UNIVERSIDADE FEDERAL DO PAMPA
DOUTORADO EM CIÊNCIAS FISIOLÓGICAS

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USO DE TESTES CLÍNICOS PARA AVALIAR VARIÁVEIS BIOMECÂNICAS RELACIONADAS COM O RISCO DE LESÃO DO LCA

Uruguaiana
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Tese de Doutorado apresentada ao Programa de Pós-graduação Multicêntrico em Ciências Fisiológicas da Universidade Federal do Pampa, como requisito para obtenção do título de Doutora em Ciências Fisiológicas.

Orientador: Prof. Dr. Felipe Pivetta Carpes

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Uruguaiana
2022

Ficha catalográfica elaborada automaticamente com os dados fornecidos
pelo(a) autor(a) através do Módulo de Biblioteca do
Sistema GURI (Gestão Unificada de Recursos Institucionais) .

S872u Stoelben, Karine Josibel Velasques
Uso de testes clínicos para avaliar variáveis biomecânicas relacionadas com o risco de lesão do LCA / Karine Josibel Velasques Stoelben.
141 p.

Tese(Doutorado)-- Universidade Federal do Pampa, DOUTORADO EM CIÊNCIAS FISIOLÓGICAS, 2022.
"Orientação: Felipe Pivetta Carpes".

1. Extremidade inferior. 2. Ligamento cruzado anterior. 3. Medicina esportiva. 4. Joelho. 5. Prevenção de lesão. I. Título.

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Área de concentração: Ciências Fisiológicas

Tese de doutorado defendida e aprovada em: 25 de março de 2022.

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Assinado eletronicamente por **Fábio Mícolis de Azevedo**, **Usuário Externo**, em 30/03/2022, às 13:54, conforme horário oficial de Brasília, de acordo com as normativas legais aplicáveis.

Assinado eletronicamente por **Luciana De Michelis Mendonça**, **Usuário Externo**, em 30/03/2022, às 14:49, conforme horário oficial de Brasília, de acordo com as normativas legais aplicáveis.

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DEDICATÓRIA

Dedico essa tese ao meu avô João Baptista Velasques (in memorian) por sempre incentivar os meus estudos e a busca por meus sonhos. Decido essa tese também aos meus pais, Isabel Cristina Velasques Stoelben e José Stoelben, pela educação que me deram e incentivo durante esses 11 anos e meio de estudos em nível superior. Por último, mas não menos importante, dedico essa tese aos participantes de pesquisa que fizeram ela ser possível e aos que participaram de outros projetos vinculados à tese que não puderam ser finalizados.

AGRADECIMENTOS

A ***mim***, agradeço por ter sido resiliente nesse período de formação e aprendido a equilibrar mais quanto aos limites de trabalho e descanso, sobre aproveitar mais o momento presente e viver. Foram anos de intenso aprendizado pessoal.

Ao ***Laboratório de Biomecânica*** da Universidade Federal de Santa Maria, minha eterna gratidão por ter abertos as portas para mim e me iniciado nesse meio acadêmico.

Ao ***Marcelo Duarte***, em especial, agradeço por ter me apresentado o laboratório e me mostrado a parte divertida das coletas de dados.

À ***Estele Caroline Welter Meereis***, por ter me acolhido e me orientado nas primeiras atividades de pesquisa.

À ***Priscila Goulart Padoin***, por ter me ensinado que é possível realizar os sonhos quanto a pesquisa e que não precisamos ter medo de contatar pessoas e ir atrás do que queremos, também por ter me guiado na construção do meu tema de pesquisa.

Ao professor ***Carlos Bolli Mota***, não tenho palavras que expressem corretamente a minha gratidão, o incentivo e ter acreditado na minha capacidade de realizar as coisas foram primordiais para que eu hoje aqui estivesse realizando meu sonho de defender meu doutorado. Não posso deixar de agradecer também por sempre me apoiar nas minhas "loucuras" e invenções, sem o teu apoio Bolli, elas teriam sido apenas devaneios. Além de sempre estar me orientando e auxiliando mesmo sem estar mais oficialmente me orientando. Também por sempre enxergar a personalidade de cada um e com maestria nos guiar. O senhor além de um grande amigo se tornou um pai e uma pessoa que eu posso confiar.

A todos ***colegas de LABIOMEC***, pela recepção, o convívio e que de algum modo estão presentes e contribuíram na minha história. Sempre tivemos um convívio como o de uma grande família.

À ***Universidade Federal do Pampa***, por ter aberto suas portas para mim e me oportunizar ter uma formação de excelência.

Ao ***Programa de Pós-Graduação Multicêntrico em Ciências Fisiológicas***, por ter me oportunizado cursar o curso de doutorado, além de oportunizar conhecer outras Universidades da rede do programa.

À ***Patrícia Altermann***, secretária do PPGMCF, por sempre estar disposta a auxiliar e resolver todas as burocracias. Foi ótimo ter te conhecido e convivido contigo nesse período.

Aos ***professores e professoras do PPGMCF***, pela convivência e aprendizados, especialmente na Comissão Local do Curso.

Aos meus ***colegas discentes do PPGMCF***, pela parceria, ajuda, troca de experiências e por me deixar representá-los junto ao programa.

Ao ***Conselho Nacional de Desenvolvimento Científico e Tecnológico*** pelo suporte financeiro.

Ao professor ***Paulo Roberto Pereira Santiago***, o preto, por ter me recebido na Universidade de São Paulo e me mostrado que sempre devemos acreditar em nós mesmos e trabalhar para conquistar nossos sonhos. Isso tudo sem perder o contato humano e fazer grandes amizades no percurso.

Aos amigos ***Rafael Fujita*** e ***Marina Villalba***, pelo convívio e amizade que construímos, além da parceria em trabalho.

Ao professor ***Matheus Gomes***, por ter aberto às portas do seu grupo e ter permitido construirmos um trabalho além de amizade e conhecimentos adquiridos.

Ao ***Grupo de Pesquisa em Neuromecânica Aplicada***, por ter me recebido e oportunizado o desenvolvimento de pesquisa, além de construção de amizades.

À ***Andressa Lemes Lemos***, pela parceria e amizade que construímos, as quais certamente perdurarão por muito tempo.

À ***Gabrielly Dalcanale Martins***, pela ajuda nas coletas e tabulação de dados e estar sempre disposta a ajudar e aprender.

À ***Inaê de Oliveira Marcelo***, ***Gabriel Palermo Del Rosso Barbosa***, por terem permitido que eu orientasse eles e construíssemos uma amizade ao longo do caminho. Além de toda ajuda nas coletas de dados.

À ***Milena Aguiar***, pela amizade, recepção e muitos abraços, além da rede de apoio e aprendizados.

À minha grande amiga ***Eliane Celina Guadagnin***, por toda ajuda e aprendizado na pesquisa e na vida. Obrigada por sempre compartilhar os momentos comigo e sempre podermos contar uma com a outra independentemente da distância.

Ao meu orientador professor ***Felipe Pivetta Carpes***, pela orientação e aprendizados. Especialmente por sempre oportunizar novas experiências, incentivar a realizar nosso objetivos e sonhos, e sempre estar disponível para ajudar. Faltam palavras para expressar minha gratidão por tudo que construímos nesses anos e por sempre respeitar minha opinião e ideias. Realmente a palavra orientador lhe serve muito bem, pois o senhor sempre guia os nossos passos nos mostrando o caminho e quais dificuldades termos que enfrentar.

Ao meu coorientador ***Evangelos Pappas***, pela longa caminhada de orientação e aprendizado. Especialmente por sempre enxergar o lado humano dos seus orientados e sempre acreditar e nos incentivar a realizar mesmo o que as vezes parece muito difícil. A sua bondade e sutileza na orientação deixa o trabalho mais leve, prazeroso e aumenta a motivação, sem perder o rigor.
Ao professor ***Marco Aurélio Vaz***, por me receber em seu laboratório e realizarmos uma colaboração de pesquisa. Não posso deixar de agradecer por todas as conversas e orientações sobre a ciência, mas principalmente sobre a vida, sua leveza e educação sempre me inspiraram.
Aos professores ***Jeam Marcel Jeremia*** e ***Matias Frohlich***, pelos aprendizados, conversas, amizade e parceria. Além da cooperação científica e auxilio no delineamento e coleta de dados.
À professora ***Michele Forgiarini Saccol***, pelo auxílio nas coletas de dados e por ser essa amiga que sempre podemos conversar e contar.
Ao professor ***André Gustavo Pereira de Andrade***, pelas conversas, debates e ajuda na análise de dados.
Aos professores ***Bruno Manfredini Baroni***, ***Fábio Mícolis de Azevedo*** e ***Luciana de Michelis Mendonça*** por serem parte da minha banca de avaliação na qualificação e na defesa do doutorado. Meu muito obrigada por todas contribuições e reflexões.
Aos ***participantes das pesquisas***, sem a participação voluntária de todos nada disso seria possível e teria sentido.
À ***Sociedade Brasileira de Biomecânica***, pelo apoio financeiro e por me receber dentro da sociedade.
À ***Internacional Society of Biomechanics***, pelo apoio financeiro.
Ao ***Latinx in Biomechanics***, por me receber na organização e comando dessa iniciativa. Além de me proporcionar fazer amigos e conhecer muitos pesquisadores. Não posso deixar de agradecer nominalmente ao ***Jonaz Moreno Jaramillo***, ***Lyndsey Trejo***, ***Rick Pimentel***, ***Heidi Fehr***, ***Ericber Jumenez Francisco***, ***Luis Nolasco*** e ***Jazmin Cruz*** por toda troca de conversas, aprendizado e amizade.
Aos meus amigos e amigas que de alguma forma me apoiaram e contribuíram para que eu chegasse até aqui.
A todos os ***professores*** que eu tive na minha vida, de alguma forma todos eles me trouxeram até aqui e me incentivaram.
Ao ***Jonatan Larrosa Carrasco***, por me apoiar em todos os momentos, por tornar esses últimos meses mais leves mesmo dentro de uma turbulência, por ter paciência comigo e me aceitar. Eu não passaria por esse momento tão feliz quanto podendo contar contigo e te ter ao meu lado.

À minha irmã ***Aline Velasques Stoelben***, por sempre acreditar no meu potencial e me incentivar.

Aos meus pais ***José Stoelben*** e ***Isabel Cristina Velasques Stoelben*** por sempre acreditarem em mim e me incentivarem mesmo muitas vezes tendo de abdicar de objetivos seus. Por sempre estarem do meu lado nos momentos ruins e bons. Por me educarem, mostrarem que eu posso alcançar qualquer objetivo que eu tiver e que eu sempre vou ter para onde voltar. Por seu apoio incondicional e amor, e por sempre um exemplo para mim.

À ***Deus***, por me permitir viver tudo isso e ser um abrigo em momentos bons e ruins.

“A menos que modifiquemos a nossa maneira de pensar, não seremos capazes de resolver os problemas causados pela forma como nos acostumamos a ver o mundo”.

Albert Einstein

ABSTRACT

Non-contact anterior cruciate ligament (ACL) injury affects thousands of individuals annually. The ACL injured individuals have a lower physical activity level and increased risk of developing degenerative disease and submit to arthroplasty surgery. The assessment of risk factors plays a crucial role in ACL injury prevention. However, screening risk factors often requires a highly instrumented laboratory, frequently less accessible and expensive. To provide the best choices for the assessment of ACL injury risk, scientists and sports medicine professionals make daily use of clinical tests. However, it remains unclear how clinical tests correspond to biomechanical outcomes of jump landing tasks in which ACL is often injured. This dissertation explores how clinical tests can be used to assess risk factors of ACL injury. We developed a cross-sectional study with male recreational athletes submitted to a battery of clinical tests followed by biomechanical assessment. The associations between clinical tests and biomechanics outcomes were investigated. Our main findings support important biomechanical variables during jump landing tasks being predicted by specific combinations of clinical tests. We also found that lateral step down (LSD) test can identify two groups of participants according to proximal and distal deviations. The groups' stratification differenced participants concerning hip kinematics and impact absorption, with worse performance in participants showing both proximal and distal deviations. Considering isometric strength asymmetries, we found only a poor association of hip strength asymmetry with clinical and biomechanical asymmetries, while hip adductor strength asymmetry predicted asymmetry in the triple hop test. In addition, asymmetry in the hop tests did not correspond to asymmetry in biomechanical outcomes related to quadriceps dominance theory. Asymmetry outcomes seems also to vary according to kinetics and kinematics variables. If using the “10% symmetry criteria”, asymmetry in single and crossover hop tests identified asymmetries in kinetics but not in kinematics of unilateral landings. We conclude that clinical tests can better predict biomechanical outcomes related to a risk of ACL injury in jump landing tasks when combined. We suggest that clinical test selection should consider the main risk factors, proximal or distal deviations, and individually assess preferred and non-preferred legs. Although this reveals an already expected complex scenario, it provides important directions for clinical assessment and can potentially help clinical decision-making.

Keywords: lower extremity; anterior cruciate ligament; sports medicine; knee; injury prevention.

RESUMO

Lesões de não-contato do ligamento cruzado anterior (LCA) afetam milhares de indivíduos anualmente. A lesão do LCA acarreta menor nível de atividade física e maior risco de desenvolver doenças degenerativas, e ser submetido a cirurgia e artroplastia. Avaliar fatores de risco é essencial para prevenção de lesão do LCA. Entretanto, isso requer um laboratório altamente instrumentalizado, o qual é frequentemente de menor acesso e de alto custo. Para fornecer melhores escolhas para a avaliação de fatores de risco, cientistas e profissionais do esporte usam diariamente os testes clínicos. Porém, há dúvida se resultados de testes clínicos correspondem a desfechos biomecânicos durante tarefas de salto e aterrissagem nas quais a lesão do LCA muitas vezes acontece. Esta tese explora como utilizar testes clínicos para avaliar fatores de risco de lesão de LCA. Em um estudo transversal com atletas recreacionais do sexo masculino submetidos a uma bateria de testes clínicos seguida de avaliação biomecânica, associações entre os testes clínicos e as variáveis biomecânicas foram investigadas. Nossos principais achados suportam a predição de variáveis biomecânicas importantes durante aterrissagem de saltos por uma combinação de testes clínicos. Também encontramos que o *lateral step down* pode identificar dois grupos de participantes de acordo com desvios proximais e distais, que diferem quanto a cinemática do quadril e absorção de impacto. Pior performance foi observada nos participantes que apresentaram ambos desvios proximais e distais. Também encontramos que assimetrias na força muscular isométrica de quadril e assimetrias em variáveis biomecânicas tem fraca associação, enquanto a força de adutores de quadril foi capaz de predizer a assimetria no *triple hop test*. Além disso, assimetria nos *hop* testes não corresponderam a assimetrias em variáveis biomecânicas relacionadas a teoria de dominância do quadríceps. Utilizando o critério de “10% de assimetria”, assimetrias no *single* e *crossover hop* teste identificaram assimetrias na cinética de aterrissagens unilaterais, mas não na cinemática. Concluímos que combinações específicas de testes clínicos podem predizer melhor as variáveis biomecânicas relacionadas a fatores de risco de lesão de LCA. Sugerimos que a seleção dos testes clínicos deve considerar os fatores de risco principais, desvios proximais e distais, e avaliar individualmente as pernas preferida e não preferida. Embora esse tenha se revelado um cenário complexo esperado, nossos resultados fornecem direções importantes para avaliação clínica com potencial para auxiliar a tomada de decisão clínica.

Palavras-chave: extremidade inferior; ligamento cruzado anterior, medicina esportiva, joelho, prevenção de lesão.

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A: SEBT anterior direction

Ab: hip abductor strength

Ab/Ad: hip abductor/adductor strength ratio

Ad: hip adductor strength

ANOVA: analysis of variance

ASY: asymmetric group

BMI: body mass index

C: crossover hop test

CAs: asymmetry index of crossover hop test

COM: combined deviations group

Ext: knee extensor strength

FANOVA: functional analysis of variance

Flex/Ext: knee flexor/extensor strength ratio

GRF: ground reaction force

GRFv: vertical component of ground reaction force

L: Lunge

LE: lower extremity

LSD: lateral step down

PL: SEBT posterolateral direction

PMAs: asymmetry index of SEBT posteromedial direction

PRO: proximal deviations group

S: single hop test

SAs: asymmetry index of single hop test

SEBT: star excursion balance test

ST: SEBT total score

STAs: asymmetry index of SEBT total score

SYM: symmetric group

T: triple hop test

TAs: asymmetry index of triple hop test

SUMÁRIO

1 CHAPTER ONE - INTRODUCTION

Clinical assessments are routinely part of physiotherapists and coaches as part of the strategies aiming at injury risk screening, performance monitoring, assessment of rehabilitation status, and establishment of criteria for a decision on returning to sports after an injury. Regarding anterior cruciate ligament (ACL) injuries, there is a need for biomechanical assessments to identify the most important risk factors. However, biomechanical laboratories assessments are expensive, time-consuming and less accessible. Therefore, investigating the relationship between outcomes of clinical tests and those biomechanics variables related to an injury risk can be useful to design better screening tools, evaluation protocols and to provide more clear support for clinical and training decisions. This dissertation is based on a research project developed to elucidate applications of clinical tests for screening the risk of ACL injury. Due to the COVID pandemic, part of the initial goals was adapted. The outcomes of this dissertation are organized into nine chapters:

- <u>Chapter one</u>: aims to introduce this dissertation and explains how the document is organized;
- <u>Chapter two</u>: aims to state the research problem addressed in this dissertation;
- <u>Chapter three</u>: presents the methods applied in the project developed;
- <u>Chapters five to eight</u>: present the results. We divided these chapters according to the different specific aims of the research to clarify details of data analysis and results.
- <u>Chapter nine</u>: presents the discussion organized in sections related to each specific purpose, reports the limitations we identified and states our conclusions.

As graduation is not just about research projects, there is a final topic describing important activities developed during these four years of Ph.D. formation.

Additional sections are included at the end of the document reporting documents including ethical approval, appendixes with relevant information, and the list of references.

2 CHAPTER TWO – STATEMENT OF THE PROBLEM

In this chapter, we present a scoping review of the dissertation subject. The articles included were gathered from Pubmed database after a search using the keywords: "ACL injury", "injury prevention", "risk factors of ACL injury", "dominance theories", "leg asymmetry", "biomechanical assessment", "drop jump", "drop landing", "clinical tests", "lunge", "star excursion balance test", "lateral step down", "hop tests", "isometric strength", "knee strength", and "hip strength". Keywords adaptations were performed according to papers' keywords, and searches on papers' bibliographies were made. The summary of key topics related to dissertation purposes was made into three sessions presented below.

2.1 Knee function

The knee joint plays a fundamental role in loading absorption during daily life activities and sports (KHAN; KHAN; USMAN, 2017). Knee plays an important contribution to lower extremity performance in jumping tasks, mainly during landing phases (KOTSIFAKI; KORAKAKIS; GRAHAM-SMITH; SIDERIS *et al.*, 2021). Flexion-extension is the knee movement with a larger range of motion, but the knee can also perform internal-external rotation when flexed, which leads this joint to have a very significant role, especially in athletic activities that require pivoting (PAPPAS; ZAMPELI; XERGIA; GEORGOULIS, 2013b). Joint stabilization during these tasks is crucial, and for the knee, it relies on ligaments very significantly.

The ACL is the head of knee stabilization (LEYS; SALMON; WALLER; LINKLATER *et al.*, 2012; MOHAMMADI; SALAVATI; AKHBARI; MAZAHERI *et al.*, 2012; PAPPAS; ZAMPELI; XERGIA; GEORGOULIS, 2013b) acting preventing anterior tibial translation and guiding axial rotation during flexion and extension movements (PAPPAS; ZAMPELI; XERGIA; GEORGOULIS, 2013b). An abundant elastic system in ACL allows withstanding multiaxial stresses and varying tensile strains (DUTHON; BAREA; ABRASSART; FASEL *et al.*, 2006). In addition, ACL contributes to control of force and movement by providing afferent feedback, which can be illustrated by its contribution to the exertion of maximal quadriceps strength (KONISHI; SUZUKI; HIROSE; FUKUBAYASHI, 2003). As a result, the tear of ACL impairs substantially the lower extremity movement production and regulation in addition to specific knee joint functionality.

The annual incidence of ACL tears reaches 68.6 per 100,000 people among general population of the USA, being higher among men (81.7 per 100,000) than women (55.3 per 100,000) (SANDERS; MARADIT KREMERS; BRYAN; LARSON *et al.*, 2016). In Brazil, the number of ACL reconstructions increased by 64% between 2008 and 2014, with 82% of procedures in men (LOPES; SIMIC; PAPPAS, 2016). History of ACL injury increases by eight times the odds of developing a degenerative joint disease, including early onset of osteoarthritis (SNOEKER; TURKIEWICZ; MAGNUSSON; FROBELL *et al.*, 2019), and by seven times the odds of total knee replacement (KHAN; ALVAND; PRIETO-ALHAMBRA; CULLIFORD *et al.*, 2019). This injury may also lead to a sedentary lifestyle among recreational athletes, which increases the risk for other musculoskeletal and cardiovascular problems (DE OLIVEIRA; ROY; PAPPAS, 2020). Return to some form of sport after an ACL tear occurs in 81% of injured people, and return to competitive sport occurs in 55% of athletes (ARDERN; TAYLOR; FELLER; WEBSTER, 2014). It is also important to note that ACL may re-injure in 1 out of 4 of those previously injured (WIGGINS; GRANDHI; SCHNEIDER; STANFIELD *et al.*, 2016). It clearly justifies the need for effective prevention of an ACL injury, which involves the early detection of risk factors, a process that remains largely elusive at a wide scale.

2.2 Biomechanics characteristics in knee ACL injury

The ACL injury occurs by two principal mechanisms: contact and non-contact (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020). In this dissertation, we address the non-contact mechanism and its related factors. Around 70-90% of ACL injuries occur by a non-contact mechanism involving no direct contact at the time of tear (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020; JOHNSTON; MANDELBAUM; SCHUB; RODEO *et al.*, 2018). The non-contact ACL injury happens most at one-leg loading during cutting, change of direction, and landing tasks (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020; OLSEN; MYKLEBUST; ENGEBRETSEN; BAHR, 2004). However, the assessment of the effectiveness of injury prevention protocols (LOPES; SIMIC; MYER; FORD *et al.*, 2018) and predictions of ACL injury (LEPPANEN; PASANEN; KROSSHAUG; KANNUS *et al.*, 2017; LEPPANEN; PASANEN; KUJALA; VASANKARI *et al.*, 2017) predominantly considers bilateral loading.

In terms of joint position during a non-contact ACL injury, there are different patterns: flexion-valgus-external rotation movement, flexion-varus-internal rotation loading, forced external rotation, or hyperextension (DEEHAN; CAWSTON, 2005). A combination of trunk ipsilateral tilt and rotation towards the uninjured side when the injury happens is observed for more than 80% of the cases (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020). Rapid valgus development from 12 to 40 milliseconds after initial contact with the ground suggests that valgus loading is a key factor in the ACL injury mechanism, and the low flexion angle observed suggests that a quadriceps drawer mechanism may also contribute to ACL injury (KOGA; NAKAMAE; SHIMA; IWASA *et al.*, 2010).

Despite the injury happening very early in the landing phase, which suggests a relationship between force and load absorption, there are several biomechanical characteristics involved in the mechanisms for an ACL injury. It includes excessive knee valgus, poor trunk control, excessive quadriceps force, and leg asymmetries (PAPPAS; ZAMPELI; XERGIA; GEORGOULIS, 2013a). Biomechanical risk factors can be divided into four dominance theories, named ligament, quadriceps, trunk, and leg dominance theories (HEWETT; FORD; HOOGENBOOM; MYER, 2010). The ligament dominance theory is related to high amounts of force absorption by ligaments and joints instead of muscles, such as when the knee moves into valgus and the femur moves into adduction and internal rotation (HEWETT; FORD; HOOGENBOOM; MYER, 2010). The quadriceps dominance theory refers to an over utilization of the quadriceps muscles compared to the hamstrings (HEWETT; FORD; HOOGENBOOM; MYER, 2010). The trunk dominance theory is defined as the inability to movement control of the trunk. Imbalance in side-to-side symmetry of the lower extremities is referred to as leg dominance theory (HEWETT; FORD; HOOGENBOOM; MYER, 2010). Video analyses of ACL injuries support these four theories (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020; HEWETT; TORG; BODEN, 2009; STUELCKEN; MELLIFONT; GORMAN; SAYERS, 2016). These theories may not work alone, as it was identified that among young athletes, there can be observed a combination of quadriceps and leg dominances, followed by a combination of trunk and leg dominances, and finally the presence of ligament dominance alone (PAPPAS; SHIYKO; FORD; MYER *et al.*, 2016). The dominance theories profiles can be used to guide the development of quick and easy tests that categorize athletes and subsequently can be useful to prescribe injury prevention programs more effectively and efficiently than the current generic ones (PAPPAS; SHIYKO; FORD; MYER *et al.*, 2016).

