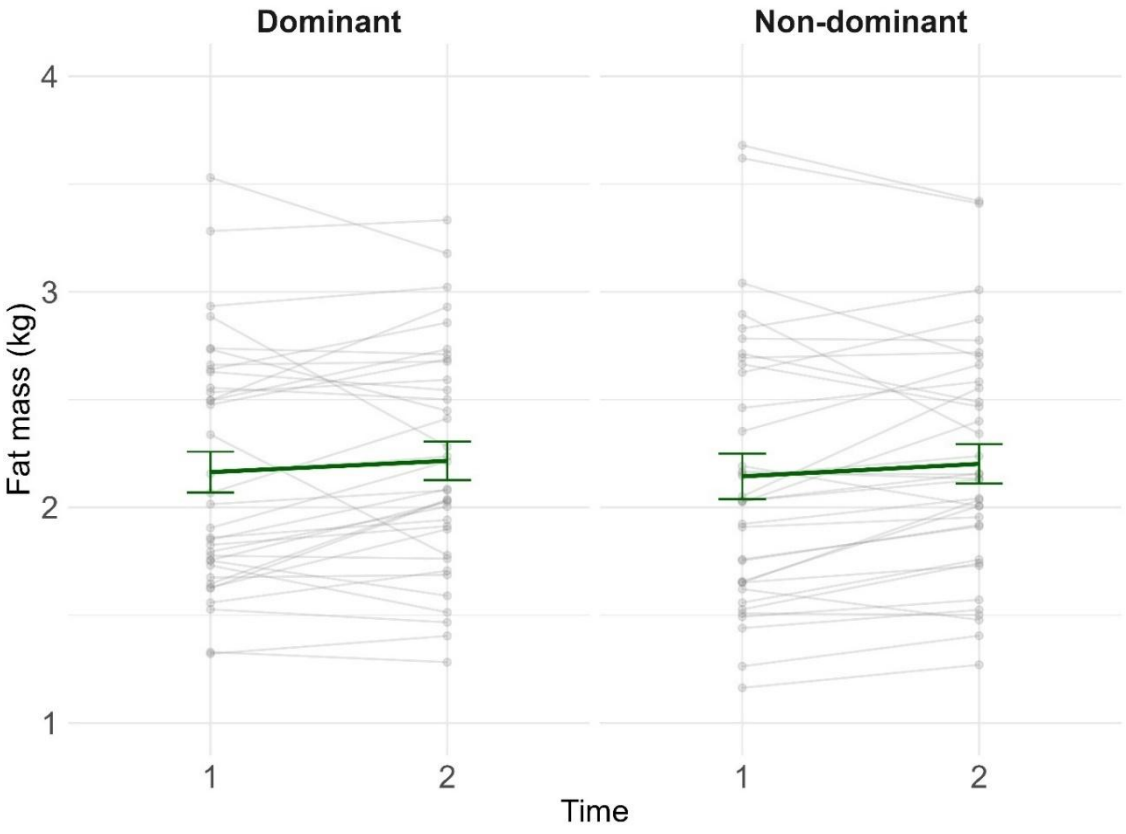
Encontra-se em dieta alimentar?

( ) Sim ( ) Não

APÊNDICE E - SUPPLEMENTARY FILES

Artigo 3:

Figure 10 – Fat mass



Artigo 3:

Table 3 - Changes across 12-weeks for peak torque and fatigue

	Fixed effects			Level 1 standard deviation	Level 2 standard deviation
	Intercept	Time	Lean mass		Intercept
Peak torque					
Dominant concentric knee extensor	2.63 (2.06 to 3.23)	0.03 (-0.00 to 0.06)	1.18 (0.91 to 1.44)	0.10 (0.08 to 0.13)	0.10 (0.06 to 0.14)
Non-dominant concentric knee extensor	3.18 (2.56 to 3.85)	0.03 (-0,01 to 0,06)	0.96 (0.65 to 1.23)	0.10 (0.07 to 0.12)	0.12 (0.08 to 0.17)
Dominant concentric knee flexor	1.95 (1.14 to 2.78)	0.03 (-0.01 to 0.07)	1.26 (0.88 to 1.62)	0.12 (0.09 to 0.16)	0.16 (0.11 to 0.22)
Non-dominant concentric knee flexor	1.93 (1.19 to 2.70)	0.04 (-0.02 to 0.09)	1.25 (0.90 to 1.59)	0.16 (0.12 to 0.21)	0.12 (0.04 to 0.19)
Dominant eccentric knee flexor	2.42 (1.48 to 3.36)	0.06 (0.02 to 0.11)	1.14 (0.71 to 1.57)	0.13 (0.10 to 0.17)	0.19 (0.13 to 0.25)
Non-dominant eccentric knee flexor	2.49 (1.68 to 3.33)	0.01 (-0.03 to 0.06)	1.11 (0.73 to 1.48)	0.14 (0.11 to 0.18)	0.16 (0.10 to 0.22)
Fatigue					
Dominant concentric knee extensor	-2,25 (-3.66 to –1.37)	0.06 (-0.05 to 0.16)	0.63 (0.09 to 1.15)	0.27 (0.22 to 0.34)	0.06 (0.00 to 0.17)
Non-dominant concentric knee extensor	-1,79 (-3.12 to –0,44)	0.14 (0.03 to 0.25)	0.28 (-0.35 to 0.89)	0.27 (0.20 to 0.37)	0.18 (0.02 to 0.31)
Dominant concentric knee flexor	-3.20 (-5.24 to –0.97)	0.19 (0.01 to 0.37)	0.98 (-0.03 to 1.92)	0.46 (0.34 to 0.60)	0.24 (0.02 to 0.48)
Non-dominant eccentric knee flexor	-2.46 (-3.64 to –1.23)	0.05 (-0.07 to 0.17)	0.63 (0.06 to 1.17)	0.31 (0.24 to 0.38)	0.10 (0.01 to 0.24)