The evaluation and monitoring of these risk factors require expensive, time-consuming and complex biomechanical laboratory tests. On the other hand, clinical assessments are traditionally used on return to sport (SIUPSINSKAS; GARBENYTE-APOLINSKIENE; SALATKAITE; GUDAS *et al.*, 2019; WEBSTER; HEWETT, 2019), but can potentially be also used for injury prevention, helping to identify risk factors and participants' stratification in different groups. The most common clinical tests are the hop tests (single, triple, crossover, and 6-m timed hop) (WEBSTER; HEWETT, 2019). Furthermore, the lateral step down (LSD) and star excursion balance test (SEBT) are often used to provide an overview of the quality of movement control (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019; SIUPSINSKAS; GARBENYTE-APOLINSKIENE; SALATKAITE; GUDAS *et al.*, 2019), while the lunge test is considered important in the management of joint load during bilateral drop-landings (HOWE; BAMPOURAS; NORTH; WALDRON, 2019).

A relationship between clinical (field) and biomechanical (laboratory) tests has been found after ACL injury (XERGIA; PAPPAS; GEORGOULIS, 2015), and benefit the monitoring of responses to training programs aiming at injury prevention without submitting the athlete to biomechanical tests (SIUPSINSKAS; GARBENYTE-APOLINSKIENE; SALATKAITE; GUDAS *et al.*, 2019). However, it remains unclear whether and which biomechanical characteristics of movement could be predicted by clinical tests commonly applied for prevention assessments in the sports environment. There is evidence of biomechanical outcomes predicting key biomechanical outcomes related to ACL strain (HEWETT; WEBSTER; HURD, 2019; UENO; NAVACCHIA; DICESARE; FORD *et al.*, 2020), but identifying which accessible, low-cost clinical tools can identify those at risk for future first injury is essential for developing injury prevention programs at a population level.

2.3 Clinical tests as potential tools for screening injury risk

Clinical tests that are used in the routine of training and rehabilitation provide reproducible measures to assess activity limitation and restrictions that may compromises stability and movement coordination (LOGERSTEDT; SNYDER-MACKLER; RITTER; AXE *et al.*, 2010). Although several studies evaluated protocols for clinical assessments of the knee, evidence for the measurement quality of these clinical tests is limited and conflicting (HARRISON; YORGEY; CSIERNIK; VOGLER *et al.*, 2017). While one single test may provide limited information concerning an injury resultant of multifactorial factors, the combination of clinical tests was associated with lower extremity injuries in elite athletes. Imperfect functional movement patterns and poor jump-landing biomechanics during pre-season screening were associated with lower extremity injuries (SIUPSINSKAS; GARBENYTE-APOLINSKIENE; SALATKAITE; GUDAS *et al.*, 2019). However, it is unclear what risk factors can be predicted by functional tests. Despite that, it is plausible to consider that functional tests can predict some of those biomechanics characteristics considered as risk factors for an injury such as the knee ACL tear. Lunge test is a weight-bearing test measuring ankle dorsiflexion range of movement (LIMA; FERREIRA; DE PAULA LIMA; BEZERRA *et al.*, 2018). The test consists in measuring the distance from big toe to wall (BENNELL; TALBOT; WAJSWELNER; TECHOVANICH *et al.*, 1998) or leg angle performed by inclinometer, and both measures are valid (HALL; DOCHERTY, 2017). Ankle dorsiflexion during the lunge is a more sensitive measure for identifying those at risk for high-risk movement patterns compared with non-weight bearing passive-ankle dorsiflexion measures (DILL; BEGALLE; FRANK; ZINDER *et al.*, 2014). Individuals with limited dorsiflexion displayed less knee and ankle sagittal plane displacement as well as smaller peak knee flexion angles during squatting (DILL; BEGALLE; FRANK; ZINDER *et al.*, 2014) and jumping tasks (HOWE; BAMPOURAS; NORTH; WALDRON, 2019). Despite the lunge test identifying asymmetries in dorsiflexion, the relation with injury risk needs to be clarified (HOCH; MCKEON, 2011).

The SEBT is a test of dynamic balance broadly used for assessment of healthy individuals and those with a history of lower extremity injury in research and clinical settings (ELTOUKHY; KUENZE; OH; WOOTEN *et al.*, 2017). Trunk and hip muscle activations are direction-dependent during the SEBT performance (BHANOT; KAUR; BRODY; BRIDGES *et al.*, 2019). Anterior direction elicits a higher level of activation of gluteus medius, and contra and ipsilateral rectus abdominis, while posterolateral direction elicits recruitment of ipsilateral erector spinae, gluteus medius and contralateral external oblique, and posteromedial direction of gluteus medius, contralateral external oblique, contralateral erector spinae (BHANOT; KAUR; BRODY; BRIDGES *et al.*, 2019). Smaller hip flexion and greater knee flexion were associated with greater anterior reach in SEBT (PINHEIRO; OCARINO; BITTENCOURT; SOUZA *et al.*, 2019). In addition, greater hip flexion was associated with greater posteromedial reach and greater knee flexion was associated with greater posterolateral reach (PINHEIRO; OCARINO; BITTENCOURT; SOUZA *et al.*, 2019). There is strong evidence that the modified 3-directions SEBT (anterior, posteromedial, and posterolateral) can predict injury in lower extremity (HEGEDUS; MCDONOUGH; BLEAKLEY; BAXTER *et al.*, 2015). Both a composed reach score difference of less than 94% and an anterior reach difference of 4 cm or greater are associated with increased injury risk (PLISKY; RAUH; KAMINSKI; UNDERWOOD, 2006). A reduced hip internal rotation, knee flexion, and trunk rotation in the supporting leg during the SEBT might be considered as a risk factor for a non-contact ACL injury (UEBAYASHI; AKASAKA; TAMURA; OTSUDO *et al.*, 2019). A higher probability of a non-contact injury was also reported among participants with increased side-to-side asymmetry in the anterior direction of the SEBT (STIFFLER; BELL; SANFILIPPO; HETZEL *et al.*, 2017).

The LSD is a clinical test to assess movement quality being primarily used in healthy individuals (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). The LSD is easy to perform in a clinical environment (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). It assesses arm strategy, trunk and pelvic alignment, knee position, and steady stance during unilateral step down movements (RABIN; KOZOL; MORAN; EFERGAN *et al.*, 2014). Pelvis horizontal plane loss of movement control and knee medialization are the most frequent compensations identified by the LSD (RABIN; KOZOL; MORAN; EFERGAN *et al.*, 2014). A poor performance in LSD is associated with lower knee extension and hip external rotation strength (RABIN; KOZOL; MORAN; EFERGAN *et al.*, 2014), and with increased hip adduction and internal rotation (MOSTAED; WERNER; BARRIOS, 2018). The activation of hip abductors and adductors to stabilize the pelvis seems crucial to control step down movement (GOTTSCHALL; OKITA; SHEEHAN, 2012). Worse quality of movement was associated with deficits in hip external rotation and knee extension strength as well as ankle dorsiflexion range of motion (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). In this regard, LSD scores improve after strengthening of hip and trunk muscles (ARAUJO; SOUZA; CARVALHAIS; CRUZ *et al.*, 2017), which supports an important role of these muscles in the performance of the task. Regarding movement impairments, the LSD identifies the tasks with the highest sensitivity to detect the kinematic differences in individuals with and without patellofemoral pain (LOPES FERREIRA; BARTON; DELGADO BORGES; DOS ANJOS RABELO *et al.*, 2019)

There are important tests involving a significant amount of movement part of clinical testing routine. It is the case of the s ingle, triple, and crossover hop tests for distance, the hop tests more often used in research and clinical environment (HEGEDUS; MCDONOUGH; BLEAKLEY; COOK *et al.*, 2015). The maximal reach distance is assessed for one hop in the single leg hop, three hops in sequence in the triple leg hop, and three hops in sequence crossing sides in the crossover hop (PEEBLES; RENNER; MILLER; MOSKAL *et al.*, 2019). Hop tests performance, in general, will fail to predict self-reported functional outcomes (HEGEDUS; MCDONOUGH; BLEAKLEY; COOK *et al.*, 2015). The ability of any hop test battery to identify athletes at risk for ACL re-injury has not been established, nor has the ability of hop testing to predict which patients will be able to return to their previous level of activity, or which will have higher subjective reported knee function (LOSCIALE; BULLOCK; CROMWELL;

LEDBETTER *et al.*, 2020). On the other hand, single hop differentiates between a normal and not normal knee between an ACL-repaired and the uninvolved knee (AUGUSTSSON; THOMEE; KARLSSON, 2004), ACL-repaired and healthy matched controls knee (MYER; SCHMITT; BRENT; FORD *et al.*, 2011), and ACL-deficient and healthy matched controls knee (TEGNER; LYSHOLM; LYSHOLM; GILLQUIST, 1986). Triple hop test can identify those participants with a high-risk profile of ACL injury (PATERNO; HUANG; THOMAS; HEWETT *et al.*, 2017). However, single and triple hop tests did not distinguish between patients who did and did not have a second ACL injury (WEBSTER; FELLER, 2019). Finally, the crossover hop test can detect differences in the surgically repaired knee and the unaffected knee and the changes throughout the rehabilitation (BJORKLUND; ANDERSSON; DALEN, 2009), but it is not sensitive enough to detect abnormal limb symmetry in an ACL-deficient population (NOYES; BARBER; MANGINE, 1991).

All the functional tests will involve force capacity, but in addition to them, measurement of muscle strength for the different muscle groups producing joint motion is also important. Muscle strength assessment is a fundamental component of physical examination, especially when it comes to injury risk screening. The hand-held dynamometer is a clinically viable alternative associated with gold standards measures. Knee and hip strength are often assessed during pre-season, following rehabilitation and return to sport criteria. Poor hip strength has been associated with a higher risk of developing knee injuries (KHAYAMBASHI; GHODDOSI; STRAUB; POWERS, 2016) and is related to long-term adaptations after injury and risk of re-injury (VANNATTA; KERNOZEK, 2021). However, quadriceps, hamstrings, and hip abductors strength were not associated/predictors of knee valgus during bilateral drop jump (NILSTAD; KROSSHAUG; MOK; BAHR *et al.*, 2015). Additionally, no differences were found between injured and uninjured athletes (STEFFEN; NILSTAD; KRISTIANSLUND; MYKLEBUST *et al.*, 2016). In dynamic maneuvers, there will need more than strength to better performance, but we cannot exclude these important strength outcomes from screening assessments. We need better understand the application of strength measures in the assessment of risk factors of ACL injury and its relationship with key biomechanical outcomes that predict injury. Strength and movement patterns in the performance of clinical tests could allow stratifying individuals, especially when it comes to injury risk during sports activities. Alterations in movement kinetics and kinematics during landings can increase the risk of injuries in sports like floorball and basketball (LEPPANEN; PASANEN; KUJALA; VASANKARI *et al.*, 2017), and improving clinical tests can enhance the application of clinical tests help guide their use.

2.4 Purposes

- To identify the capacity of clinical tests commonly employed in sports physiotherapy to predict biomechanical outcomes during unilateral jump landing tasks associated with risk factors for an ACL injury.
- To determine the capacity of clinical tests commonly employed in sports physiotherapy to predict biomechanical outcomes associated with ACL injury during the performance of bilateral jump landing tasks.
- To investigate whether individuals with proximal deviation only (frontal pelvis drop down) present 3D biomechanical differences during landing from those showing combined proximal and distal (frontal pelvis drop down and medial knee displacement to 2nd toe) deviations during the LSD test performance.
- To determine whether hip strength asymmetry predicts asymmetries in clinical and biomechanical outcomes in recreational male athletes.
- To identify whether asymmetries in hop tests elucidate differences in key biomechanical outcomes related to knee injury risk during unilateral landings in male recreational athletes.

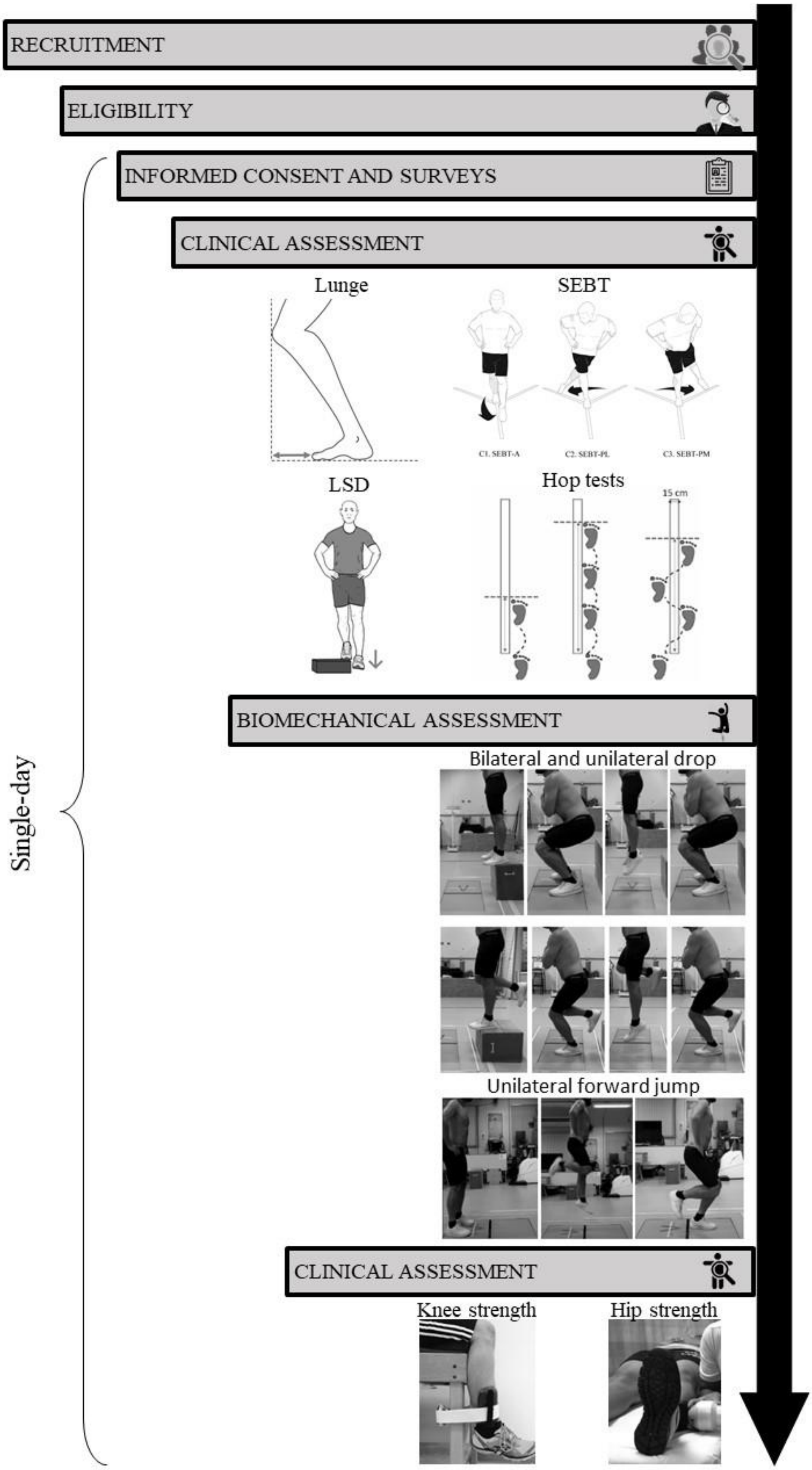
3 CHAPTER THREE - METHODS

The current chapter describes the common methodology regarding the experimental design, participants' eligibility criteria, detailed experimental procedures, and methods to develop the different experiments presented in this dissertation.

3.1 Experimental design

This research was a cross-sectional study in which recreational male athletes were submitted to a battery of clinical tests (lunge test, star excursion balance test, lateral step down and hop tests) and performed jump landing tasks (bilateral and unilateral drop jumps, and unilateral forward jump) while 3D kinematics and kinetics were acquired. All assessments were performed in a one-day visit to the laboratory. Figure 1 provides a schematic representation of the procedures composing the experimental design.

Figure 1 – Experimental design.



LSD: lateral step down; SEBT: star excursion balance test.
Source: by the author.

3.2 Participants

Participants were recruited by convenience from the local community through dissemination in social media and the university campus in January, February, August, and September of 2019. Participants signed a consent form to participate in the study. The local institutional ethics committee approved this study (protocol number: 96793518.3.0000.5323; Annex 1) and all procedures complied with the declaration of Helsinki.

Participants were men between 18 and 30 years old, recreational athletes (self-reported as enrolled with practice of some sport-related activity, not needed to be regularly). They had to be free of acute lower extremity injuries at least for the past six months, with no history of any surgery or ligament/tendon ruptures in the lower extremity or any neurological or musculoskeletal condition that could impair jump performance. Individuals with a body mass index greater than 35 kg/m^2 and those unable to complete the tests were excluded.

3.3 Procedures

Data collection followed the order of items:

1. *Surveys*: Demographic data collected included name, age, questions about physical activity status and previous injury;
2. *Leg preference to kick a ball*: participants were asked which leg they would choose to kick a ball with accuracy;
3. *Physical activity level*: the Tegner scale was used to determine physical activity level from physical activities reported in anamnesis;
4. *Knee function*: the self-reported Lysholm scale was applied (PECCIN; CICONELLI; COHEN, 2006);
5. *Lower extremity function*: the self-reported Lower Extremity Functional Scale was used (BINKLEY; STRATFORD; LOTT; RIDDLE, 1999);
6. *Clinical assessments*: the lunge, modified SEBT, LSD, and hop tests (single, triple and crossover) were performed;
7. *Biomechanical assessments*: participants performed bilateral and unilateral drop jumps and unilateral forward jumps for 3D kinematics and kinetics data collection;
8. *Clinical assessments*: knee and hip isometric strength were measured using hand-held dynamometry.

All procedures were conducted at the Laboratory of Neuromechanics from Universidade Federal do Pampa in a room with temperature controlled between 20 and 24º C. An interval between tests was allowed according to the participants' request and standardized protocols cited below.

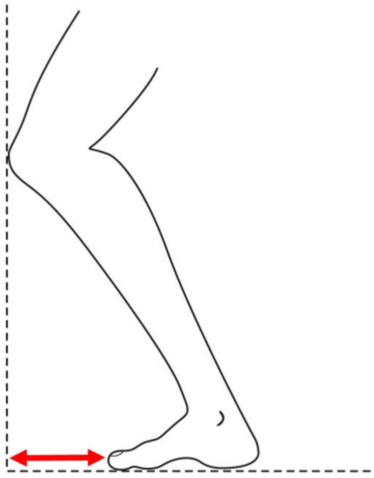
3.4 Clinical tests

Clinical tests were performed in the following order: lunge test, SEBT, LSD and hop tests (single leg hop, triple leg hop, and crossover hop). The non-preferred leg was tested first, except for strength measurements.

3.4.1 Lunge test

The distance from the big toe to the wall was measured in the lunge test (BENNELL; TALBOT; WAJSWELNER; TECHOVANICH *et al.*, 1998). The participants were barefoot and instructed to place one foot on a plane surface and align the big toe to a tape measure placed perpendicular to the wall. The foot was placed 10 cm from the wall. The participants were requested to move the knee toward the wall, bending the knee while maintaining the heel in contact with the ground (Figure 2). The non-tested foot served to assist with balance. Up to two familiarization trials were allowed and then the measure started. Foot position was adjusted by 1 cm for every attempt until the highest distance from the wall was achieved without losing heel contact.

Figure 2 – Lunge test.

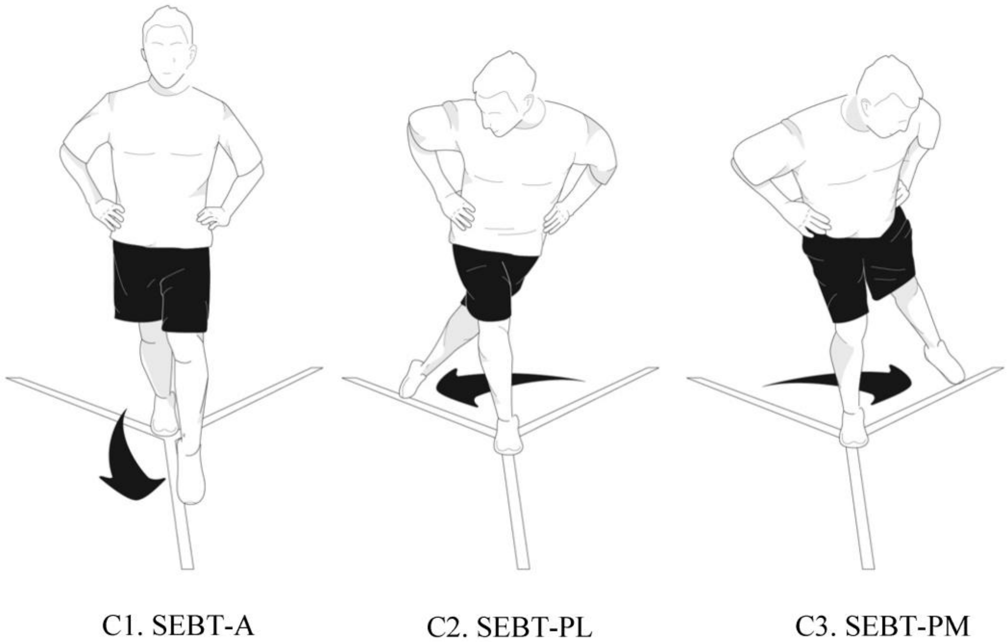


Source: by the author.

3.4.2 Modified star excursion balance test (SEBT)

The maximal reach distance was measured for anterior, posteromedial and posterolateral directions of the modified SEBT (STIFFLER; SANFILIPPO; BROOKS; HEIDERSCHEIT, 2015). Participants were instructed to stand on one leg, barefoot (tested leg), with the most distal aspect of the great toe at the origin line and the second and third toes between a line perpendicular to the origin. The non-tested leg reached for distance in each direction while the tested leg maintained balance. For a valid trial, the hands needed to stand on hips, stance foot must not lift or move, and the participants should not transfer weight to the reaching foot or lose balance at any point during the test. The test procedures were explained and demonstrated for each participant. Then, participants performed four practice trials for each direction with each leg and, after 2 min rest, performed three valid trials. Directions were randomized by balanced random list generation using an online resource (http://www.randomization.com). The highest value for each direction was considered for analysis. SEBT results were normalized to the participant's leg length, and asymmetry indexes were estimated using the equation [(preferred leg/non-preferred leg)*100].

Figure 3 – Directions of star excursion balance test.



SEBT: star excursion balance test; SEBT-A: anterior direction; SEBT-PL: posterolateral direction; SEBT-PM: posteromedial direction.
Source: adapted from Rodrigo et al. (RODRIGO; ALVES; RIVERA, 2020).

3.4.3 Lateral step down test (LSD)

The total score was assessed during LSD (RABIN; KOZOL; MORAN; EFERGAN *et al.*, 2014). A score between 0 to 7 (lower values mean better performance) was obtained considering the sum of five criteria (see Table 1 for further details). Participants were instructed to stand barefoot on one leg on a step (tested leg) and slowly lower the body until the contralateral heel touched the ground, without transferring weight, and return to the start position (Figure 4). Five repetitions were requested in sequence. The second toe of the tested leg was aligned with tape placed onto the step. Participants were cued to maintain the best upright alignment of the body. The step height ranged between 15 and 25 cm, which was determined based on participant individual height. Participants shorter than 165 cm used a 15-cm step, those with a height between 165 and 185 cm used a 20-cm step, and participants taller than 186 cm used a 25-cm step. Verbal instruction, visual demonstration, and at least 1 test practice trial (5 repetitions) were given before the test trial started. Skin markers were bilaterally attached to the anatomical reference over the anterior superior spine iliac and tibial tuberosities to serve as a visual reference. An experienced physiotherapist was positioned ~3 m apart from the clinical assessment step.

Figure 4 – Lateral step down execution.

Source: adapted from workoutsprograms.com.

Table 1 – Lateral step down test assessment criteria.

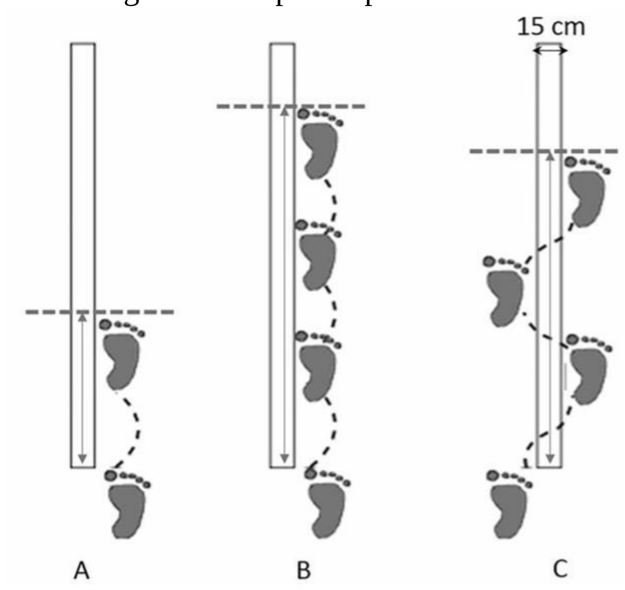
Criteria	Interpretation	Score
Arm strategy	Removal hand from waist	+1
Trunk alignment	Leaning in any direction	+1
Pelvic plane	Loss of horizontal plane	+1
Knee position	Tibial tuberosity medial to second toe	+1
	Tibial tuberosity medial to foot medial border	+2
Steady stance	Load weight onto non-tested leg	+1

Source: by the author.

3.4.4 Hop tests

The maximal reach distances for the single leg hop, triple leg hop, and crossover hop were measured (PEEBLES; RENNER; MILLER; MOSKAL *et al.*, 2019). Each hop test was completed with both legs independently and in the same order (first the single, and then the triple and crossover). Participants wore their athletic footwear. Two tape measures of 15cm width were placed apart on the floor. The initial position in reference to the tape measure was standardized for all participants, with the heel positioned over a mark on the tape. During the single leg hop test, participants were instructed to hop forward as far as possible while taking off and landing on the same foot (Figure 5A). Participants jumped three consecutive times on the same leg for the triple hop test without pausing between hops (Figure 5B).

Figure 5 – Hop tests performance.



A: single leg hop; B: triple leg hop; C: crossover hop.
Source: Adapted from Rambaud et al. (2017)

Similarly, participants hopped three consecutive times for the crossover hop test without pausing; however, they had to laterally crossover the 15cm wide tape (Figure 5C). Participants were requested to stick the final landing for all three tests, defined as maintaining balance for 2s without touching the ground with the contralateral leg or hand, and not making a second little hop or moving the heel when landing. Arm movements were allowed during jumps. The tests were demonstrated with video and verbal instructions. Participants were allowed to practice each test, and failed tests were repeated until achieving three successful trials.

Hop distance was measured to the nearest centimeter on each test from the heel. The best values from three successful trials were considered. An interval of at least 2 min was given between tests. Hop distances were normalized to the participant's leg length, and asymmetry indexes were estimated using the equation [(preferred leg/non-preferred leg)*100].

3.4.5 Isometric strength

Knee extensor and flexor and hip adductor and abductors' maximal isometric strength were estimated by using a hand-held dynamometer (Microfet 2, Hogan Health industries, West Jordan, UT, USA). Strength measurements were performed after the biomechanical assessments. Force was recorded in Newton and multiplied by shank length (distance between lateral femoral epicondyle and dynamometer) to estimate knee torques, and lower limb length (distance between anterior-superior iliac spine and dynamometer) to estimate hip torques. Torque outcomes were normalized to the individual body mass.

To assess knee strength, individuals were seated with hip and knee flexed at 90º and both hands crossed on chest (HANSEN; MCCARTNEY; SWEENEY; PALIMENIO *et al.*, 2015). Belts were attached to the proximal and distal thigh for stabilization. The dynamometer was placed 5 cm above the lateral malleolus with a modified belt-stabilized configuration (HANSEN; MCCARTNEY; SWEENEY; PALIMENIO *et al.*, 2015). For assessment of hip strength, individuals were supine with the hip at a neutral position and both hands crossed on the chest. The contralateral knee and hip were flexed, and belts were attached to the anterior superior iliac spines and distal thigh of the tested limb (JACKSON; CHENG; SMITH; KOLBER, 2017). The dynamometer was placed 5cm above the lateral malleolus and polyvinyl chloride (also known as PVC) pipes ensured a proper technique (JACKSON; CHENG; SMITH; KOLBER, 2017). Participants were asked to perform 5s maximal isometric contractions receiving standardized strong verbal instructions. Peak values were recorded for at least three repetitions (if a difference greater than 10% was observed between the trials, additional repetitions were required) with 1 min rest period between contractions and 2 min between legs/muscle groups.

The order of the first leg, the muscle group, and the joint tested was randomized by balanced random list generation in blocks of 10 using an online resource (http://www.randomization.com). The highest value among the three peak values recorded was considered for analysis, and the outcomes of interest were the flexor and extensor strength, flexor to extensor strength ratio, abductor and adductor strength, and abductor to adductor strength ratio.

3.5 Biomechanical assessments

Bilateral drop jump, unilateral drop jump, and unilateral forward jump were performed. The participants wore their athletic footwear during jumps performance. Two force plates (OR6-2000, AMTI Inc., Watertown, MA, USA) embedded at the level of the laboratory floor sampled the kinetic data at 3kHz, and the motion was captured with fifteen cameras (Bonita B10, VICON Motion Systems, Oxford, UK) sampling data at 200 Hz. The same researcher always placed twenty-one 14 mm spherical reference markers according to the Plug-in Gait Full-Body model adapted on the anatomical references of the clavicle, sternum, 7^{th} cervical vertebra, 10^{th} thoracic vertebra, right back, the anterior and posterior superior iliac spines, lateral thigh, lateral femoral epicondyle, lateral shank, calcaneus, lateral malleolus, and 2^{nd} metatarsal head for both sides. At least three successful trials for each jump were recorded for each participant, being the averaged values considered for further analysis (majority a mean of 3 to 4 trials, a couple of participants had two trials included due to processing issues). A trial was considered successful when participants landed on the force plates without losing balance or double hopping. The initial contact (IC) with the ground was identified by a force threshold of 20N from vertical ground reaction force data.

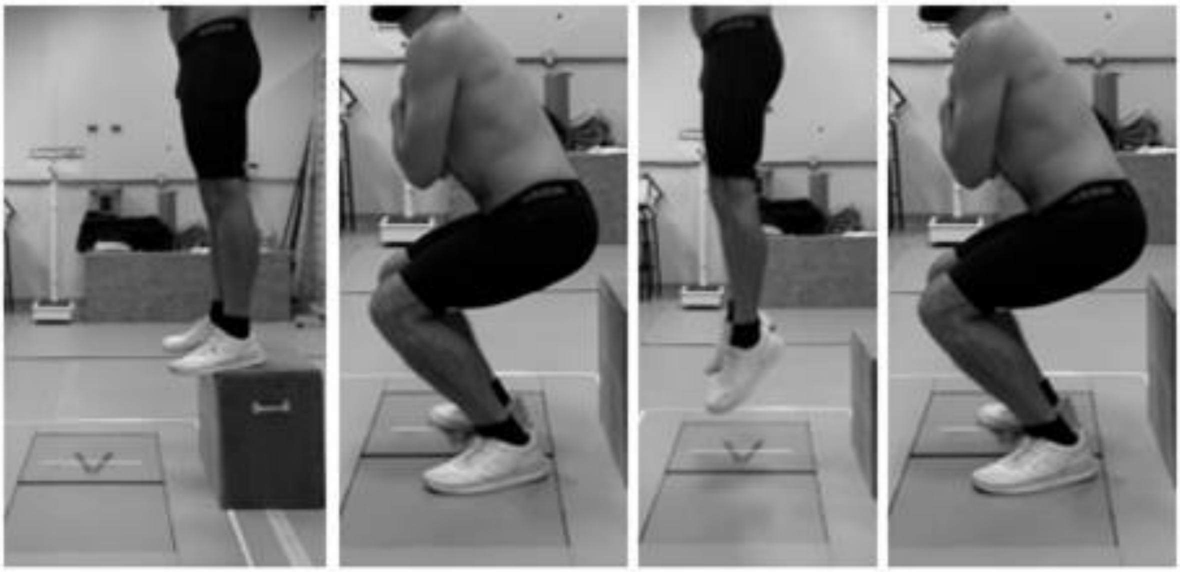
The order of the first leg tested for unilateral jumps was randomized by balanced random list generation in blocks of 10 using an online resource (http://www.randomization.com). Unfiltered ground reaction force signals were used to determine peak force values. For estimations of joint angles and moments, kinematic and kinetic data were low pass filtered by a 4^{th} order zero-lag Butterworth filter with a cut-off frequency of 8Hz, which was determined by residuals criteria (WINTER, 2009). Three-dimensional joint angles were estimated for ankle, knee, hip, pelvis, and trunk. Three-dimensional external joint moments (ankle, knee, and hip joints) were calculated with inverse dynamics equations of motion by Vicon Plug-In Gait Model

(Nexus software, version 1.8.5), filtered with the same filter design from kinematic and kinetic data, and normalized to the individual body mass.

3.5.1 Bilateral drop jump

To perform the bilateral drop jump landing task participants were standing upright on the top of a rigid box 40 cm high with arms crossed over their chest. They were instructed to drop off and land on double support with one leg on each force plate. After landing, they were instructed to immediately jump, as high as possible, performing a countermovement, and landing again with one foot on each force plate (Figure 6). The participants used their athletic shoes. The second landing was analyzed.

Figure 6 – Bilateral drop jump performance with the sequence of events from the left to the right (drop off, first landing, countermovement jump, and second landing).

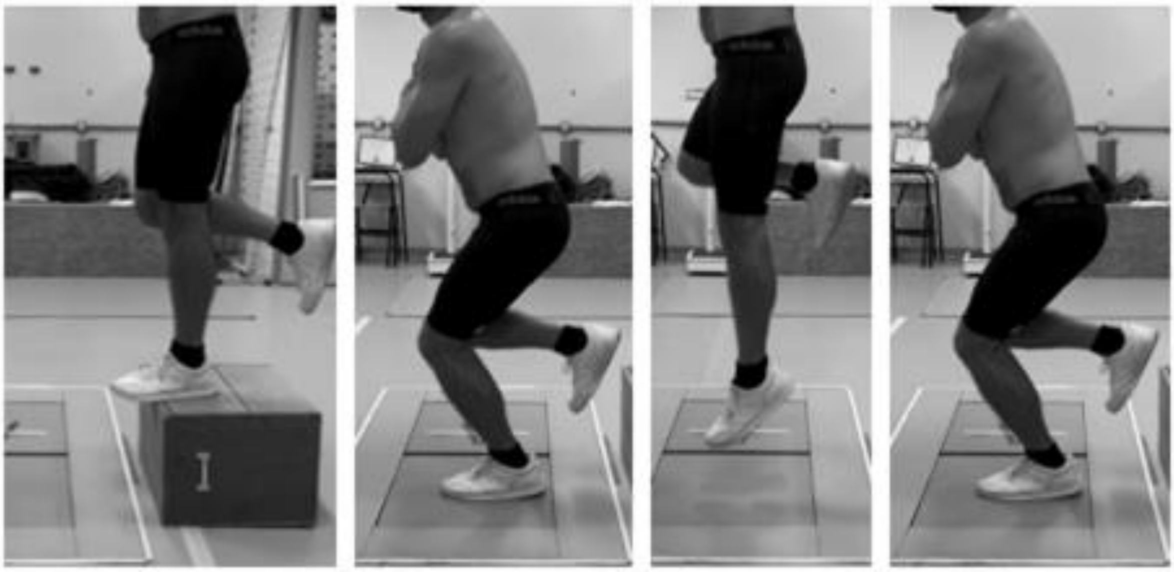


Source: by the author.

3.5.2 Unilateral drop jump

For the biomechanical assessment of unilateral drop jumps, participants were standing upright on the top of a rigid box 30cm high. They were instructed to drop off on one leg and immediately jump as high as possible, performing a countermovement, and landing on a force plate under single leg support (Figure 7). The second landing was analyzed.

Figure 7 – Unilateral drop jump performance with the sequence of events from the left to the right (drop off, first landing, countermovement jump, and second landing).



Source: by the author.

3.5.3 Unilateral forward jump

For unilateral forward jump assessment, participants stood on a force plate with their hands on their waist and should jump as high as possible before landing on a second force platform placed ~20cm in front of them. The landing was analyzed.

Figure 8 – Unilateral forward jump performance with the sequence of events from the left to the right (standing, jumping, and landing on single leg stance).

Source: by the author.

3.6 Statistical analysis

Descriptive statistics were used to describe the participants' characteristics. Additional statistical approaches were selected according to the specific objectives of this research, and have the full description as well as the selected outcomes detailed at the beginning of each chapter.

4 CHAPTER FOUR – CLINICAL TESTS PREDICTING BIOMECHANICAL OUTCOMES DURING UNILATERAL LANDINGS

The presence of a relationship between outcomes from clinical (field) and biomechanical (laboratory) tests found in individuals after ACL injury (XERGIA; PAPPAS; GEORGOULIS, 2015) suggest that monitoring responses to training programs aiming at injury prevention without submitting the athlete to biomechanical tests can be relevant to prevent injury (SIUPSINSKAS; GARBENYTE-APOLINSKIENE; SALATKAITE; GUDAS *et al.*, 2019). There is evidence of other biomechanical outcomes predicting key biomechanical outcomes related to ACL strain (HEWETT; WEBSTER; HURD, 2019; UENO; NAVACCHIA; DICESARE; FORD *et al.*, 2020), but identifying which accessible, low-cost clinical tools can identify those at risk of injury is essential for developing injury prevention programs at a population level.

Unilateral landing is a complex task requiring precise control of different joints at different planes of motion. Due to the complex mechanics of this movement, it would be expected that a combination of clinical tests evaluating different components of the technique would result in a better prediction of its biomechanical characteristics. This chapter presents the results from an analysis identifying the capacity of clinical outcomes to predict biomechanical outcomes during unilateral drop jump. The content of this chapter is currently submitted as an original article to the *Journal of Sport and Health Science* under the title "Can clinical tests predict biomechanical outcomes associated with ACL injury? Part 1: unilateral landings".

4.1 Purpose

To identify the capacity of clinical tests commonly employed in sports physiotherapy to predict biomechanical outcomes during unilateral jump landing tasks associated with risk factors for an ACL injury.

4.2 Outcomes

Clinical outcomes included:

- distance from the big toe to the wall in the lunge test;

- maximal reach distance normalized to leg length and asymmetry index in anterior, posterolateral and posteromedial SEBT directions;
- total score of LSD;
- maximal reach distance normalized to leg length and asymmetry index of single leg hop, triple leg hop, and crossover hop.

The kinematics and kinetics outcomes were determined according to the ligament, quadriceps and trunk dominance theories. Outcomes related to ligament dominance theory were ankle sagittal plane angle [at the initial contact (IC) and maximal knee flexion (MF)], knee frontal plane angle and moment (at IC, MF and peak values), knee frontal plane range of motion, hip frontal plane angle and moment (at IC and MF), and hip transverse plane angle (at IC and MF). Outcomes related to quadriceps dominance theory were knee sagittal angle and moment (at IC and MF), hip sagittal plane angle (at IC and MF), the vertical component of ground reaction force (GRFv, peak value and at MF), and the rate of GRFv in the landing phase data. Trunk dominance theory-related outcomes were pelvis and trunk sagittal, frontal and transversal planes angle (at IC and MF).

4.3 Statistical analysis

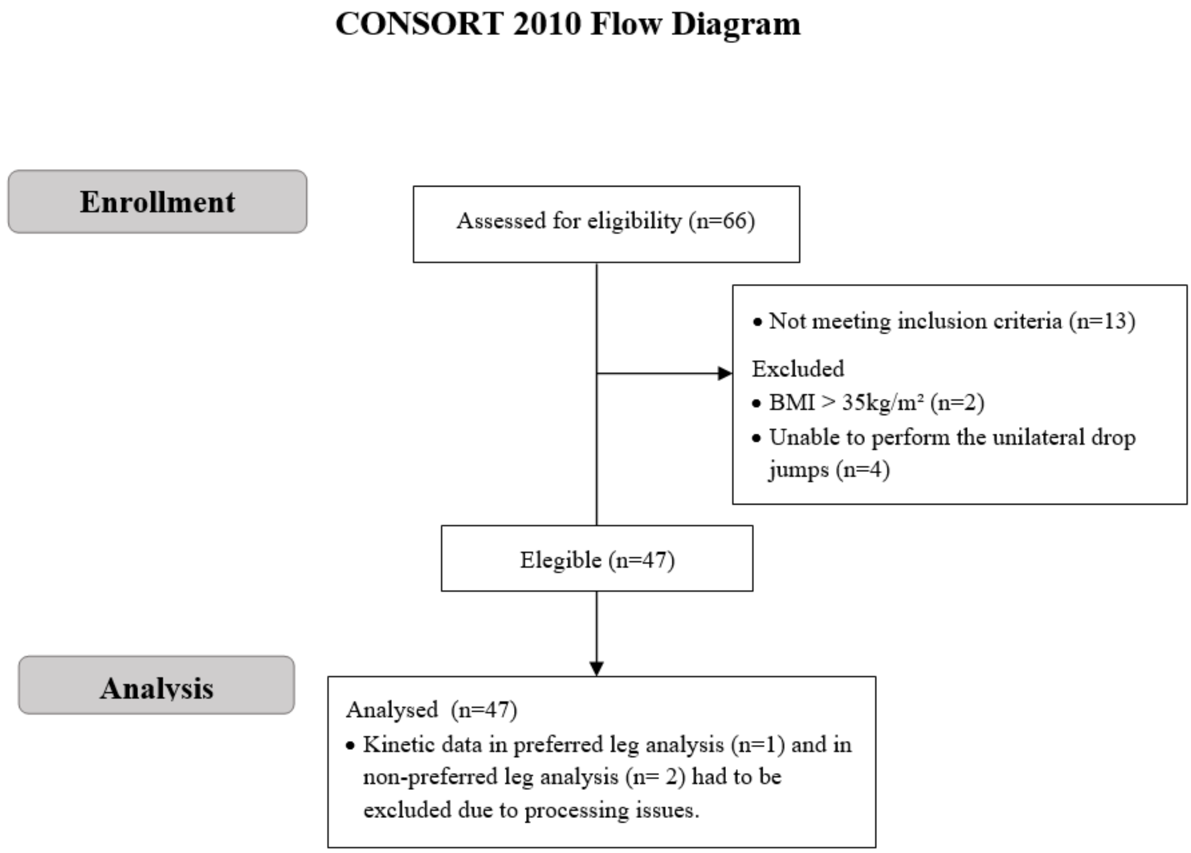
The capacity of clinical tests to predict the biomechanical outcomes was assessed with linear regression analyses and a two-steps process considering data from the preferred and non-preferred legs separately. The first step was selecting clinical outcomes for the regression model by Pearson or Spearman correlation tests (according to data normality verified with Shapiro-Wilk test). Clinical outcomes with association with biomechanical outcome showing a $p \leq 0.20$ were inserted in the regression model (Appendix A). Clinical outcomes with a strong correlation ($r \geq 0.7$) between them were not included simultaneously (Appendix B); the independent outcome with a stronger association with the biomechanical outcome was selected.

The second step included stepwise multiple linear regression analyses performed for each biomechanical outcome. Assumptions of linear regression analysis were confirmed: independence of observations (Durbin-Watson value between 1 and 3); linear relationship; data homoscedasticity; non-multicollinearity (correlation coefficients < 0.7, tolerance value > 0.02, and variance inflation factor value < 10); and normality of residuals distribution. Influent cases were identified and excluded when the standard residual was higher than 3, Cook's distance higher than 1, or Mahalanobis distance higher than 11. All tests were performed using a commercial statistical package (SPSS 17.0 IBM Corp., Armonk, USA), considering a significance level of 0.05. The power and global effect size (f^2) of the final model were also computed. Effect size (f^2) interpretation was: small to ≥0.02, medium to ≥0.15, and large to ≥0.35 (COHEN, 1988).

4.4 Results

From the 66 participants recruited, we were able to include 53 satisfying all the inclusion criteria. During the experiments, two participants were excluded because of BMI greater than 35 kg/m^2, and four were unable to perform the unilateral drop jumps (Figure 9). Thus, the results are from 47 individuals with a mean age (standard deviation; min-max) of 25 years old (3; 18-30), body mass of 81 kg (13; 52-109), height of 177 cm (7; 162-192), Tegner physical activity level of 5 (2; 1-9), knee function in the Lysholm scale of 92 (7; 75-100), and Lower Extremity Functional Scale of 78 (3; 63-80). Thirty-nine participants identified the right leg as preferred. Kinetic data from one participant in preferred leg analysis and two participants in non-preferred leg analysis had to be excluded due to processing issues.

Figure 9 – Flow diagram of eligibility criteria.



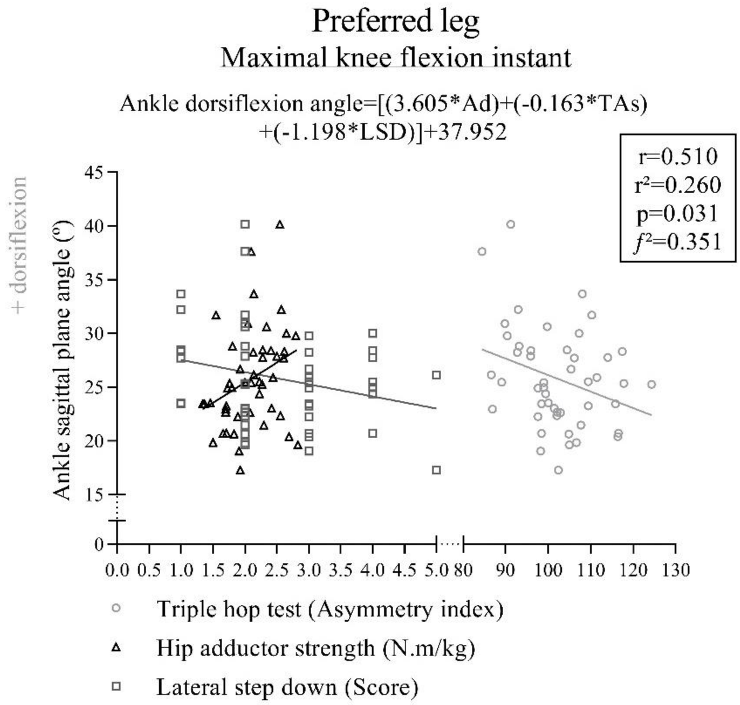
BMI: body mass index.
Source: by the author.

We focus the results and discussion sections on those models that explained >20% of the variance and potentially provide meaningful tools for clinicians and researchers. A summary of all models is in Appendix C and figures from models achieving <20% of variance are available in Appendix D.

In terms of biomechanical outcomes related to the ligament dominance theory, hip adductor strength, triple hop test, and LSD predicted ankle dorsiflexion angle at MF (large effect size) for jump landing with the preferred leg (Figure 10). Higher hip adductor strength and lower distance in triple hop test as well as lower scores in LSD were associated with higher ankle dorsiflexion angle. Knee varus/valgus angle at IC was predicted by SEBT total score, and single hop test (medium effect size, Figure 11B). Peak knee valgus angle was predicted by single hop test, and LSD for jump landing with the preferred leg (large effect size, Figure 11C). Lower knee valgus angle was associated with lower single hop test distance asymmetry and LSD score, and higher SEBT total score.

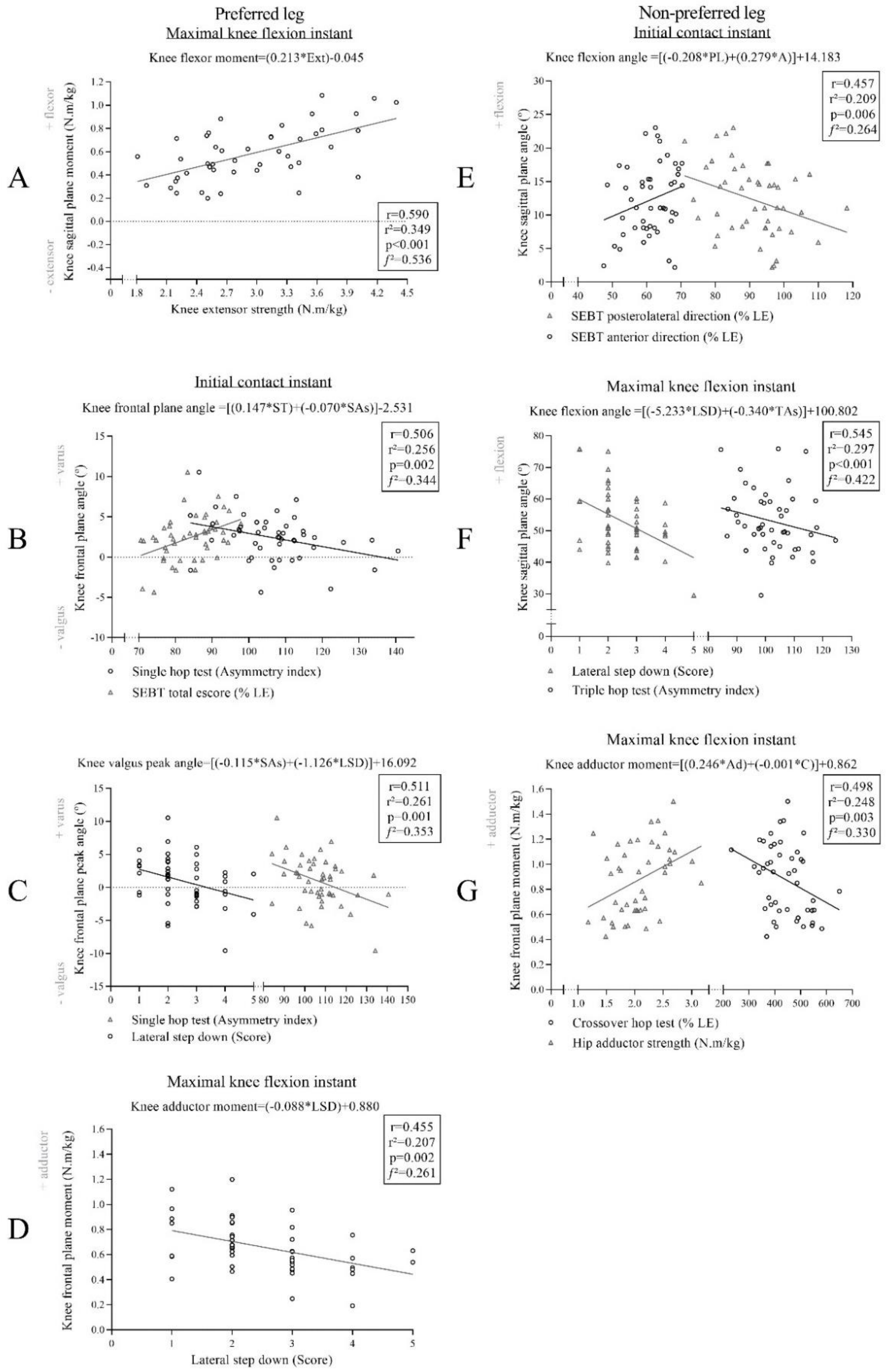
The knee adductor moment at MF was predicted by LSD for jump landing with the preferred leg, by hip adductor strength and crossover hop test for jump landing with the non-preferred leg (medium effect sizes, Figure 11D, G). Stronger hip adductors, lower crossover hop distance and LSD score were associated with higher knee adductor moment. Finally, hip adduction/abduction angles and adductor moment in jump landing with the non-preferred leg were predicted by hip and knee strength at MF (large effect size, Figure 12A, B). Stronger hip abductors and higher knee flexor/extensor ratio were associated with higher hip adduction angle, and stronger hip abductors and lower knee flexor/extensor ratio were associated with higher hip adductor moment. Triple hop test and hip adductor strength predicted hip internal/external rotation angle at IC and MF (medium effect size, Figure 12 C, D). Stronger hip adductors and lower triple hop distance were associated with higher hip external rotation angle.

Figure 10 – Ankle dorsiflexion angle at maximal knee flexion for jump landing with the preferred leg predicted by clinical tests.



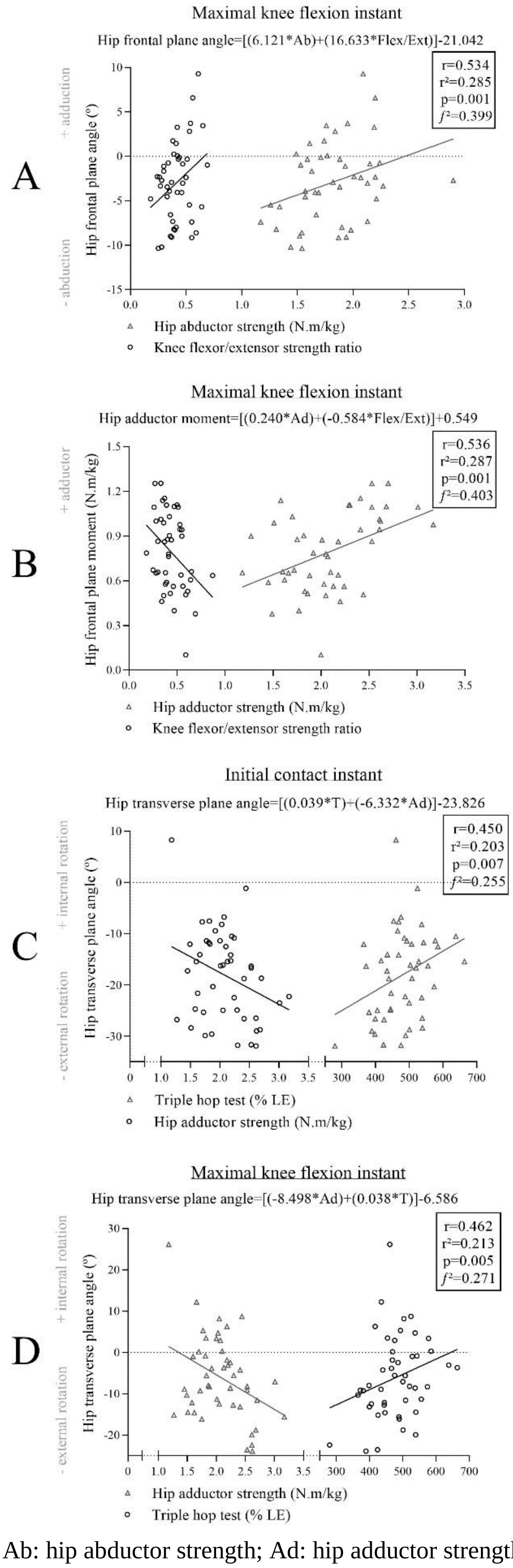
Ad: hip adductor strength; LSD: lateral step down; TAs: asymmetry index in triple hop test.
Source: by the author.

Figure 11 – Clinical tests predicted knee sagittal and frontal planes angles and moments considering the events of initial contact, maximal knee flexion, and peak value for jump landing with preferred and non-preferred legs.



A: SEBT anterior direction; Ad: hip adductor strength; Ext: knee extensor strength; C: crossover hop test; LE: lower extremity; LSD: lateral step down; PL: SEBT posterolateral direction; SAs: asymmetry index of single hop test; SEBT: star excursion balance test; ST: SEBT total score; TAs: asymmetry index of triple hop test.
Source: by the author.

Figure 12 – Hip frontal and transverse planes biomechanical outcomes predicted by clinical tests for jump landing with non-preferred leg.

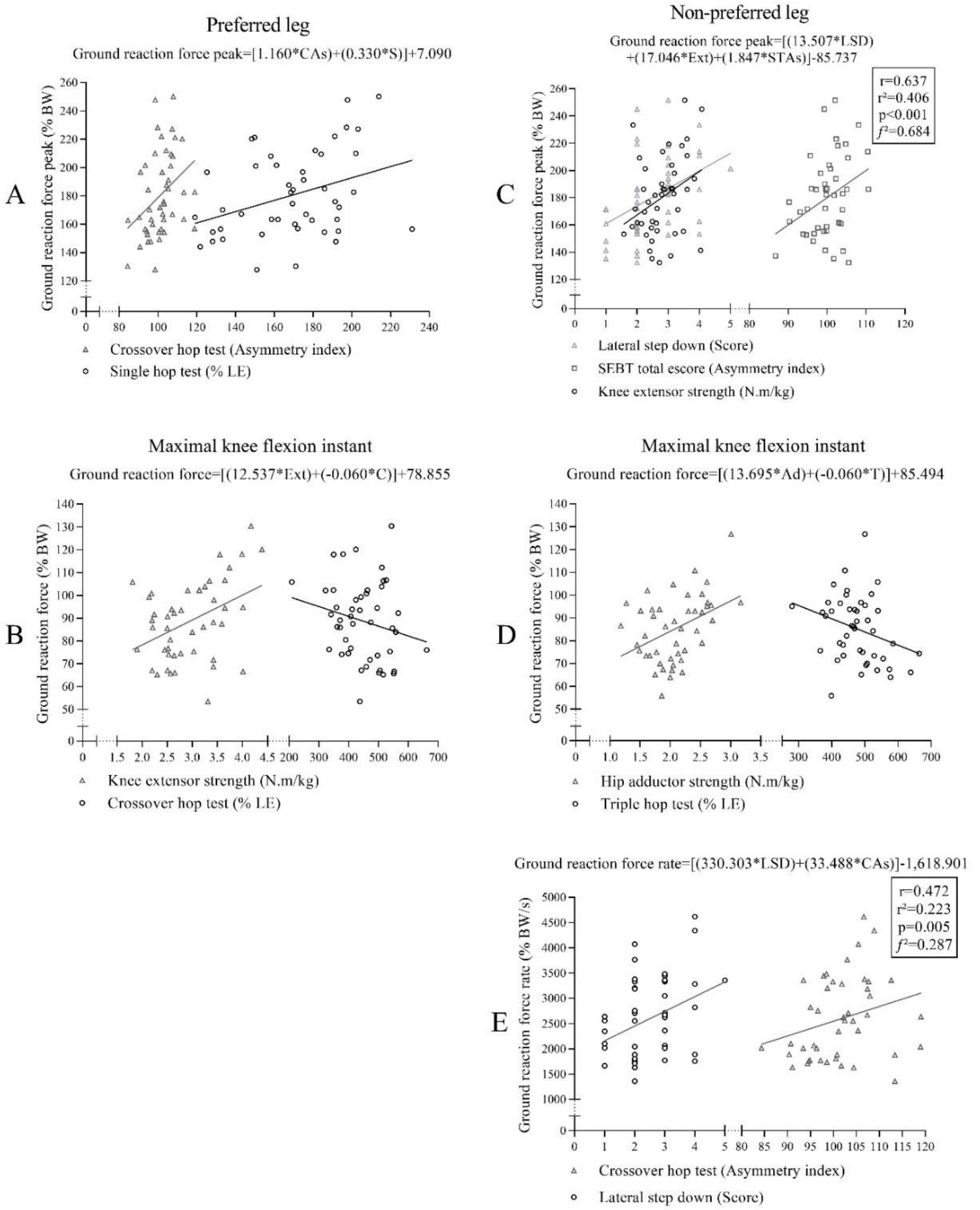


Ab: hip abductor strength; Ad: hip adductor strength;
Flex/Ext: knee flexor/extensor strength ratio; LE: lower extremity; T: triple hop test.
Source: by the author.

The clinical tests predicted biomechanical outcomes related to the quadriceps dominance theory, with models explaining up to 35% of the variance in knee variables. SEBT posterolateral and anterior directions predicted knee flexion angle at IC for jump landing with the non-preferred leg (medium effect size, Figure 11E). The LSD and triple hop test predicted knee flexion angle at MF for jump landing with the non-preferred leg (large effect size, Figure 11F). Lower SEBT posterolateral reach, LSD score and triple hop test distance asymmetry, and higher SEBT anterior reach were associated with higher knee flexion angle. Knee flexor moment at MF was predicted by knee extensor strength for jump landing with preferred leg (large effect size, Figure 11A). Stronger knee extensors were associated with higher knee flexor moment.

Peak GRFv was predicted by crossover and single hop test for jump landing with the preferred leg (medium effect size, Figure 13A), and by LSD, knee extensor strength and SEBT total score for jump landing with the non-preferred leg (large effect size, Figure 13C). Higher crossover hop test distance asymmetry, longer single hop test distance, higher LSD score and SEBT total score asymmetry, and stronger knee extensors were associated with higher GRFv peak. The GRFv at MF was predicted by knee extensor strength and crossover hop test for jump landing with the preferred leg (medium effect size, Figure 13B), and by hip adductor strength and triple hop test for jump landing with the non-preferred leg (medium effect size, Figure 13D). Stronger knee extensors and hip adductors, and lower crossover and triple hop test distances were associated with higher GRFv. The GRFv rate was predicted by LSD and crossover hop test for jump landing with the non-preferred leg (medium effect size, Figure 13E). Higher crossover hop test distance asymmetry and LSD score were associated with a larger GRFv rate.

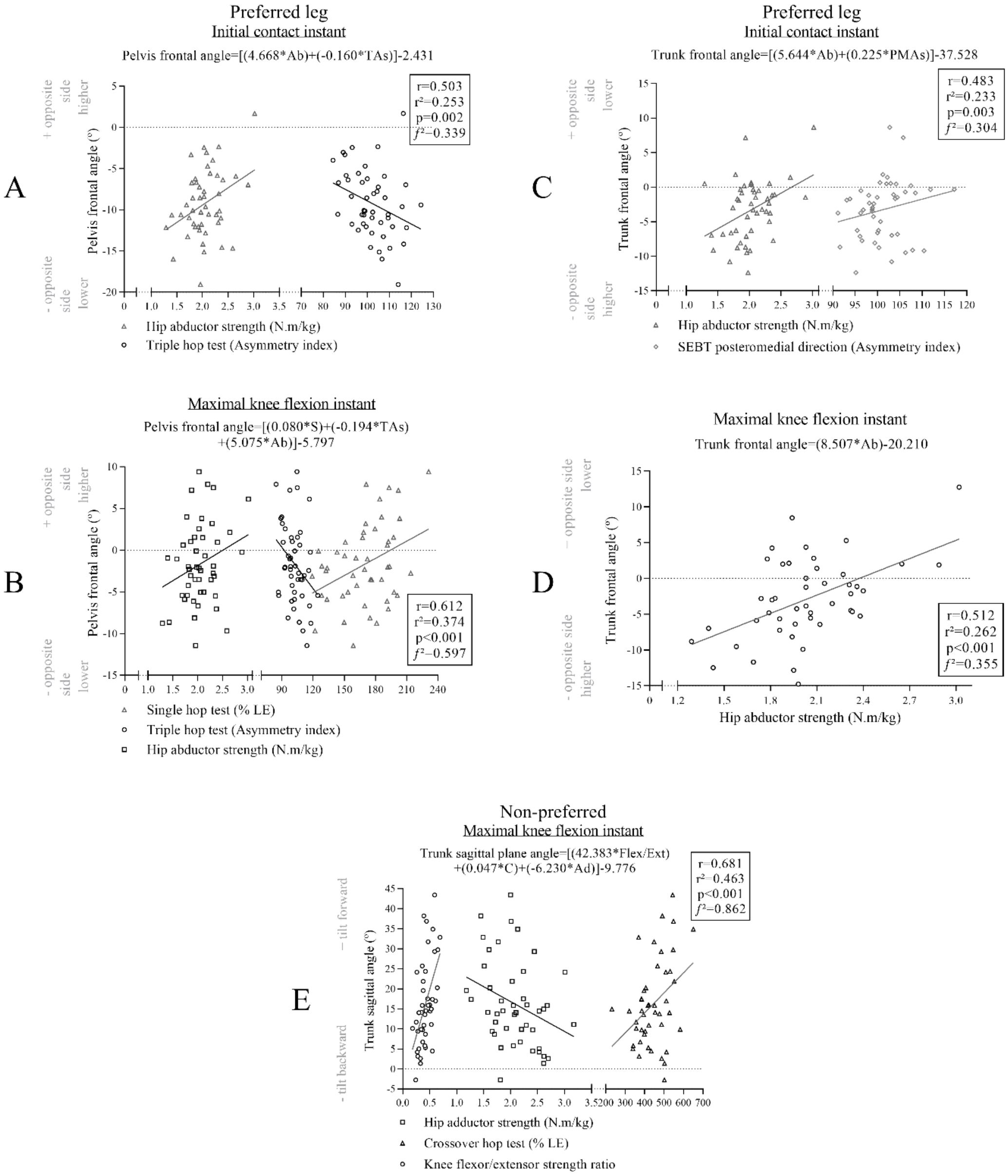
Figure 13 – Ground reaction force outcomes predicted by clinical tests for jump landing with preferred and non-preferred leg.



Ad: hip adductor strength; CAs: asymmetry index of crossover hop test; C: crossover hop test; Ext: knee extensor strength; LE: lower extremity; LSD: lateral step down; S: single hop test; SEBT: star excursion balance test; STAs: asymmetry index of SEBT total score; T: triple hop test.
Source: by the author.

In terms of the trunk dominance theory, pelvis obliquity at IC and MF for jump landing with the preferred leg were predicted by hip abductor strength, triple and single hop test (medium to large effect size, Figure 14A, B). Stronger hip abductors, higher single hop test distance and lower triple hop test distance asymmetry were associated with pelvis opposite side in a higher position. Trunk sagittal plane angle at MF was predicted by knee and hip strength, and crossover hop test for jump landing with the non-preferred leg (large effect sizes, Figure 14E). Higher distance in crossover hop test, higher knee flexor/extensor strength ratio, and weaker hip adductor strength were associated with larger trunk forward tilt. Frontal plane trunk angles at IC and MF were predicted for jump landing with preferred leg by hip abductor strength and SEBT posteromedial direction (medium and large effect size, Figure 14C, D). Stronger hip abductors and higher asymmetry index in SEBT posteromedial direction were associated with trunk opposite side in a lower position.

Figure 14 – Pelvis frontal plane angle and trunk sagittal and frontal plane angles predicted by clinical tests for jump landing with preferred and non-preferred leg.



Ab: hip abductor strength; Ad: hip adductor strength; C: crossover hop test; Flex/Ext: knee flexor/extensor strength ratio; LE: lower extremity; PMAs: asymmetry index of SEBT posteromedial direction; S: single hop test; SEBT: star excursion balance test; TAs: asymmetry index of triple hop test.
Source: by the author.

5 CHAPTER FIVE – CLINICAL TESTS PREDICTING BIOMECHANICAL OUTCOMES DURING BILATERAL LANDINGS

Bilateral landing is less challenging and might elicit a lower risk for injury than unilateral landing. These assumptions are based on the fact that bilateral drop landing is associated with lower impact, center of mass displacement (MALONEY; RICHARDS; FLETCHER, 2018), hip flexor, adductor and internal rotator moments, and knee flexor and external rotator moments (TAYLOR; FORD; NGUYEN; SHULTZ, 2016). Kinematic outcomes of bilateral landing in sagittal plane also indicate a lower risk for injury due to larger hip and knee flexion (DONOHUE; ELLIS; HEINBAUGH; STEPHENSON *et al.*, 2015; PAPPAS; HAGINS; SHEIKHZADEH; NORDIN *et al.*, 2007; TAYLOR; FORD; NGUYEN; SHULTZ, 2016), combined with lower muscle activity of knee extensors and flexors, and lower knee valgus angles (PAPPAS; HAGINS; SHEIKHZADEH; NORDIN *et al.*, 2007). However, bilateral landings have been associated with larger knee abductor moment than unilateral drop jumps (DONOHUE; ELLIS; HEINBAUGH; STEPHENSON *et al.*, 2015). This suggests that the demand for movement control in the frontal plane might rely on higher relation with hip strength to help control valgus (MCCURDY; WALKER; ARMSTRONG; LANGFORD, 2014). Around 70% of ACL injuries occur during single limb loading (DELLA VILLA; BUCKTHORPE; GRASSI; NABIUZZI *et al.*, 2020), but the effectiveness assessment of injury prevention protocols predominantly considers bilateral drop jump (LOPES; SIMIC; MYER; FORD *et al.*, 2018). Bilateral landings are commonly used to screen ACL injury risks (LEPPANEN; PASANEN; KROSSHAUG; KANNUS *et al.*, 2017; LEPPANEN; PASANEN; KUJALA; VASANKARI *et al.*, 2017). Therefore, investigating biomechanical outcomes of bilateral drop jumps is crucial for identifying predictors of biomechanical deficits associated with ACL injury. As conducted for the unilateral landing, the relationship between clinical tests and biomechanics outcomes were also investigated considering bilateral landing. Here, the goal was to identify the capacity of clinical outcomes to predict biomechanical outcomes during bilateral drop jump. The content of this chapter is currently submitted as a companion paper to the previous chapter and is under review in the *Journal of Sport and Health Science* under the title "Can clinical tests predict biomechanical outcomes associated with ACL injury? Part 2: bilateral landings".

5.1 Purpose

To determine the capacity of clinical tests commonly employed in sports physiotherapy to predict biomechanical outcomes associated with ACL injury during the performance of bilateral jump landing tasks.

5.2 Outcomes

Clinical outcomes were the same as described in chapter four. The kinematic and kinetic biomechanical outcomes were the same as chapter four but considering the performance of bilateral drop jump.

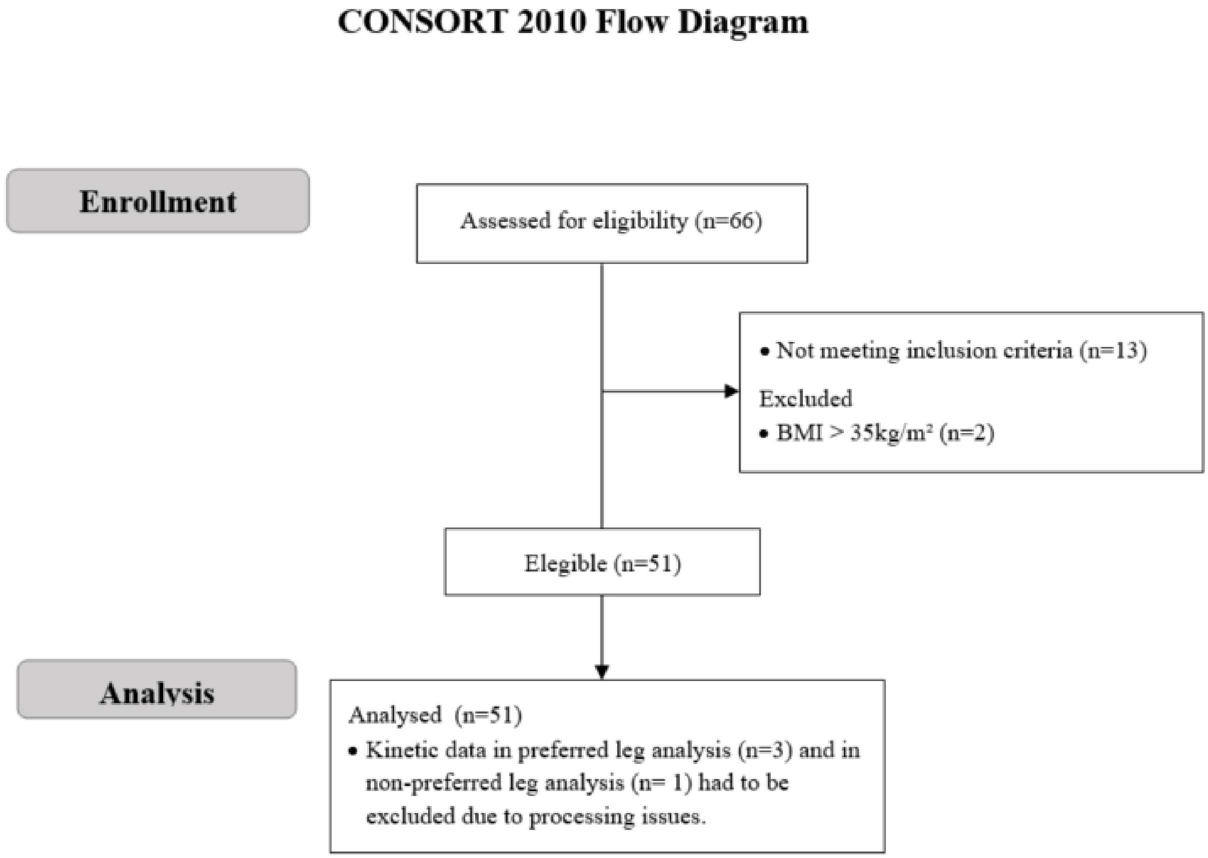
5.3 Statistical analysis

Statistical analysis was divided into the same two steps and followed the same criteria as described in chapter four. The correlation matrix and selected predictors of each model can be found in Appendixes E and F.

5.4 Results

Of the 66 participants recruited, 53 satisfied all the inclusion criteria. During the experiments, two participants were excluded because their BMI was greater than 35 kg/m^2 (Figure 15). Thus, the results are from 51 individuals with a mean age (standard deviation; min-max) of 24 years old (3; 18-30), body mass of 81 kg (13; 52-109), height of 177 cm (6; 162-192), Tegner physical activity level of 5 (2; 1-9), knee function in the Lysholm scale of 92 (8; 72-100), and Lower Extremity Functional Scale of 77 (3; 63-80). The right leg was preferred for 41 participants. Kinetic data from three participants in the analysis of preferred leg and one participant in the analysis of non-preferred leg were excluded due to signal processing issues.

Figure 15 – Flow diagram of eligibility criteria.



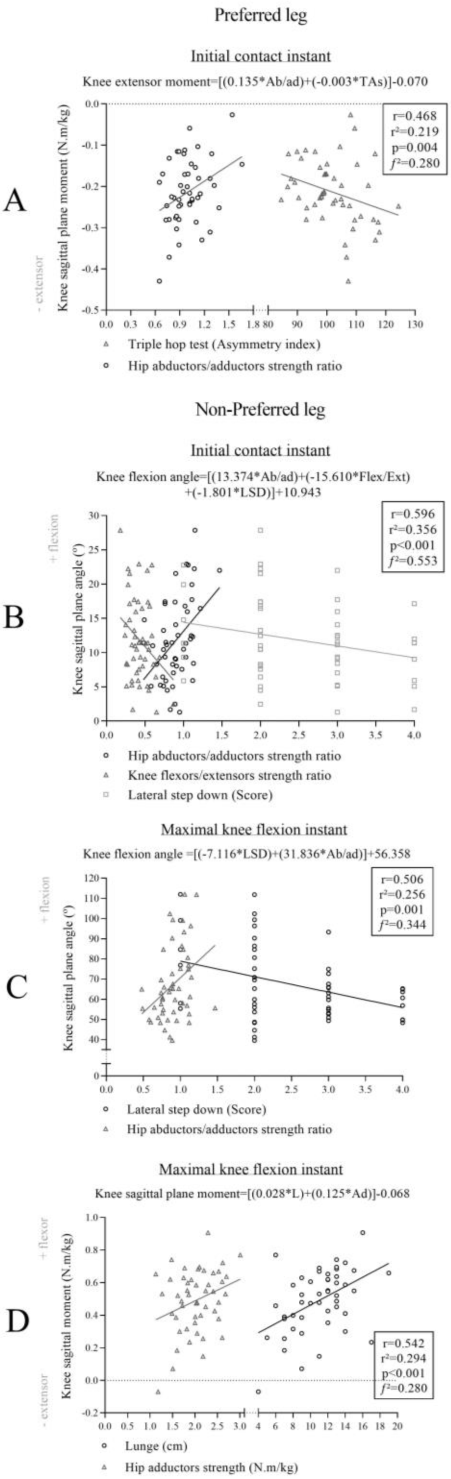
BMI: body mass index.
Source: by the author.

We focus the results and discussion sections on those models that explained > 20% of the variance and potentially provide meaningful tools for clinicians and researchers. All models can be found in Appendix G and figures from models < 20% are available in Appendix H.

Biomechanical outcomes related to the quadriceps dominance theory were predicted by clinical tests with models explaining up to 45% of the variance. Hip abductor/adductor strength ratio, knee flexor/extensor strength ratio, and LSD predicted knee flexion angle at IC for non-preferred leg (large effect size, Figure 16B). The LSD and hip abductor/adductor strength ratio predicted peak knee flexion angle for non-preferred leg (medium effect size, Figure 16C). Higher hip abductor/adductor strength ratio, lower LSD score and lower knee flexor/extensor strength ratio were associated with greater knee flexion angle.

Hip abductor/adductor strength ratio and triple hop asymmetry predicted knee extensor moment at IC for preferred leg (medium effect size, Figure 16A). Lunge and hip adductor strength predicted knee extensor moment at MF for non-preferred leg (large effect size, Figure 16D). Lower triple hop test distance, higher hip abductor/adductor strength ratio, stronger hip adductors and higher lunge distance were associated with higher knee sagittal plane moment.

Figure 16 – Knee sagittal plane joint angles and moments at the initial contact and maximal knee flexion predicted by clinical tests.



Ab/Ad: hip abductor/adductor strength ratio; Ad: hip adductor strength; Flex/Ext: knee flexor/extensor strength ratio; L: lunge; LSD: lateral step down; TAs: asymmetry index in the triple hop test.
Source: by the author.

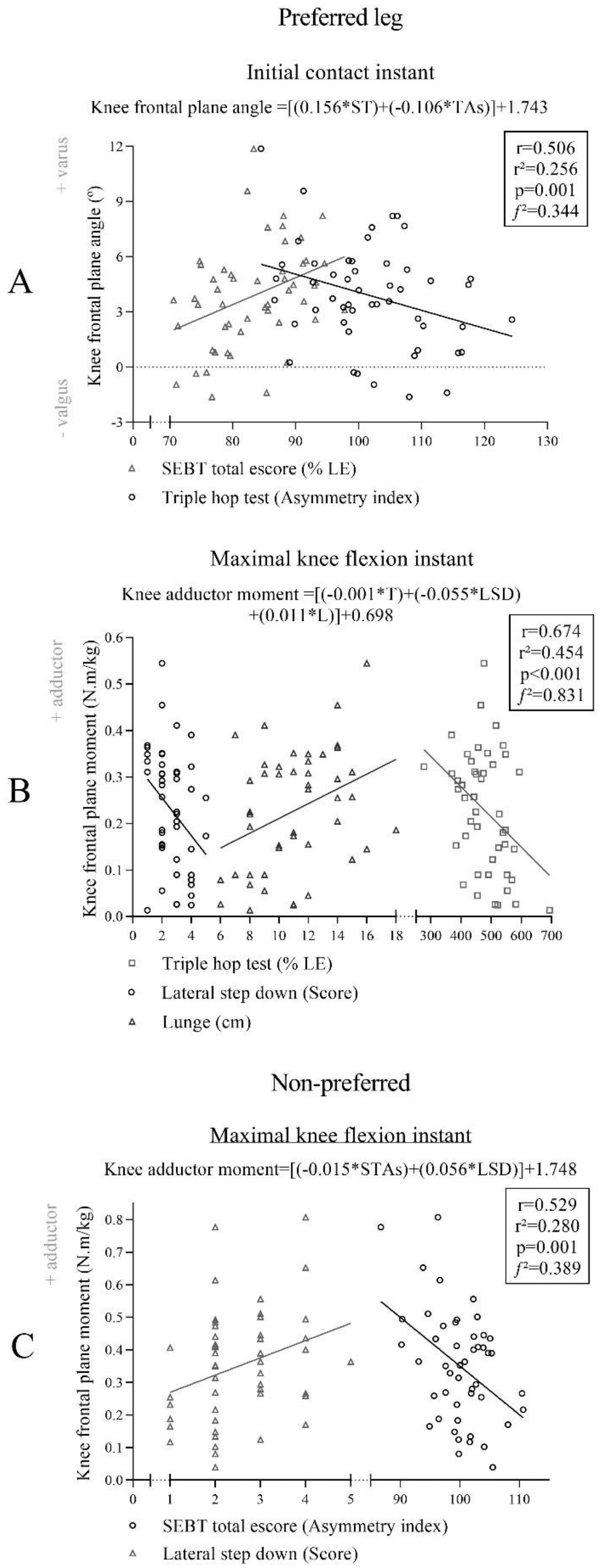
In terms of the ligament dominance theory, knee varus/valgus angle at IC was predicted by SEBT total score and triple hop test asymmetry for preferred leg (medium effect size, Figure

17A). Higher SEBT total score and lower triple hop test asymmetry distance were associated with lower knee valgus. The knee adductor moment at MF was predicted by triple hop test, LSD and lunge for preferred leg, and by SEBT total score asymmetry and LSD for non-preferred leg (large effect sizes, Figure 17B, C). Higher lunge distance, lower LSD score and lower triple hop test distance were associated with higher knee adductor moment for the preferred leg. For the non-preferred leg, a higher LSD score and lower SEBT total score asymmetry were associated with higher knee adductor moment.

Hip abduction angle in the non-preferred leg at IC was predicted by SEBT total score and triple hop asymmetry (large effect size, Figure 18B). Hip adduction/abduction angle in the preferred leg was predicted by crossover hop and knee strength at MF (medium effect size, Figure 18A). Higher knee flexor/extensor strength ratio, higher SEBT total score, lower crossover hop test distance and lower triple hop test asymmetry distance were associated with lower hip abduction angle. Hip adductor strength and knee flexor strength predicted hip adductor moment in non-preferred leg at MF (large effect size, Figure 18C). Stronger hip adductors and weaker knee flexors were associated with greater hip adductor moment. Hip internal/external rotation angle in non-preferred leg was predicted by hip adductor strength and triple hop (medium effect size, Figure 18D). Weaker hip adductors and higher triple hop test distance were associated with higher hip internal rotation angle.

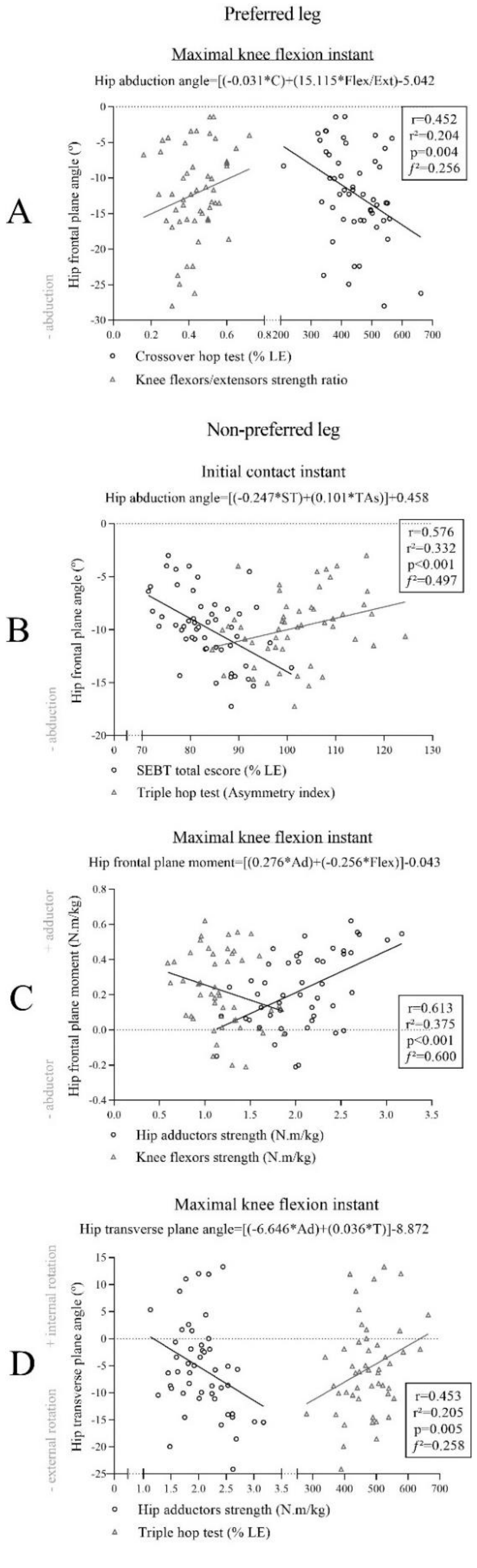
In terms of the trunk dominance theory, pelvic obliquity at IC for both legs was predicted by triple hop asymmetry (medium effect sizes, Figure 19A, B). Higher triple hop test asymmetry distance was associated with pelvis opposite side in a lower position for the preferred leg and with pelvis opposite side in a higher position for the non-preferred leg. Trunk sagittal plane angle at MF was predicted by crossover hop test for non-preferred leg (medium effect size, Figure 19C). Higher crossover hop test distance was associated with larger trunk forward tilt.

Figure 17 – Knee frontal plane joint angles and moments predicted by clinical tests at initial contact and maximal knee flexion.



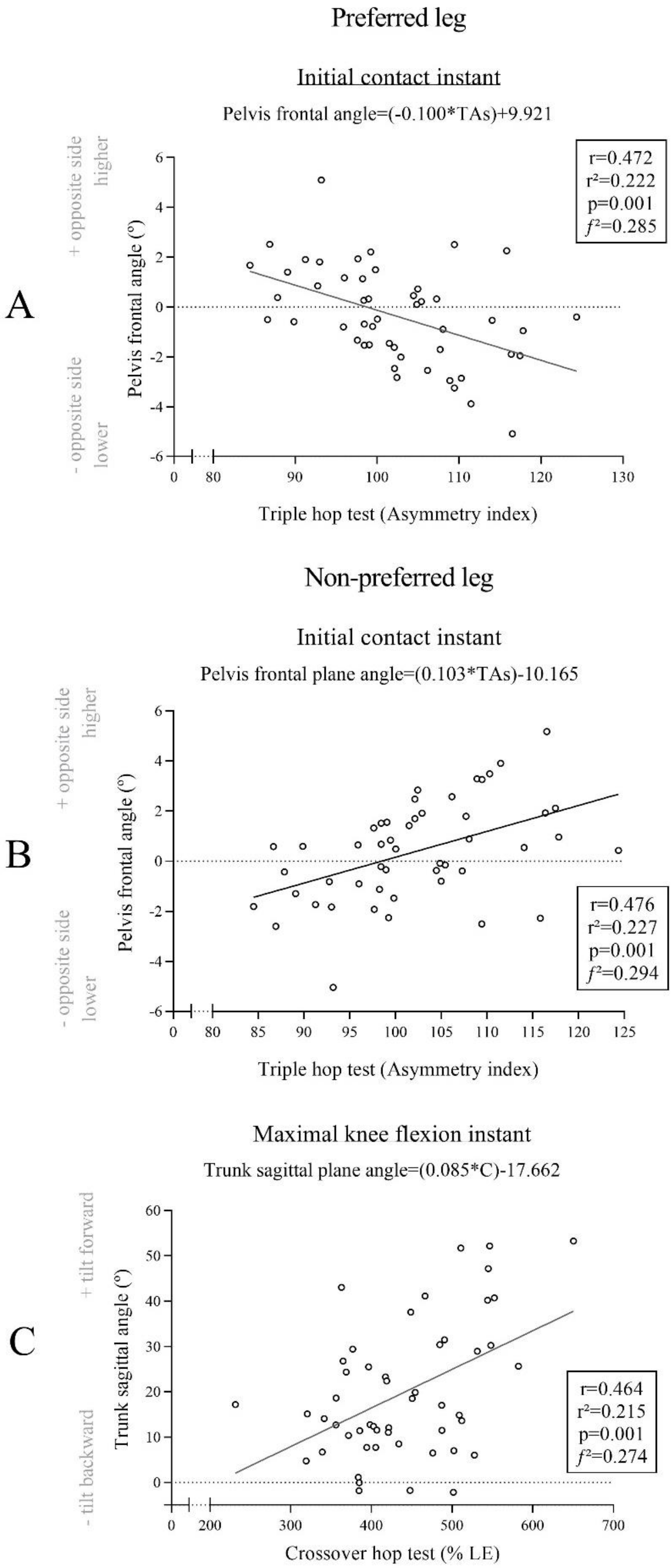
L: lunge; LE: lower extremity; LSD: lateral step down; SEBT: star excursion balance test; ST: total score of SEBT; STAs: asymmetry index in SEBT total score; T: triple hop test; TAs: asymmetry index in the triple hop test.
Source: by the author.

Figure 18 – Hip joint angles and moments predicted by clinical tests at initial contact and maximal knee flexion.



Ad: hip adductor strength; C: crossover hop test; Flex: knee flexor strength;
Flex/Ext: knee flexor/extensor strength ratio; LE: lower extremity; SEBT: star excursion balance test;
ST: total score of SEBT; T: triple hop test; TAs: asymmetry index in triple hop test.
Source: by the author.

Figure 19 – Pelvis and trunk angles predicted by clinical tests at initial contact and maximal knee flexion.



C: crossover hop test; LE: lower extremity; TAs: asymmetry index in triple hop test.
Source: by the author.

6 CHAPTER SIX – THE USE OF LATERAL STEP DOWN FOR STRATIFICATION OF BIOMECHANICAL DIFFERENCES

In the previous chapters, we discussed how clinical tests could better predict biomechanics outcomes. In addition to these approaches, which can guide routines of assessment and monitoring performance in sports physiotherapy, individual clinical tests are also relevant. In this regard, the patterns of movement in the performance of clinical tests could classify individuals, especially when it comes to injury risk during sports activities. Alterations in movement kinetics and kinematics during landings can increase the risk of injuries in sports like floorball and basketball (LEPPANEN; PASANEN; KUJALA; VASANKARI *et al.*, 2017), and improving the application of clinical tests can help guide their use. The LSD is a clinical test with potential application to assess the general quality of motion and differentiate individuals with or without impairments for movement control (LOPES FERREIRA; BARTON; DELGADO BORGES; DOS ANJOS RABELO *et al.*, 2019; RABIN; KOZOL, 2010; SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). The LSD aims to identify proximal and distal deviations during the task. However, the biomechanical differences during high-risk athletic maneuvers (such as landing from a jump) between those who demonstrate proximal only compared to those with combined proximal and distal deviations in the LSD test are currently unclear. This chapter identified whether stratification of participants by LSD could reflect differences in biomechanical outcomes. The content of this chapter will be submitted as an original article for *Journal of Orthopaedic & Sports Physical Therapy* under the title "Biomechanical differences in landing between individuals with proximal and combined deviations during lateral step down test performance".

6.1 Purpose

To investigate whether individuals with proximal (PRO) deviation only (frontal pelvis drop down) present 3D biomechanical differences during landing from those showing combined (COM) proximal and distal (frontal pelvis drop down and medial knee displacement to 2nd toe) deviations during the LSD test performance.

6.2 Outcomes

We determined the knee and hip sagittal and frontal planes angles and knee sagittal and frontal plane moments at the initial contact (IC, threshold of 50 N) and maximal knee flexion (MF) during unilateral and bilateral drop jumps and unilateral forward jumps. Peak values for knee abduction and hip adduction angles, knee abduction moment, and GRFv, as well as the knee frontal plane range of motion, time to GRFv peak, and GRFv impact absorption rate were determined.

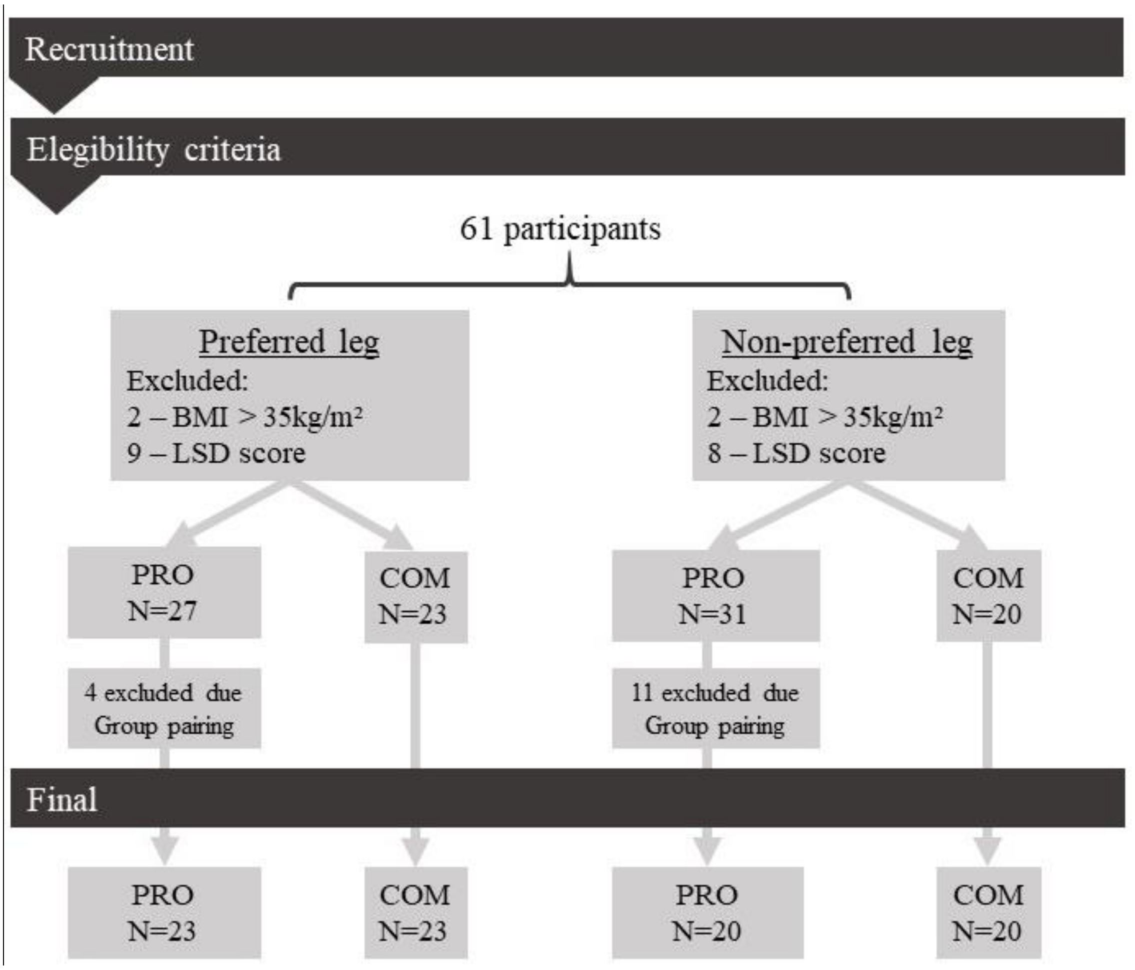
6.3 Statistical analysis

Participants' demographic characteristics were compared between groups with an independent t-test. Kinematic and kinetic outcomes were compared between groups for each leg independently with an independent t-test or Mann-Whitney test (according to data distribution verified with Shapiro-Wilk test). A significance level of 0.05 was considered for all tests. All tests were performed using a commercial statistical package (SPSS 17.0 IBM Corp., Armonk, USA). The Cohen effect size (*d*) was computed with interpretation: small to ≤0,2, a medium between 0,2 and 0,5, and large to ≥0,8 (COHEN, 1988).

6.4 Results

Sixty-one individuals took part in the study. Two participants were excluded due to a BMI higher than 35kg/m², and nine for preferred and eight for non-preferred leg analysis due to LSD classification (participants were not classified as showing pelvis or combined pelvis and knee deviations). Four and 11 participants were excluded during group matching (because of body mass, height and BMI) to guarantee the same number of participants between PRO and COM groups for preferred and non-preferred legs, respectively (Figure 20). Therefore, 46 participants took part in preferred leg analysis (23 in each group) and 40 participants in non-preferred leg (20 in each group, see Figure 20). Four participants could not perform unilateral drop jumps and were excluded from this jump analysis. Demographic or anthropometric characteristics did not differ between groups (Table 2).

Figure 20 – Flow diagram of the eligibility criteria.



BMI: body mass index; COM: combined deviations group;
LSD: lateral step down; PRO: proximal deviations group.
Source: by the author.

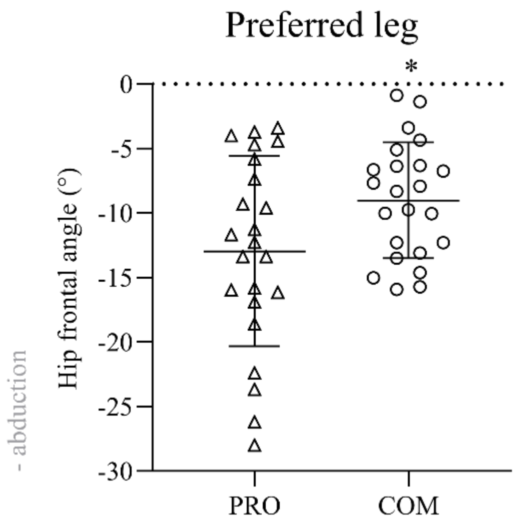
Table 2 – Participants characteristics. Data are presented as mean (standard deviation; min-max).

	Legs					
	Preferred (n=46)		p value between groups*	Non-preferred (n=40)		p value between groups*
Characteristics	PRO	COM		PRO	COM	
Age (years)	25 (1; 19-30)	24 (1; 18-30)	0.134	25 (1; 19-30)	24 (1; 18-30)	0.314
Body mass (kg)	80 (2; 58-100)	78 (2; 52-107)	0.524	81 (2; 66-95)	80 (3; 52-107)	0.757
Height (cm)	176 (1; 162-192)	177 (1; 166-192)	0.953	178 (1; 170-192)	177 (1; 164-192)	0.424
BMI (kg/m^2)	26 (1; 21-32)	25 (1; 18-29)	0.418	25 (1; 21-29)	25 (1; 18-33)	0.922

PRO: proximal deviations group; COM: combined deviations group; BMI: body mass index; *independent t-test.
Source: by the author.

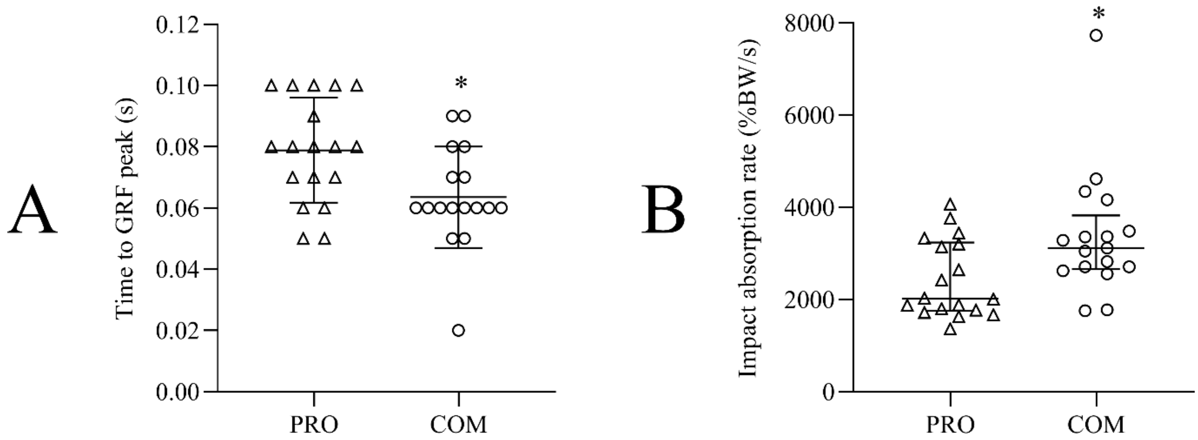
Participants from COM group presented lower hip abduction angle at MF in the preferred leg during bilateral drop jump (p=0.035, *d*=0.647, Figure 21). For unilateral drop jump, COM group also presented shorter time to reach GRFv peak (p=0.009, *d*=0.938, Figure 22A) and consequently an increased impact absorption rate (p=0.020, *d*=0.835, Figure 22B) in the non-preferred leg. We did not find differences between groups in the forward jump (p≥0.068).

Figure 21 – Hip abduction at maximal knee flexion in preferred leg during bilateral drop jump.



The central line represents the mean value and dispersion lines the standard deviation.
PRO: proximal deviations group; COM: combined deviations group. * difference between groups.
Source: by the author.

Figure 22 – Outcomes of impact absorption in the non-preferred leg during unilateral drop jump.



A: Central line represents the mean value and dispersion lines to DP.
B: Central line represents the median value and dispersion lines to interquartile.
PRO: proximal deviations group; COM: combined deviations group. * difference between groups.
Source: by the author.

7 CHAPTER SEVEN – HIP STRENGTH ASYMMETRIES AS A PREDICTOR OF CLINICAL AND BIOMECHANICAL ASYMMETRIES

Most sports-related activities involve demanding maneuvers for the lower extremities that elicit inherent injury risks. Additionally, acceleration, deceleration, and change of direction actions require strength from the lower extremity and rely on hip muscles' strong participation to provide stabilization (CRONIN; JOHNSON; CHANG; POLLARD *et al.*, 2016; IMWALLE; MYER; FORD; HEWETT, 2009). During the performance of sports activities, asymmetrical movement patterns and forces, movement dysfunctions, misalignments and disparities in lower extremity demand between joints are suggested as factors associated with injury risk (HEWETT; FORD; HOOGENBOOM; MYER, 2010). Poor hip strength has been associated with a higher risk of developing knee injuries (KHAYAMBASHI; GHODDOSI; STRAUB; POWERS, 2016) and is related to long-term adaptations after injury and risk of re-injury (VANNATTA; KERNOZEK, 2021). Proximal stabilization has been associated with movement quality during the performance of dynamic movements such as tasks involving step down (GOTTSCHALL; OKITA; SHEEHAN, 2012) and jumping (HERMAN; PRITCHARD; COSBY; SELKOW, 2022). Stabilization depends on strength, movement control, and symmetry at the hip joint. For example, a good hip and pelvis strength condition can benefit performance in movements involving running and jump-landing (HERMAN; PRITCHARD; COSBY; SELKOW, 2022; KOTSIFAKI; KORAKAKIS; GRAHAM-SMITH; SIDERIS *et al.*, 2021; SILVA; DE LIRA; VANCINI; ANDRADE, 2018).

Strength is an important clinical measure due to its clinical relevance and for being relatively easy to measure with low costs. In chapter four we identified that hip strength was a predictor of 12 biomechanical outcomes during landing involving sagittal and frontal angles, hip and knee kinetics and ground reaction force. However, the association of asymmetry in strength and asymmetry in biomechanics and functional tests are not well understood. For example, a weak hip might not be necessarily associated with lower limb misalignments, such as excessive knee valgus during dynamic movements (NILSTAD; KROSSHAUG; MOK; BAHR *et al.*, 2015). Therefore, understanding how strength measures relate to clinical and biomechanical outcomes can help to elucidate how to better use strength outcomes in clinical practice. The current chapter determines whether hip strength asymmetries are related to asymmetries in clinical and biomechanical outcomes in unilateral jump landings. This chapter was submitted as long abstract to the 2022 Congress of International Society of Biomechanics in Sports under the title "Hip strength asymmetry as a predictor of clinical and biomechanical asymmetries in male recreational athletes". Its full version will be prepared as an original article for submission to the *Journal of Orthopaedic & Sports Physical Therapy*.

7.1 Purpose

To determine whether hip strength asymmetry predicts asymmetries in clinical and biomechanical outcomes in recreational male athletes.

7.2 Outcomes

Hip adductor and abductor maximal isometric strength were determined as independent outcomes. The dependent outcomes are described in table 3.

Table 3 – Clinical and biomechanical outcomes.

Type of outcome	Measure
Clinical outcomes	Maximal distances reached in posterolateral and posteromedial SEBT directions; LSD total score; Maximal reach distance in single, triple and crossover hop tests.
Biomechanical during unilateral drop jumps	Peak hip adduction; Peak knee valgus angle; Peak knee abduction moment.

LSD: lateral step down; SEBT: star excursion balance test.
Source: by the author.

The limb symmetry index for all outcomes was estimated by the equation [(preferred leg/non-preferred leg)*100].

7.3 Statistical analysis

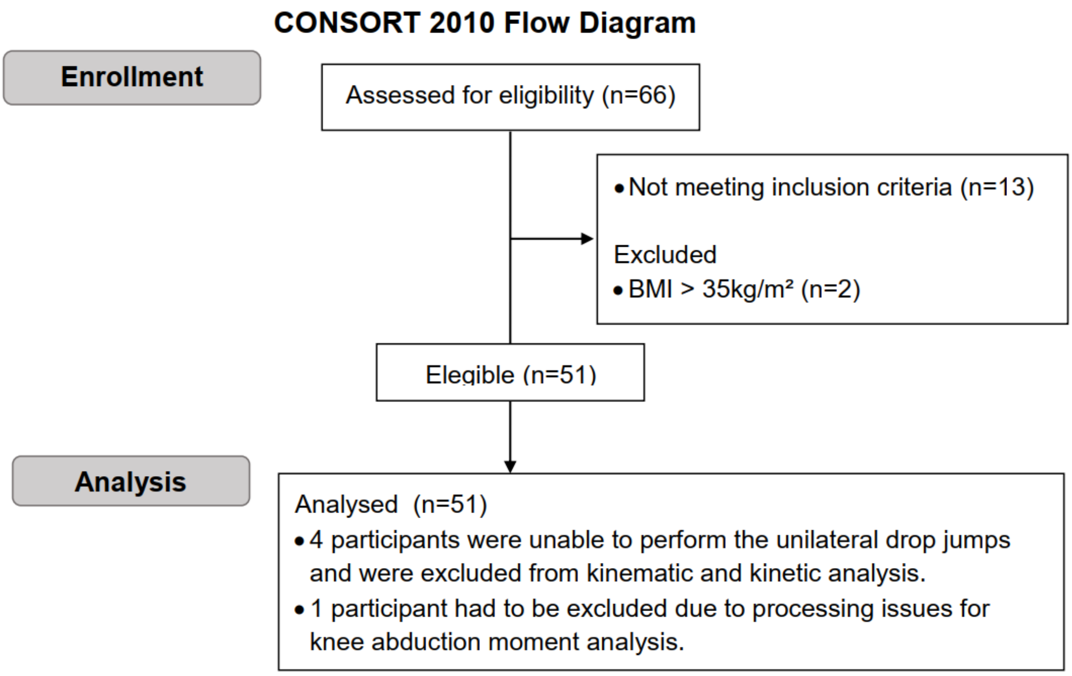
Linear regression analyses were performed to determine the capacity of hip strength asymmetry to predict asymmetries in the biomechanical and functional outcomes of the unilateral landing. Hip adductor asymmetry and hip abductor asymmetry were not strongly correlated (r=0.30). Therefore, they were inserted as predictors for each dependent variable (functional and biomechanical outcomes) in the stepwise multiple linear regression analyses. Assumptions of linear regression analysis were confirmed: independence of observations

(Durbin-Watson value between 1 and 3); linear relationship; data homoscedasticity; non-multicollinearity (correlation coefficients <0.7, tolerance value >0.02, and variance inflation factor value <10); and normality of residuals distribution. All tests were performed using a commercial statistical package (SPSS 27.0 IBM Corp., Armonk, USA) and considered a significance level of 0.05. The power and global effect size (f^2) of the final model were also computed. Effect size (f^2) interpretation was: small to ≥0.02, medium to ≥0.15, and large to ≥0.35 (COHEN, 1988).

7.4 Results

Fifty-one participants satisfied all eligibility criteria (Figure 23). They had a mean age (standard deviation) of 24 (3) years old, body mass of 81 (13) kg, height of 177 (6) cm, Tegner physical activity level of 5 (2), knee function in the Lysholm scale of 92 (8), and Lower Extremity Functional Scale of 77 (3).

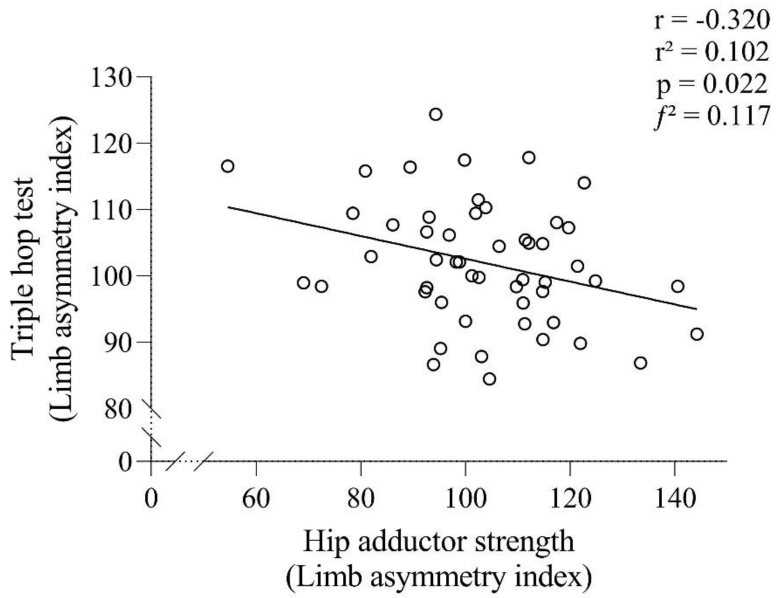
Figure 23 – Flow diagram of participants' eligibility.



BMI: body mass index.
Source: by the author.

Asymmetry in hip abductor strength did not predict kinematic, kinetic, or functional outcomes. Hip adductor strength asymmetry predicted asymmetry in the triple hop test (Figure 24). A negative relationship was identified between hip adductor strength asymmetry and triple leg hop for distance asymmetry. However, hip strength asymmetry still explained only 10% of the triple hop test asymmetry variance.

Figure 24 – Hip adductor strength asymmetry predicts triple hop test asymmetry.



Source: by the author.

8 CHAPTER EIGHT – HOP TEST ASYMMETRY CORRESPONDENCE WITH BIOMECHANICAL OUTCOMES IN LANDINGS TASKS

The use of hop tests is extensive in sports physical therapy (DAVIES; MYER; READ, 2020). Several studies use hop tests as criteria to identify risk of injury, follow-up of injured individuals and return to sport. There is an anecdotal clinical establishment of a 10% criteria to determine asymmetry in these tests (EBERT; EDWARDS; PREEZ; FURZER *et al.*, 2021; THOMEE; KAPLAN; KVIST; MYKLEBUST *et al.*, 2011). The triple and crossover tests were the only tests providing good predictions of biomechanical outcomes when considered alone, as we described in chapters four and five. However, the identification of differences in biomechanical outcomes between individuals presenting symmetrical and asymmetrical classification by hop tests is of interest for clinical interpretation. Therefore, in this chapter, we aimed to identify if asymmetries in hop tests provide similar asymmetry patterns in jumping biomechanics using the clinical 10% criteria. We investigated the single hop test because this test is widely employed in sports physiotherapy practice and in previous studies investigating ACL injury and has been suggested as a return to sports criteria. Its full version will be prepared as an original article for submission to the Journal *Physical Therapy in Sport*.

8.1 Purpose

To identify whether asymmetries in hop tests elucidate differences in key biomechanical outcomes related to knee injury risk during unilateral landing cycle in male recreational athletes.

8.2 Outcomes

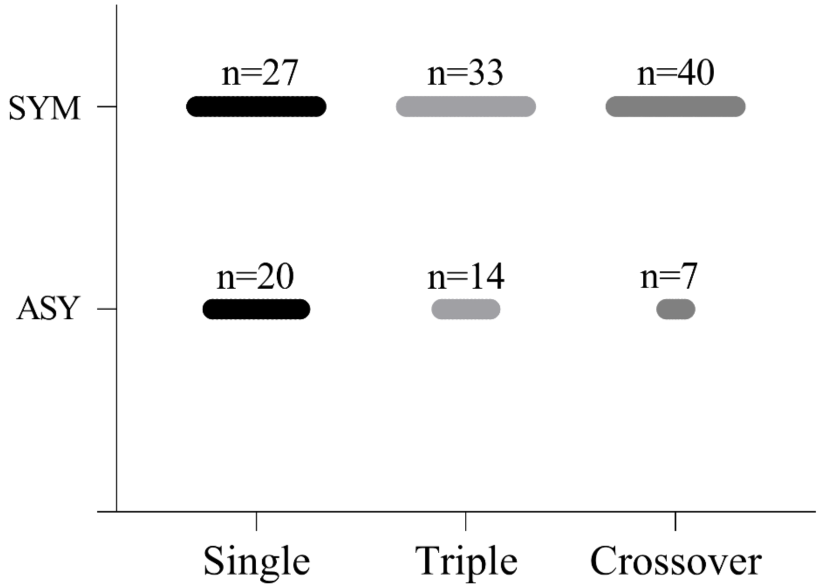
Chapter four identified that outcomes related to trunk and quadriceps dominance theories had stronger predictive models considering unilateral drop jumps. Therefore, here we choose to determine the effect of leg asymmetry in biomechanical outcomes related to the quadriceps dominance theory during unilateral landing.

Landing cycle curves were considered from data of the landing cycle, which was determined from initial contact (threshold of 20 N) to the maximal knee flexion. Knee and hip sagittal plane angle, knee and hip sagittal plane moment, and GRFv were determined for the landing cycle. All outcomes include data from 2 to 5 trials from each participant. The landing cycle was normalized to 101 points.

8.3 Statistical analysis

The participants included in the symmetrical and asymmetrical groups were determined according to the results from single, triple and crossover hops using the criteria of 10% difference between legs (90 to 110% were considered symmetrical). To determine differences considering the temporal series of the biomechanical outcomes curves, a two-way functional analysis of variance (FANOVA) for repeated measures was applied, considering the factors legs (preferred vs. non-preferred) and group (symmetrical vs. asymmetrical). Three FANOVA were applied for each of the biomechanical outcomes, one for each group classification following the criteria for each hop test (Figure 25, Table 4). The agreement between the three tests classification was verified by Kappa coefficient. The hop tests presented poor agreement between them (0.094 to 0.109; single and triple: 0.094; single and crossover: 0.097; triple and crossover: 0.109).

Figure 25 – Group classification according to each hop test.



ASY: asymmetric group; SYM: symmetric group.
Source: by the author.

Table 4 – Individual classification according to each hop test.

ID	Classification		
	Single	Triple	Crossover
1	ASY	ASY	SYM
2	SYM	ASY	SYM
3	SYM	ASY	SYM
4	ASY	SYM	ASY
5	SYM	SYM	SYM
6	ASY	ASY	SYM
7	ASY	SYM	SYM
8	SYM	SYM	SYM
9	SYM	ASY	SYM
10	SYM	SYM	SYM
11	SYM	SYM	SYM
12	SYM	SYM	SYM
13	ASY	ASY	ASY
14	SYM	SYM	SYM
15	SYM	SYM	SYM
16	SYM	SYM	SYM
17	SYM	ASY	SYM
18	SYM	ASY	SYM
19	SYM	SYM	SYM
20	SYM	SYM	SYM
21	SYM	SYM	SYM
22	ASY	SYM	SYM
23	SYM	SYM	SYM
24	ASY	SYM	SYM
25	SYM	SYM	SYM
26	ASY	SYM	SYM
27	ASY	ASY	SYM
28	ASY	SYM	SYM
29	ASY	SYM	SYM
30	SYM	SYM	ASY
31	SYM	SYM	SYM
32	SYM	SYM	ASY
33	SYM	SYM	SYM
34	SYM	ASY	SYM
35	ASY	SYM	SYM
36	SYM	SYM	SYM
37	SYM	SYM	ASY
38	ASY	SYM	SYM
39	ASY	ASY	SYM
40	ASY	ASY	ASY
41	ASY	ASY	ASY
42	SYM	ASY	SYM
43	ASY	SYM	SYM
44	ASY	SYM	SYM
45	SYM	SYM	SYM

46	ASY	SYM	SYM
47	ASY	SYM	SYM

ASY: asymmetrical group; SYM: symmetrical group.
Source: by the author.

To perform the FANOVA analysis, the first step was to convert the data to a functional form; i.e., the raw data for observation "i" was used to define the "x_i" function, which could be evaluated at all *t* values of landing cycle. The function was defined using B-splines that are considered more stable and computationally efficient basis than cubic splines, and any cubic spline basis can be represented with B-splines (PARK; SEELEY; FRANCOM; REESE *et al.*, 2017). Using a least-square fitting technique, four B-splines were applied to obtain a smooth and accurate representation of the data, as previously adopted (RAMSAY; SILVERMAN, 2005). It means that each curve in the dataset is composed of the same four basis functions (weighted and added together), although the weights are allowed to vary from curve to curve. We also performed the curve registration before generating the average curve for each condition. As the time series of different attempts shows some variation in phase or amplitude, the average curve may not accurately represent the real behavior.

The mean function and their 95% confidence bands were defined by a pointwise approach that led to an average curve. The average curve represents the common structure with average dynamics and average intensity (KNEIP; GASSER, 1992). Equation 1 describes the FANOVA approach (ZHANG, 2013).

$$y_{ijk}(t) = \mu(t) + \alpha_j(t) + \beta_k(t) + \alpha\beta_{jk}(t) + \varepsilon_{ijk}(t) \qquad \text{equation 1}$$

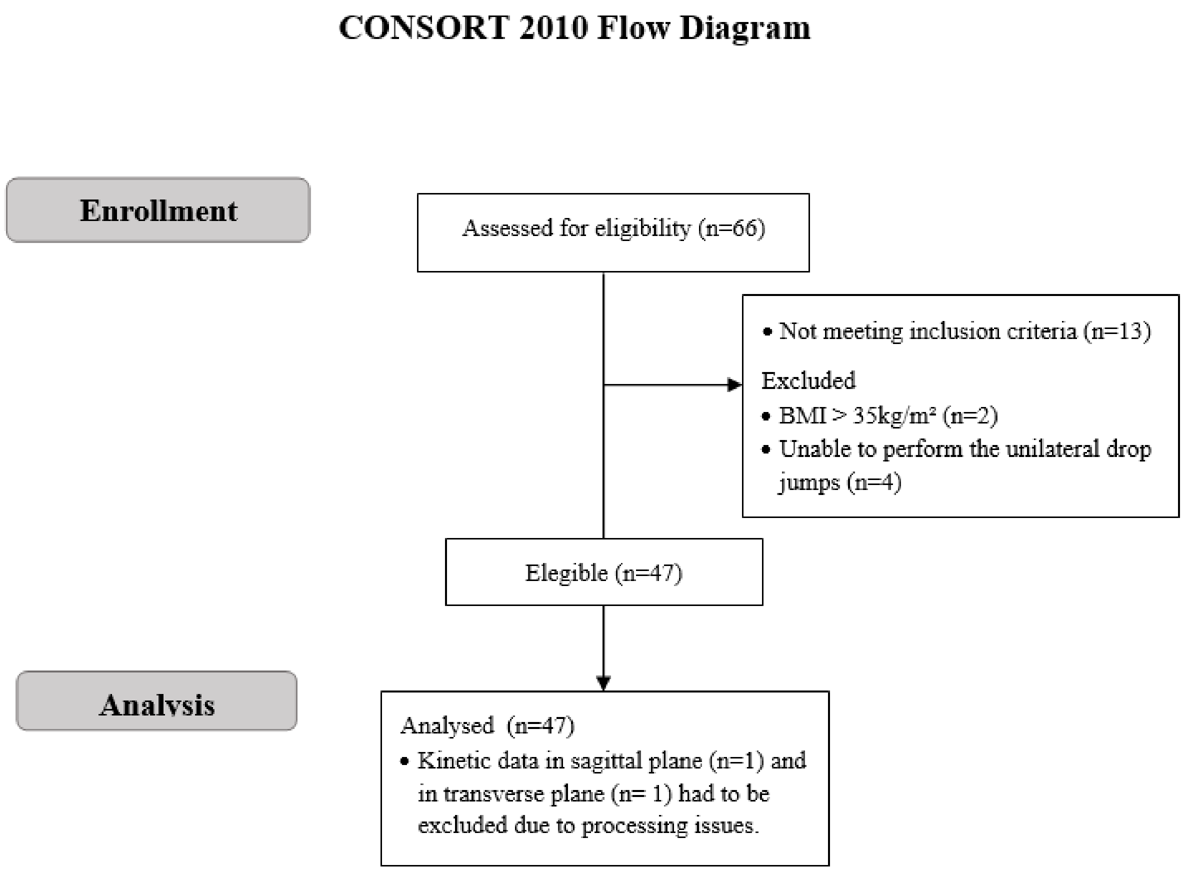
where α(t) is the factor leg with 2 levels, β(t) is the factor group with 2 levels, αβ(t) is the interaction between these two factors with 4 levels, μ(t) is the overall mean, $\varepsilon_{ijk}(t)$ are the residuals of the model, and t is the time (percent of landing cycle, in this case).

Thus, the biomechanical outcomes and each effect in the model are functions of time. We adopted the pointwise F-test and Bonferroni post-hoc analysis (ZHANG, 2013). We plot our estimates of these pairwise comparison functions and 95% confidence bands to determine significance. FANOVA considered a significance level set at 0.05. If the p-values were lower than the level of significance adopted, the result was considered significant, similar to traditional ANOVA interpretation. As a function of t, p(t) is continuous. Similarly, any p-value function computed from the data is continuous (COX; LEE, 2008). All the procedures were implemented in Matlab 2017a (MathWorks, USA), according to da Silva Soares et al. (2021).

8.4 Results

From the 66 participants recruited, we were able to include 53 satisfying all the inclusion criteria. During the experiments, two participants were excluded because of a BMI greater than 35 kg/m^2, and four because they were unable to perform the unilateral drop jumps (Figure 26). Thus, the results are from 47 individuals with a mean age (standard deviation; min-max) of 25 years old (3; 18-30), body mass of 81 kg (13; 52-109), height of 177 cm (7; 162-192), Tegner physical activity level of 5 (2; 1-9), knee function in the Lysholm scale of 92 (7; 75-100), and Lower Extremity Functional Scale of 78 (3; 63-80). Thirty-nine participants referred to their right leg as preferred. Kinetic data from one participant in sagittal plane and one participant in transverse plane were excluded due to processing issues.

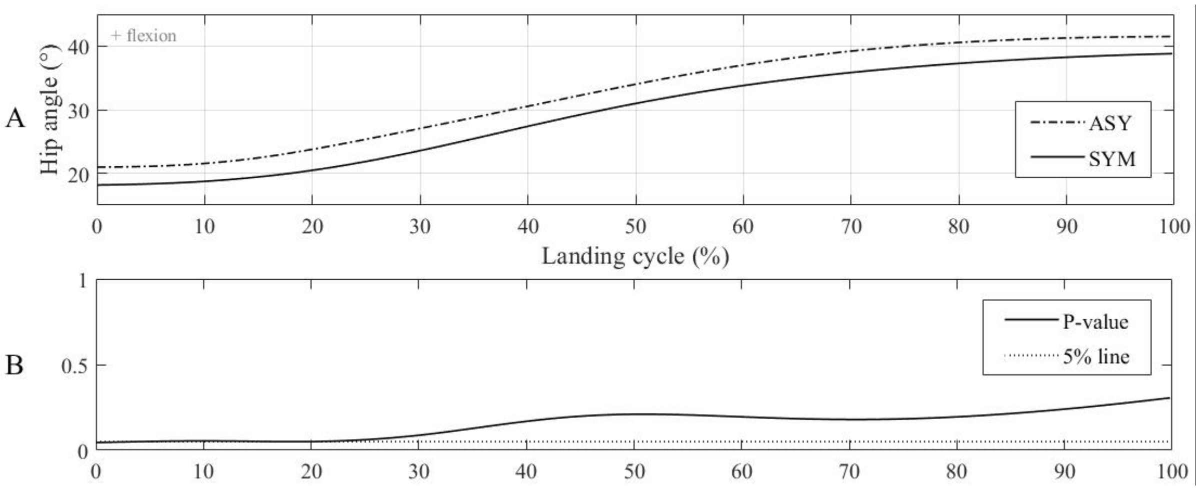
Figure 26 – Flow diagram of participants' eligibility.



BMI: body mass index.
Source: by the author.

Considering the single hop test classification, we did not find differences between groups or group*leg interaction for knee sagittal plane angles. For hip sagittal plane angles, there was a group effect between 0 to 3% and 18 to 19% of the landing cycle (Figure 27). Previous study report that to be considered differences should be in more than 5 consecutive percentages (STOELBEN; PAPPAS; MOTA, 2019). Therefore, we did not consider this difference for discussion and valid for interpretation since it was up to 3% in sequence.

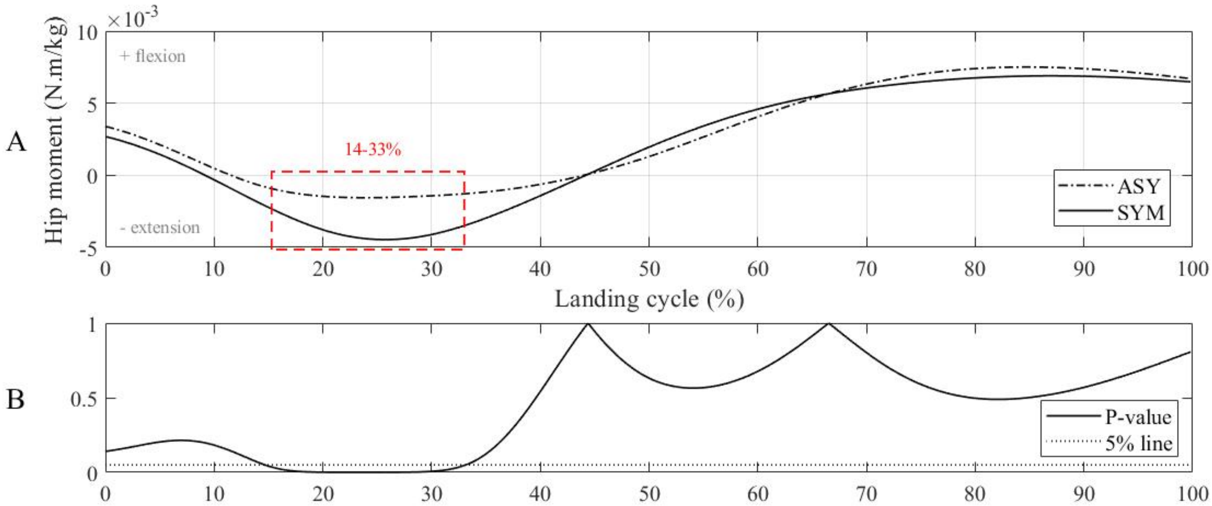
Figure 27 – Effect of group for hip sagittal plane angle considering single hop test classification.



A: mean of each group for hip sagittal angle; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; SYM: symmetrical group.
Source: by the author.

Knee sagittal moment did not present effect of group or group*leg interaction considering single hop test classification. We found a group effect for hip sagittal plane moment. The asymmetrical group presented lower hip extension moment from 14 to 33% of landing cycle (Figure 28).

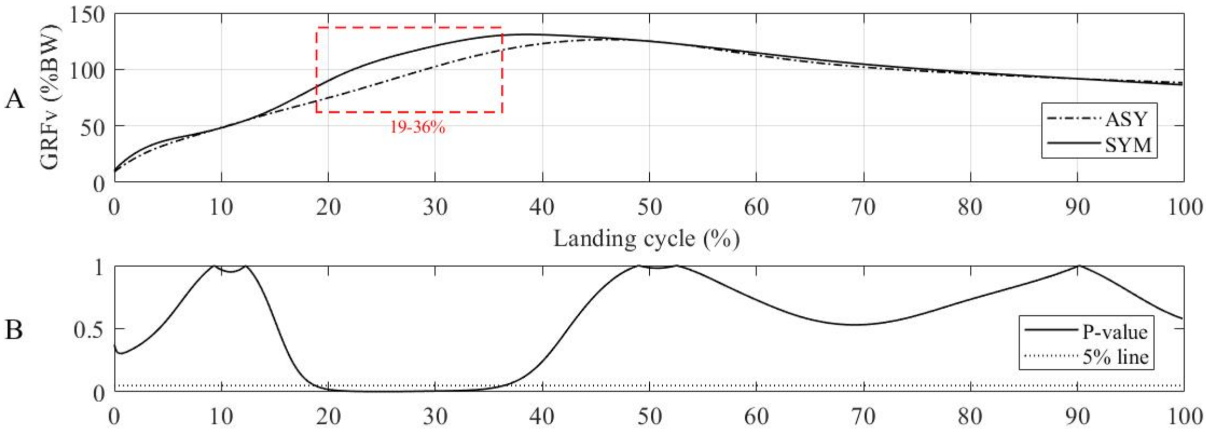
Figure 28 – Effect of group for hip sagittal plane moment considering single hop test classification.



A: mean of each group for hip sagittal moment, the red dotted line showed interval with differences between groups; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; SYM: symmetrical group.
Source: by the author.

The GRFv presented a main effect of group considering single hop test classification. Symmetrical group presented higher values from 19 to 36% of landing cycle (Figure 29).

Figure 29 – Effect of group for GRFv considering single hop test classification.

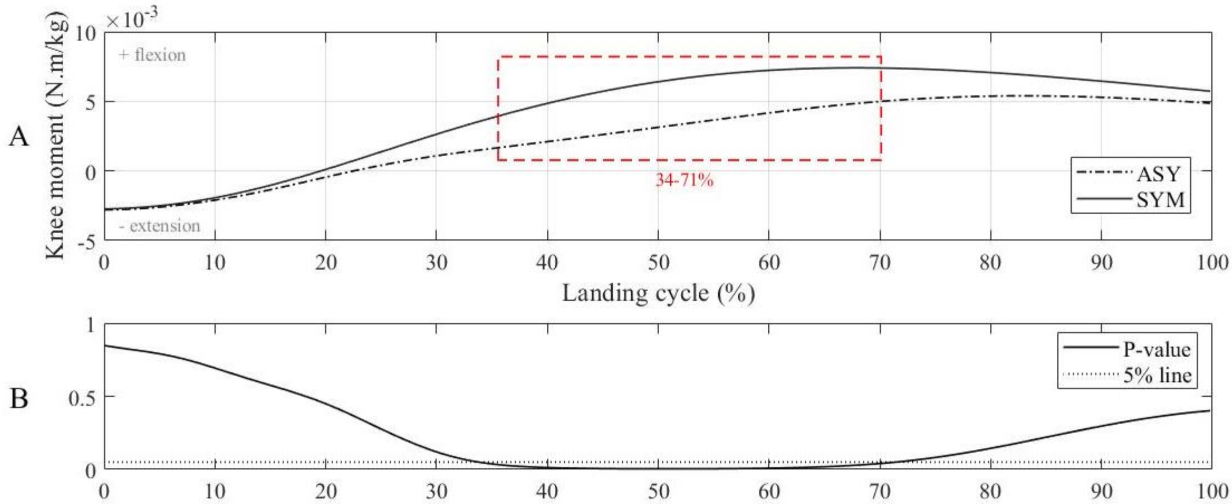


A: mean of each group for GRFv, the red dotted line showed interval with differences between groups; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; BW: body weight; GRFv: vertical component of ground reaction force; SYM: symmetrical group.
Source: by the author.

We did not find either a group effect or group*leg interaction for any biomechanical outcome considering the triple hop test classification.

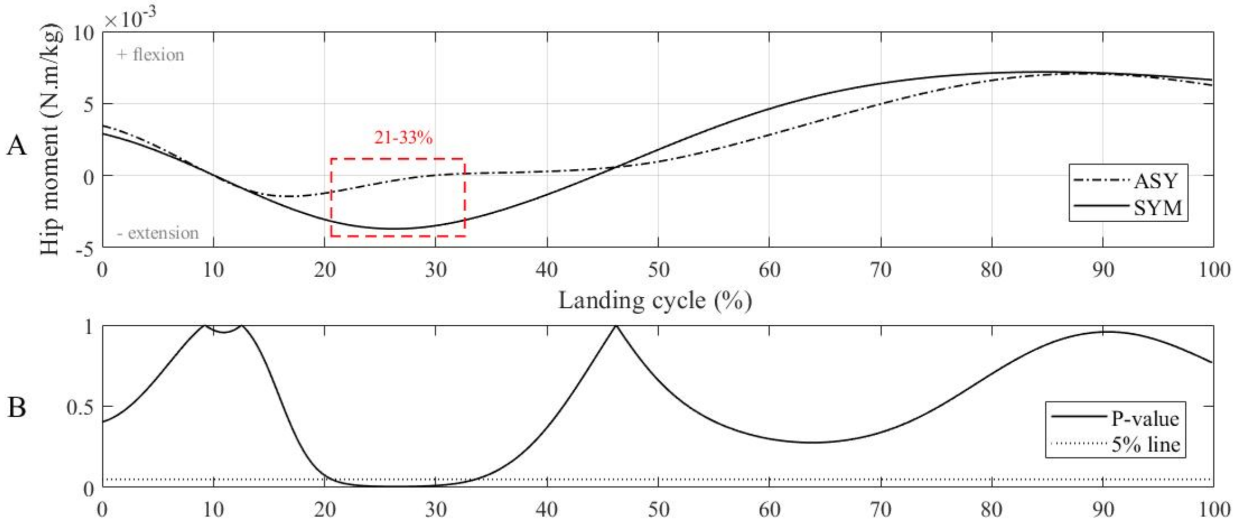
Knee and hip sagittal angles did not present effect of group or group*leg interaction considering crossover hop test classification. We found a group main effect for knee and hip sagittal moment. Symmetrical group presented higher knee flexion moment from 34 to 71% of the landing cycle (Figure 30) and lower hip extension moment from 21 to 33% of the landing cycle (Figure 31).

Figure 30 – Effect of group for knee sagittal plane moment considering triple hop test classification.



A: mean of each group for knee sagittal moment, the red dotted line showed interval with differences between groups; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; SYM: symmetrical group.
Source: by the author.

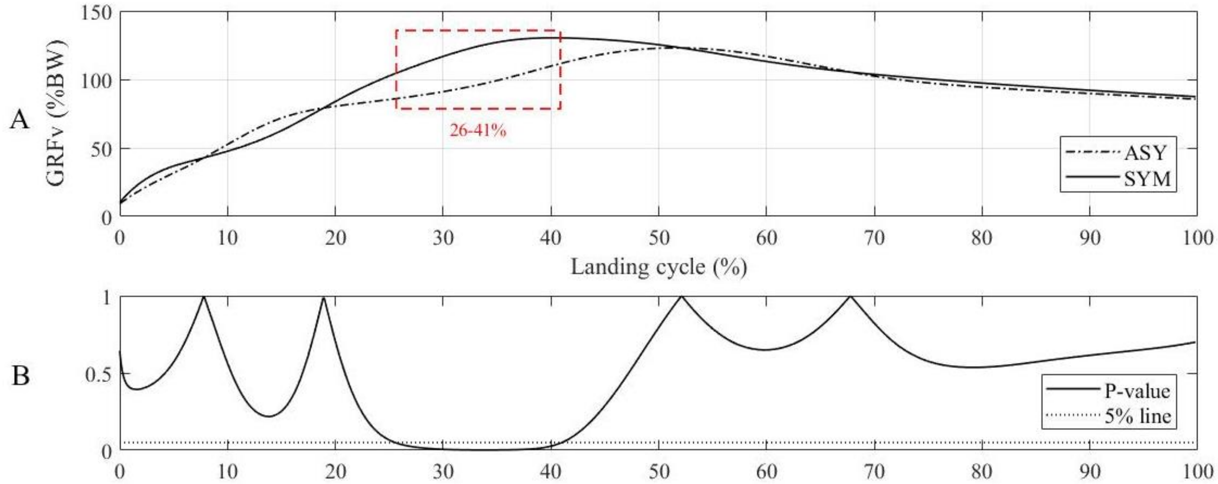
Figure 31 – Effect of group for hip sagittal plane moment considering triple hop test classification.



A: mean of each group for hip sagittal moment, the red dotted line showed interval with differences between groups; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; SYM: symmetrical group.
Source: by the author.

GRFv presented group main effect considering crossover hop test. The symmetrical group presented higher values from 26 to 41% of the landing cycle (Figure 32).

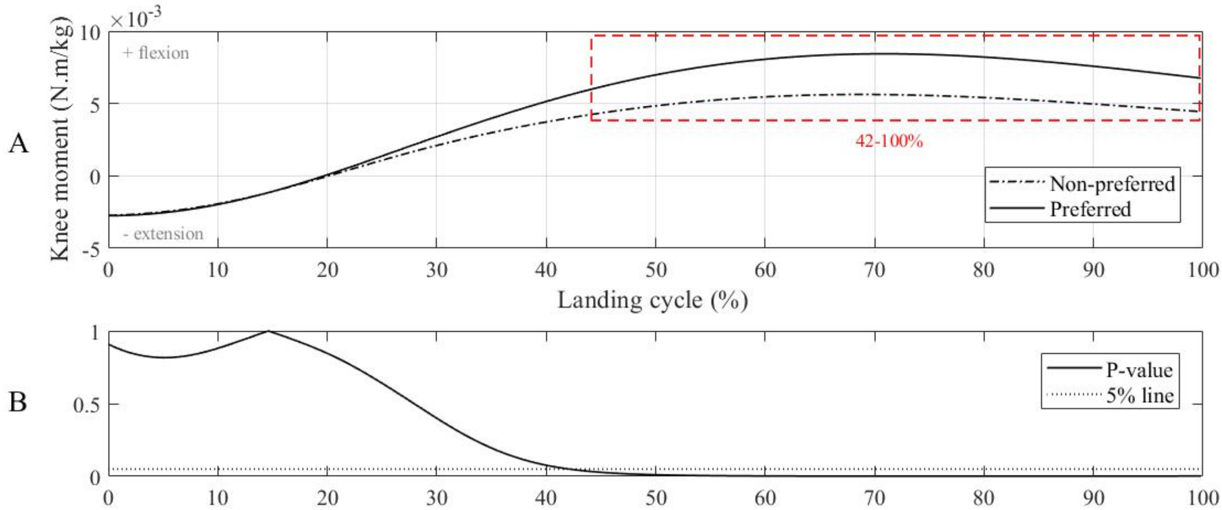
Figure 32 – Effect of group for GRFv by crossover hop test classification.



A: mean of each group for GRFv, the red dotted line showed interval with differences between groups; B: p value throughout landing cycle for group effect.
ASY: asymmetrical group; BW: body weight; GRFv: vertical component of ground reaction force; SYM: symmetrical group.
Source: by the author.

Regarding leg main effect, only for knee sagittal plane moment leg played an effect. Preferred leg presented higher values from 42 to 100% of landing cycle (Figure 33).

Figure 33 – Effect of leg for knee sagittal plane moment.



A: mean of each leg for knee sagittal moment; B: p value throughout landing cycle for leg effect.
Source: by the author.

9 CHAPTER NINE – DISCUSSION AND CONCLUSIONS

This dissertation explores how clinical tests can be used to assess risk factors of ACL injury. We found that particular combinations of clinical tests can predict important biomechanical variables during performance of unilateral and bilateral drop jumps. Furthermore, there are key biomechanical differences between a group of participants showing proximal only deviations and a group showing both proximal and distal deviations during the LSD test performance. Male recreational athletes showing both proximal and distal deviations in the LSD performed landing tasks in a way that may increase the risk for injury in landing tasks common in sports practice, e.g., with lower hip abduction and worse impact absorption. Regarding asymmetries, despite being a measure easy to implement, isometric hip strength asymmetry was just poorly associated with clinical and biomechanical asymmetries, and only hip adductor strength asymmetry predicted asymmetry in one clinical test, the triple hop test. In addition, we identified that asymmetry in the hop tests does not correspond to asymmetry in biomechanical outcomes related to quadriceps dominance theory. On the other hand, using 10% symmetry criteria, the single and crossover hop test asymmetry classifications can identify differences in the unilateral landing kinects in male recreational athletes but not in kinematics. Association with strength resultant of concentric and eccentric actions still need clarification. Altogether, we suggest that clinical test selection should consider the main risk factors, proximal or distal deviations, and individually assess preferred and non-preferred legs. Although this reveals an already expected complex scenario, it provides important directions for clinical assessment and can potentially help clinical decision making.

9.1 The use of clinical tests as predictors of biomechanical outcomes during lading tasks

We aimed to investigate models that could include results of clinical tests to predict biomechanics characteristics of movement that are associated with risk factors and mechanisms for an ACL injury during unilateral and bilateral jump landing tasks. Our main finding is that combinations of clinical tests can predict important biomechanical characteristics associated with risk factors of ACL injury in healthy individuals. However, when clinical tests are applied individually, they rarely provided good predictions. Among the more important biomechanical outcomes during unilateral landings in the context of an ACL injury, those related to trunk and quadriceps dominance theories had stronger predictive models when a combination of tests was utilized (up to 46% and 41% of variance explained, respectively). For the ligament dominance theory, predictions were weak, with up to 29% of explained variance for unilateral landings, while better predictions were found for bilateral landings biomechanics, explaining up to 45% of variance, mainly for hip frontal plane outcomes. Individually, only the triple and the crossover hop tests provided good predictions for bilateral landings biomechanics. In general, combining a test of strength or performance with a test of dynamic balance or quality of movement improves predictive power. We suggest that particular combinations of clinical tests can predict important biomechanical variables.

9.1.1 Prediction of unilateral landings biomechanics

The evidence suggests that neuromuscular deficit profiles relate to biomechanical or neuromuscular coordination (HEWETT; FORD; HOOGENBOOM; MYER, 2010). In chapter four, we addressed risk factors related to three of these profiles (the ligament, the quadriceps, and the trunk dominance theories). For the dominance theory, we investigated whether a group of clinical tests could provide a more robust screening for a knee injury. The different clinical tests predicted most biomechanics outcomes related to the quadriceps dominance theory. Crossover hop test, lateral step down, and knee extensor strength were stronger predictors for outcomes related to the quadriceps dominance (e.g., anterior shear stress to the tibia due to unbalanced recruitment of the knee flexors and extensors (LOPES; SIMIC; MYER; FORD *et al.*, 2018)). However, these outcomes were also predicted by hip adductor strength, triple and single hop tests, SEBT anterior and posterolateral directions, and SEBT total score.

Different outcomes predicted sagittal and frontal plane biomechanical characteristics related to the trunk dominance theory. Sagittal plane kinematics were predicted mostly by knee and hip strength, while frontal plane measures were better predicted by hip strength. As observed for other outcomes, the combination of performance tests improves prediction, specifically frontal plane outcomes being predicted by hip strength and single and triple hop tests. Hip strength is largely included in predictions of trunk dominance theory outcomes because hip muscle activity is important for pelvic stability (GOTTSCHALL; OKITA; SHEEHAN, 2012). In addition, hip strength predictions may result from the larger demands on hip musculature in unilateral landing. The performance of unilateral landings elicits lower sagittal plane movement but requires higher knee and hip frontal plane movement control capacity (PAPPAS; HAGINS; SHEIKHZADEH; NORDIN *et al.*, 2007; TAYLOR; FORD; NGUYEN; SHULTZ, 2016). Knee strength also contributes to pelvis movement control during unilateral landings showing association with hip adduction (MCCURDY; WALKER;

ARMSTRONG; LANGFORD, 2014). Therefore, knee and hip strength are important clinical outcomes related to trunk dominance theory outcomes.

The ligament dominance theory has received a lot of attention in the literature (PAPPAS; SHIYKO; FORD; MYER *et al.*, 2016) and in terms of clinical tests predictors (SALMON; RUSSELL; MUSGROVE; PINCZEWSKI *et al.*). However, unlike bilateral landings, we did not find strong predictors related to this dominance theory during unilateral landings by clinical tests. Knee abductor moment (KAM) is a key measure to estimate ACL strain (BATES; SCHILATY; NAGELLI; KRYCH *et al.*, 2019), but it is also a complex variable to determine. The fact that the crossover hop test, LSD, and hip adductor strength predicted KAM in our study, even with small to medium effect sizes, may provide important additional support to help decide about what variables to include in a biomechanics assessment. The magnitude of KAM is influenced by the capacity of control of multiarticular movement (KETTLETY; LINDSEY; EDDO; PREBBLE *et al.*, 2020; NGUYEN; TAYLOR; WIMBISH; KEITH *et al.*, 2018). We expected that the crossover hop test could predict KAM and also be part of other predictions. Crossover hop test does not require only strength (SCHMITT; PATERNO; HEWETT, 2012), but it also leads to larger KAM due to the need for control of mediolateral movements, greater hip adduction and flexion, and proximal movements of the trunk and pelvis (ORTIZ; OLSON; TRUDELLE-JACKSON; ROSARIO *et al.*, 2011). These biomechanical characteristics are associated with the ACL injury mechanisms, which may explain the findings. Non-sagittal knee kinematics are important during landing tasks because dynamic knee valgus involves frontal and transverse plane movements that are associated with ACL strain and considered a high-risk factor for an ACL injury (BATES; MYER; HALE; SCHILATY *et al.*, 2020). Larger dynamic valgus results in excessive hip adduction and internal rotation during weight-bearing. Knee valgus angle and moment are higher in the presence of a reduced range of motion for hip and knee flexion (POLLARD; SIGWARD; POWERS, 2010) and ankle dorsiflexion during landing (LIMA; FERREIRA; DE PAULA LIMA; BEZERRA *et al.*, 2018). An altered dynamic knee valgus may originate from proximal or distal joints, which challenges the identification of prediction models. The complexity for control of this movement may account for predictions observed considering hop tests (single, triple, and crossover), LSD, and SEBT total scores with moderate to large effect sizes. The LSD was included in most prediction models for the preferred leg. We argue that its association with tests for performance most likely results of its execution requiring complex and combined neuromuscular control for the trunk, hip, and knee (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). The influence of leg preference was not specifically addressed in our experiment, but we would hypothesize that daily recruitment of preferred leg for tasks requiring performance outcomes might have accounted for this result in LSD predictions (CARPES; MOTA; FARIA, 2010).

Although most participants showed right footedness, there were different predictive outcomes for the preferred and non-preferred leg. The preferred leg is generally more recruited for actions requiring force and mobility, while the non-preferred leg is more recruited for stabilization tasks (CARPES; MOTA; FARIA, 2010). There is no clear relationship between the preferred leg to kick a ball and the preferred leg to perform a unilateral landing (CARCIA; CACOLICE; MCGEARY, 2019). Non-preferred leg makes better force absorption in motor tasks like the change of direction, whereas preferred leg may be more related to performing technical skills (CONDELLO; KERNOZEK; TESSITORE; FOSTER, 2016). Asymmetries are known to be task-dependent, and therefore the particular demand for each leg in different tasks can lead to different strategies during performance of clinical tests, which limits prediction models. It is difficult to identify which leg can be injured, therefore, the assessment and prevention for both legs still is the better choice. The influence of leg preference and related asymmetries on assessment and prediction models still needs further exploration.

Despite the variation in prediction considering the landing leg, a combination of at least two clinical tests improves the predictive power of the clinical assessment. However, there was a specific test showing predictive potential when considered alone, the knee and hip strength. Knee strength is associated with knee movement control during unilateral landings (KOBAYASHI; KUBO; MATSUBAYASHI; MATSUO *et al.*, 2013; NAGAI; SELL; HOUSE; ABT *et al.*, 2013) and plays an important role in impact attenuation during landing (NAGAI; SELL; HOUSE; ABT *et al.*, 2013), while hip strength is associated with the prediction of new non-contact ACL injuries (KHAYAMBASHI; GHODDOSI; STRAUB; POWERS, 2016). Those associations could explain the impact of these measures on assessment with a focus on injury prevention. We recommend that not only knee strength should be part of the clinical test batteries, but also hip strength.

Our results support the use of the single hop test combined with another clinical test to predict knee valgus, pelvis obliquity and GRF in the preferred leg. However, single hop test showed no predictive potential when considered alone. The triple hop test predicted most biomechanics outcomes related to the pelvis and hip rotations. It makes sense as the triple hop test requires significant effort from the gluteus maximus, gluteus medius, and erector spinae to compensate adduction torque generated by the contralateral body weight (ALVIM; LUCARELI; MENEGALDO, 2018). Moreover, it requires knee co-contraction and moderate activity of knee extensors to compensate knee flexion by hamstrings, eccentric control of hip and knee flexion, and co-contraction of ankle muscles (ALVIM; LUCARELI; MENEGALDO, 2018). This complex movement involving at least three joints from the lower extremity and the number of degrees of freedom to control explain the triple hop test predicting ankle, knee, and hip sagittal plane angles. It is important to note that we found good predictive capacity for the triple hop test with the distance performance standardized, such as another study including this test in a model to predict the risk for re-injury and return to sport (PATERNO; HUANG; THOMAS; HEWETT *et al.*, 2017). Results from tests with non-standardized distances were not inserted in other predictions models (LOSCIALE; ZDEB; LEDBETTER; REIMAN *et al.*, 2019). The crossover hop test has also shown a good predictive capacity for KAM, trunk sagittal angles, and GRF outcomes. We consider these outcomes resulting from the larger hip adduction and flexion angles, and greater extension and abduction knee moments observed during crossover performance in healthy individuals (ORTIZ; OLSON; TRUDELLE-JACKSON; ROSARIO *et al.*, 2011). Therefore, the consideration of different hop tests in the assessment of landing biomechanics is highly recommended.

9.1.2 Prediction of bilateral landings biomechanics

We interpreted our findings as demonstrating a better prediction capacity by clinical tests for outcomes related to the ligament dominance theory during bilateral landings. These findings supplement those from unilateral landings, where predictions were stronger for quadriceps and trunk dominance theories outcomes and demonstrate the variability and complexity in prediction of biomechanical deficits. The triple hop test, SEBT total score, LSD, and knee and hip strength were the main clinical tests predicting ligament dominance theory outcomes. Hip strength and LSD were the main clinical tests predicting outcomes related to the quadriceps theory. The triple and crossover hop tests predicted outcomes related to the trunk dominance theory. Individually, only the triple and the crossover hop tests provided good predictions.

The SEBT, LSD, triple hop test, and hip strength were the clinical tests more frequently related to predictions for ligament dominance theory. The LSD predictions are supported by the association between hip external rotation, knee extension strength, and the quality of movement in the test (SILVA; PINHEIRO; LINS; DE OLIVEIRA *et al.*, 2019). Peak knee valgus angle measured during bilateral drop landings was inversely related to isometric hip external rotation, abductor strength, and knee extensor and flexor strength (MCCURDY; WALKER; ARMSTRONG; LANGFORD, 2014). Our findings agree with these previous studies and provide evidence that hip and knee strength are associated with hip outcomes related to the ligament dominance theory (ALVIM; LUCARELI; MENEGALDO, 2018). Due to the higher challenge for controlling frontal plane movements, the predictions of ligament theory outcomes should be expected. Higher SEBT total score and lower SEBT total score asymmetry, stronger hip adductors, and lower triple hop test asymmetry were associated with lower deficits related to the ligament dominance theory. Therefore, clinicians can be encouraged to include SEBT, LSD, triple hop test, and hip strength assessments for predicting biomechanical outcomes related to ligament dominance.

The predictive roles of knee and hip isometric strength differ between biomechanics of unilateral and bilateral landings. Bilateral landing is less demanding considering movements in sagittal plane but requires knee strength contribution and frontal plane movement control due to larger joint excursions. Hip strength was more associated with outcomes of bilateral than unilateral jumps (MCCURDY; WALKER; ARMSTRONG; LANGFORD, 2014). For example, a previous study did not find a prediction of knee valgus during bilateral drop jump by quadriceps, hamstrings, and hip abductor isokinetic strength, while hip adductor strength was not considered (NILSTAD; KROSSHAUG; MOK; BAHR *et al.*, 2015). We would say that hip adductor strength and the ratio between adductor and abductor strength can be more relevant than assessing only hip abductor strength. The hip isometric strength is recognized as a predictor of new non-contact ACL injuries (KHAYAMBASHI; GHODDOSI; STRAUB; POWERS, 2016; LEETUN; IRELAND; WILLSON; BALLANTYNE *et al.*, 2004), and therefore, we recommend assessment of hip strength to be part of the clinical test batteries. We are aware that our discussion concerns isometric strength while landing cycle involves a significant amount of eccentric force. However, we included measures of isometric strength due to its easy implementation and also because maximal isometric strength can be higher than observed for a concentric action, and eccentric measures can be more difficult to obtain due to instrumentation requirements (BARONI; FRANKE RDE; RODRIGUES; GEREMIA *et al.*, 2016).

The potential of a single clinical test to predict outcomes related to injury is of interest. Applying a single test can expedite assessment. However, the complex movement of landing makes it challenging, not to say impossible, to identify a single clinical predictor. The more promising single clinical predictors were the triple and crossover hop tests, but these tests combine different motor control demands. As we discussed above, due to the higher demand for frontal plane control than sagittal plane, the challenge provided by these clinical tests could explain these predictions. There is a high demand for frontal plane movement control during triple and crossover hop tests to compensate adduction torque produced by contralateral body weight during single leg support (ALVIM; LUCARELI; MENEGALDO, 2018; ORTIZ; OLSON; TRUDELLE-JACKSON; ROSARIO *et al.*, 2011). Thus, a complex task challenging frontal plane movement control seems to be more critical to be considered alone than single joint strength. Therefore, the consideration of different hop tests in assessing bilateral landing biomechanics is recommended.

Even though clinical tests are better predictors of biomechanical outcomes for unilateral than bilateral landings, athletes are exposed to both unilateral and bilateral landings in sports actions. Thus, our findings provide relevant information for clinicians and highlight that the clinical tests can predict different outcomes according to the type of jump.

9.1.3 Session highlights

Table 5 summarizes the main outcomes of the different experiments involving recreational men athletes included in this section.

Table 5 – Highlights of unilateral and bilateral biomechanics predictions by clinical tests.

Unilateral landings predictions	Bilateral landings predictions
• Clinical tests can predict outcomes related to trunk and quadriceps dominance theories better than the ligament dominance theory in unilateral landings. • The combination of at least one test for strength, one for performance, and one for dynamic balance or quality of movement improve predictions. • Isometric knee and hip strength should be considered for clinical assessment of knee injury risk during the performance of unilateral landing tasks. • Crossover hop test, LSD, and knee extensor strength showed the strongest prediction for outcomes related to quadriceps dominance. • Knee and hip strength are important predictors for trunk dominance theory.	• Combining one test for strength or performance with dynamic balance or quality of movement improves predictions. • The SEBT, LSD, triple hop test, and hip strength provide good predictions for ligament dominance theory outcomes in bilateral landing. • Hip strength should be part of clinical assessment of knee injury risk during bilateral drop jump. • Clinical tests have a stronger prediction of outcomes related to ligament dominance theory than quadriceps and trunk dominance theories. • The predictive power of clinical tests may depend on jump type and leg preference.

LSD: lateral step down; SEBT: star excursion balance test.
Source: by the author.

9.2 Applicability of clinical tests to stratify individuals

We considered LSD outcomes to stratify individuals with proximal or distal performance deviations in chapter six. This stratification allowed us to identify key biomechanical differences between the groups that demonstrated proximal only deviations and the group that had both proximal and distal deviations identified by the LSD test. The proximal deviation was frontal pelvis drop down deviation and combined proximal and distal was a combination of frontal pelvis drop down and medial knee displacement to 2^{nd} toe deviations. The group with both proximal and distal deviations landed with biomechanics characteristics that may increase injury risk during unilateral drop landing.

A drop jump landing technique to minimize risk factors for injury is dependent on strength (STRUZIK; JURAS; PIETRASZEWSKI; ROKITA, 2016) and joint range of motion (MALONEY; RICHARDS; FLETCHER, 2018). Unilateral landings involve higher hip adduction, less knee and hip flexion (TAYLOR; FORD; NGUYEN; SHULTZ, 2016), higher center of mass displacement and ground reaction force (MALONEY; RICHARDS; FLETCHER, 2018) combined with lower angular velocity (DOWLING; FAVRE; ANDRIACCHI, 2012) compared to bilateral landings. Therefore, unilateral landings increase demand for kinetic absorption by lower extremity. Individuals with less quality of movement could experience worse kinetic absorption as all lower extremity movements can influence landing strategy. We found participants identified with combined deviations (hip and knee deviations) in LSD showing worse impact absorption performance than participants with only proximal deviations. The lack of control of both proximal and distal joints during a step-down was translated as a lower ability for impact absorption in unilateral landing. Because both tasks (step-down and landing) demand frontal plane control, especially from hip adduction (MOSTAED; WERNER; BARRIOS, 2018; TAYLOR; FORD; NGUYEN; SHULTZ, 2016), it would be expected to see individuals with less frontal plane control in step-down tasking also showing lower ability to absorb impact. Impact absorption involves greater sagittal plane motion, which is impaired by larger deviations in frontal plane. Even though we did not find difference between groups concerning hip angles, the lower movement control in frontal plane identifies individuals with lower ability to absorb impact. This compensation on participants from the combined group may account for an increased risk of injury due to worst impact absorption during landing (LEPPANEN; PASANEN; KUJALA; VASANKARI *et al.*, 2017).

LSD performance may show a specific relationship with performance of unilateral jump landing. As step-down tasks, squat movements elicit larger hip flexion, knee flexion, knee abduction, and hip abduction (DONOHUE; ELLIS; HEINBAUGH; STEPHENSON *et al.*, 2015). Moreover, the unilateral and bilateral jumping tasks are substantially different in between. Unilateral jumps involve lower knee and hip flexion, lower hip abduction (DONOHUE; ELLIS; HEINBAUGH; STEPHENSON *et al.*, 2015; TAYLOR; FORD; NGUYEN; SHULTZ, 2016), and higher knee valgus than bilateral jumps (PAPPAS; HAGINS; SHEIKHZADEH; NORDIN *et al.*, 2007). Forward jump also presents a different pattern from bilateral drop jump, with lower knee and hip flexion, and higher hip abduction (HEEBNER; RAFFERTY; WOHLEBER; SIMONSON *et al.*, 2017). In sports practice there are different jump landing techniques inherent to the performance; those different kinematics strategies between jumps can elucidate our different findings.

As mentioned above, frontal plane control impairs directly the performance in LSD with poor quality of movement associated with higher hip adduction (RABIN; PORTNOY; KOZOL, 2016). We found participants from the combined group presenting higher hip adduction in the preferred leg during bilateral landings than those in proximal only group. Frontal plane control in lower extremities is impaired by ankle dorsiflexion excursion, like performance in step-down and landings. However ankle excursion is not assessed as clinical criteria during LSD and less ankle dorsiflexion was seen in a poor step-down task and also during landing (DONOVAN; MIKLOVIC; FEGER, 2018). It could explain the higher frontal plane deviations in combined group showing higher hip adduction in landing.

Lateral step down test is described as highly sensitive to stratify kinematic differences in individuals with patellofemoral pain (LOPES FERREIRA; BARTON; DELGADO BORGES; DOS ANJOS RABELO *et al.*, 2019). In our study, LSD performance did not differ the majority of landing kinematic in male health individuals, especially during unilateral landings. It seems that LSD is a good test to indicate kinematic stratification in individuals with pathology, but not for identification of risk factors for knee injury in healthy individuals. We hypothesize that to identify risk factors in healthy individuals a clinical test involving more center of mass acceleration and a higher kinetic demand might be needed since the injury mechanism involves higher loading. Therefore, the clinical criteria in LSD did not translate into knee and hip kinematics differences during unilateral landings.

9.2.1 Session highlights

The main outcomes of the different experiments involving recreational men athletes included in this section are summarized below:

- LSD can stratify impact absorption differences during unilateral landings in male health individuals;
- LSD deviations did not translate into kinematic differences during unilateral landings.
- During bilateral landings, individuals with proximal and distal deviations in LSD showed more hip adduction;
- LSD deviations interact differently between unilateral and bilateral landing tasks.

9.3 Correspondence between hip strength asymmetries and asymmetries in clinical and biomechanical outcomes

Hip joint capacities for motion and stability play a major role in performance of many sports tasks. In jump landing tasks, these characteristics are associated with both jump propulsion and landing phases. Related to this, the control of knee movements in mediolateral direction also relates to proper control of hip movements (POWERS, 2010). In this regard, hip stability in the frontal plane depends on the activity of muscles producing adduction and abduction movement. Based on the assumption that leg asymmetries are often discussed as a source of performance deviation as well as a risk factor for injury, we investigated whether hip adductor and abductor strength asymmetries can predict asymmetries in clinical and biomechanical outcomes during unilateral landings in recreational male athletes performing functional tests and jump landing tasks. We found the hip adductor strength asymmetry only predicting asymmetry in the triple hop test performance. Predictions were not found either for other functional tests or the biomechanics of unilateral drop jump. Hip abductor strength asymmetry did not predict asymmetries in any clinical tests or biomechanical outcomes.

Hip adductor strength is related to great effort during specific sports activities, such as kicking (JENSEN; BANDHOLM; HÖLMICH; THORBORG, 2014). However, hip adductor strength is often underrated in studies identifying hip strength as a measure related to injury risk and altered movement patterns. In chapters four and five we identified that hip adductor strength plays a more important role in risk factors associated with ACL injury predictions than abductor strength. Hip adductor strength was mainly associated with biomechanical outcomes controlling proximal (trunk and hip) stabilization in sagittal and transverse planes, hip and knee frontal plane moments and GRFv. It helps to explain the association found between hip adductor strength asymmetry and triple hop asymmetry. Triple hop requires strong control of trunk movement, elicits co-contraction of knee muscles, eccentric control of hip motion, and stabilization of contralateral swing limb due to single leg support (ALVIM; LUCARELI; MENEGALDO, 2018). Therefore, an asymmetry hip strength could lead to worse pelvic stabilization during hoping in one leg and impair hop performance.

Asymmetry in hip abductor strength was identified as a risk factor for the development of non-contact acute lower extremity injuries (DE BLAISER; ROOSEN; WILLEMS; DE BLEECKER *et al.*, 2021). It was also associated with impairment in running economy (BLAGROVE; BISHOP; HOWATSON; HAYES, 2021). The lack of prediction of clinical tests asymmetry by hip abductor strength observed here was also reported in a previous study (WILLIGENBURG; HEWETT, 2017). The SEBT, LSD and hop test involves activation of abductors muscles and also pelvic stabilization provided by recruitment of adductors and abductors muscles (ALVIM; LUCARELI; MENEGALDO, 2018; BHANOT; KAUR; BRODY; BRIDGES *et al.*, 2019; PARK; LEE; CHEON; YONG *et al.*, 2019). All tests are performed unilaterally in a way requiring pelvic stabilization from adduction and abduction muscles. Even though we did not investigate the ratio between hip adductor and abductor strength, asymmetry in hip strength could be more associated with pelvic stabilization and asymmetry during performance of unilateral clinical tests. In addition, performance during SEBT, LSD and hop test has been associated with knee and hip extension strength (DAVIES; MYER; READ, 2020; PARK; LEE; CHEON; YONG *et al.*, 2019; PINHEIRO; OCARINO; BITTENCOURT; SOUZA *et al.*, 2019). Asymmetry in knee extension strength was associated with asymmetry in single and triple hop tests in patients after ACL reconstruction (SCHMITT; PATERNO; HEWETT, 2012). However, if this association is observed in healthy individuals and other clinical tests still claims for research considering it for predictions of clinical tests asymmetries. It is important to recognize that these movements have high complexity in terms of movement control, which can explain the lack of relationship we found here.

9.3.1 Session highlights

The main outcomes related to hip strength asymmetries and asymmetries in clinical and biomechanical outcomes are summarized as:

- Clinical and biomechanical asymmetries are poorly predicted by asymmetries in hip adductor and abductor strength;
- Hip adductor strength asymmetry predicted asymmetry in triple hop test;
- Hip strength asymmetry should not be considered alone when assessing asymmetry in dynamic movements;

- Hip adductor strength should be considered in clinical assessments and future studies.

9.4 Correspondence between the 10% asymmetry criteria in hop tests and biomechanical outcomes

There is a continuous interest in the identification of specific references values for asymmetries in terms of injury and performance. Asymmetries higher than 10% have been recognized as clinical important asymmetries (EBERT; EDWARDS; PREEZ; FURZER *et al.*, 2021; THOMEE; KAPLAN; KVIST; MYKLEBUST *et al.*, 2011). We identified whether asymmetries in hop tests elucidate the difference in key biomechanical outcomes related to knee injury risk during unilateral landings in male recreational athletes. As we have shown in chapter eight, asymmetry in hop test did not correspond to asymmetry in biomechanical outcomes related to quadriceps dominance theory using 10% criteria. Meanwhile, the group classification by single and crossover hop tests identified biomechanical differences outcomes between asymmetrical and symmetrical groups. The asymmetrical group presented lower hip extension moment and lower GRFv in the first half of landing cycle considering single and crossover classification. In addition, considering crossover hop test classification, asymmetrical group presented a lower knee flexion moment in the midphase of landing cycle. We suggest the classification by single and crossover hop test asymmetry can identify differences in the unilateral landing kinects in male recreational athletes but not in kinematics.

Biomechanical asymmetries are task-dependent. For example, an individual can show asymmetry in landing but not in squat for the same outcome. Association between hop distance and loading symmetry was found in patients after ACL reconstruction, but loading symmetry still provided different information than hop distance symmetry (PEEBLES; RENNER; MILLER; MOSKAL *et al.*, 2019). However, this is not a consistent observation in the literature. Another study did not find a relation between hop asymmetry and kinetic or kinematic asymmetries after ACL reconstruction (XERGIA; PAPPAS; GEORGOULIS, 2015). Here we found that asymmetry in hop tests did not translate into asymmetry in biomechanical outcomes during unilateral drop landing performed in male recreational athletes with no injury history. The characteristic of the task could explain the non-agreement when it comes to asymmetry. The task-dependent nature of asymmetries is observed when hop jumps and vertical jumps are compared and show different asymmetry magnitudes (ZARRO; STITZLEIN; LEE; ROWLAND *et al.*, 2021). Therefore, clinicians need to carefully interpret results regarding asymmetry from hop tests aiming to assess the risk of injury considering quadriceps dominance theory outcomes from unilateral drop jumps.

Even though asymmetry did not match between the hop test and biomechanical outcomes related to quadriceps dominance theory in unilateral drop jumps, the single and crossover hop test asymmetry can be used to differentiate participants. For example, we found that the asymmetrical participants classified by single and crossover tests presented lower hip extension moment and lower GRFv in the first half of landing cycle. It agrees with our findings described in chapter four, where we demonstrated that single and crossover hop tests are involved in predictions of GRFv. The loading characterization of the hop test can explain these findings. During single hop test there is a higher joint work demand at the hip and ankle joints during propulsion, and at the knee joint during landing (KOTSIFAKI; KORAKAKIS; GRAHAM-SMITH; SIDERIS *et al.*, 2021). This loading strategy involving all lower extremity is related to GRFv absorption demand. Also, during the crossover hop test, landing technique to absorb impact forces elicit larger hip flexion and hip adduction angles related to trunk movements in the anteroposterior and mediolateral directions (ORTIZ; OLSON; TRUDELLE-JACKSON; ROSARIO *et al.*, 2011).

Crossover hop test classification differed participants regarding knee flexion moment. The asymmetrical group presented a lower knee flexion moment in the midphase of landing cycle. The relation between crossover hop test (results presented in chapter four) and peak, rate of impact absorption and force magnitude at the maximal knee flexion of GRFv explains the high demand for kinetic control on sagittal plane. Even if crossover hop tests have intrinsic knee mediolateral demand, we cannot underestimate the demand and applicability of this test regarding knee sagittal plane kinetic. Furthermore, the higher range of motion for knee sagittal plane movement (compared to frontal and transverse planes) may explain the sensitivity of knee flexion moment in the crossover classification. Participants may rely more on sagittal knee kinetics to absorb impact during knee flexion in landing phase.

Correlation in performance and asymmetry between different hop tests is expected in an injured population (EBERT; DU PREEZ; FURZER; EDWARDS *et al.*, 2021; SONESSON; ÖSTERBERG; GAUFFIN; ARDERN *et al.*, 2021). This correlation is moderate because additional factors influence the difference between hop tests. Here, single, triple and crossover tests showed poor agreement and differed concerning their capacity to identify kinetic differences following their classification. Triple hop test asymmetry used as classification criteria masked kinetic biomechanical asymmetries identified by single and crossover hop tests. Similar findings were previously reported for injured individuals, where triple hop tests lacked to identify asymmetries in knee function (KOTSIFAKI; VAN ROSSOM; WHITELEY; KORAKAKIS *et al.*, 2022). It could be explained by the relation between triple hop test asymmetry with ankle, knee and pelvis kinematics but not with any kinetic outcome during unilateral landings, as described in chapter four. Therefore, asymmetry findings from hop tests are not correspondent to asymmetries in biomechanical outcomes.

9.4.1 Session highlights

The highlights concerning the correspondence between asymmetry in hop tests and biomechanical outcomes are summarized as follow:

- Group classification by asymmetry in hop tests does not correspond to asymmetry in biomechanical outcomes related to quadriceps dominance theory in male recreational athletes;
- The use of hop tests to identify asymmetries related to risk of injury during unilateral landing should not be encouraged;
- The use of 10% criteria for asymmetry as group classification seems relevant for kinects outcomes during unilateral landings;
- Asymmetrical group produces lower moments at the hip joint during landing, showing lower hip extension moment considering single and crossover classifications;
- The GRFv patterns to reach the peak values differ between asymmetrical and non-asymmetrical groups using single and crossover classification;
- Crossover hop test asymmetry classification identifies lower knee flexion moment in asymmetrical group;
- Group classification by asymmetry in triple hop test does not correspond to group differences in unilateral landings.

9.5 Limitations

Our study has inherent limitations. We cannot extrapolate our conclusions to women because sex differences for many of the biomechanics outcomes must be considered. Our predictions are limited to the clinical tests and biomechanical outcomes considered, therefore, we cannot ensure that predictions will remain significant if the movement technique is changed.

We considered a sample of recreational athletes who performed different sports-related activities to better translate to the clinical field. However, for highly trained athletes, these results needed to be investigated because the level of muscle strength and specific training skills can differ between them. Clinical outcomes were considered as primary defined. Our strength measures considered isometric force assessed by a hand-held dynamometer to better represents the clinical measures. However, it does not refer to dynamic muscles strength application.

9.6 Conclusions

- For recreational male athletes, functional tests can predict biomechanical outcomes suggested to increase risk factors for ACL injury during unilateral landing tasks. Better prediction is achieved when specific functional tests are combined. Outcomes related to trunk and quadriceps dominance theories show stronger predictions than ligament dominance theory. Crossover hop test, lateral step down, and knee extensor strength show stronger prediction for outcomes related to the quadriceps dominance, and knee and hip strength for trunk dominance theory. Knee and hip strength, crossover and triple hop tests, and lateral step down provide a good prediction of knee loading and dynamic valgus control during unilateral drop landings.
- Clinical tests can predict specific biomechanical outcomes during bilateral drop jump related to risk factors for ACL injury in recreational male athletes. Biomechanical outcomes related to ligament dominance theory show stronger predictions than quadriceps and trunk dominance. Triple hop test, SEBT total score, LSD, and knee and hip strength are the clinical tests better predicting ligament dominance theory outcomes. Single hop test, SEBT individual scores, and knee extensor strength individually do not predict biomechanical characteristics during landing of bilateral drop jump. A combination of at least two clinical tests is recommended for stronger predictions. Only triple and crossover hop tests show good predictions when considered alone.
- Male recreational athletes showing both proximal and distal deviations during LSD performance land in a way that may increase the risk for injury in landing tasks common in sports practice. Individuals with combined deviations in the LSD demonstrate lower hip abduction of the preferred leg and worse impact absorption landing with the non-preferred leg. We suggest special attention for LSD outcomes for preferred and non-preferred legs considering hip kinematics and impact absorption, respectively.

- Hip abductor strength asymmetry might not translate into asymmetries in clinical tests or biomechanical outcomes during unilateral drop jumps. Only hip adductor strength asymmetry predicts asymmetry in one clinical test, the triple hop test.
- Asymmetry in the hop tests does not correspond to asymmetry in biomechanical outcomes related to quadriceps dominance theory. However, the 10% symmetry criteria to classify groups identifies biomechanical differences considering asymmetries in single and crossover hop tests. The single and crossover hop test asymmetry classifications can identify differences in the unilateral landing kinetics, but not in kinematics, in male recreational athletes. The asymmetrical participants present lower hip extension moment and lower GRFv in the first half of landing cycle considering single and crossover classification. In addition, considering crossover hop test classification, asymmetrical participants present lower knee flexion moment in the midphase of landing cycle.

10 COMMENTS ABOUT GRADUATION PERIOD

During the Ph.D. program, I was involved in several activities related and non-related to my research. These activities provided me with important experiences for my academic and personal formation. The most relevant are detailed in this topic.

10.1 Activities related to the dissertation project

The original dissertation's purpose included three projects as part of a clinical trial. The first would involve a transversal design to understand the relationship between clinical tests and biomechanical outcomes, which originates part of this dissertation. The second would involve the acute effect of plyometric exercises on tendon mechanics and muscle damage (NCT04273971). The third would relate to the development of an injury prevention program lasting 10 weeks combining plyometric exercise with maximal strength (NCT04139187). However, due to the COVID pandemic, the second and third projects had to be stopped. So far, we have collected data from 21 participants (needing 9 participants to complete the sample size) and 10 participants (needing 22 participants to complete the sample size), respectively. To develop these projects, I attended courses and participated in data collection and analysis training. I have also attended courses about clinical trials methodology and data analysis. In addition, I attended a training period at Universidade Federal do Rio Grande do Sul to learn about ultrasound data collection. With the preliminary data of the unfinished projects, two abstracts were submitted to conferences. In the 2020 and 2021 Annual Congress of Brazilian Society of Physiology, I presented the abstracts “Differences in knee extensors and flexors muscle damage following plyometric exercise in healthy adults” and “Does plyometric exercises cause damage to the biceps femoris tendon in male recreational athletes?”. I expect to be able to finish these projects at some point shortly.

10.2 Activities related to Ph.D. graduate program

The Multicenter Graduate Program in Physiological Sciences involves taking courses in referential universities. I had the opportunity to attend two courses at the Universidade de São Paulo – Campus Ribeirão Preto and develop an internship in the Laboratory of Biomechanics and Motor Control under the supervision of professor Paulo Santiago. In addition, I developed a network with professor Matheus Gomes and Ph.D. students Marina

Villalba and Rafal Fujita during this period, which resulted in conducting a systematic review in collaboration. The review paper is titled "Effects of co-contraction training on neuromuscular outcomes of elbow flexors and extensors: a systematic review with meta-analysis" and currently is submitted to *Scientific Reports*.

I was also the student representative in our Graduate Program Committee from March 2018 until March 2022. It was an outstanding opportunity to get involved with administrative issues and also to get involved with all students representatives from our Program and based in other Universities part of the network that composes the program. In addition, I was involved in the organization of two events, the I and II Encontro Online do PPGMCF (2021-2022). Also, I had the opportunity to take part in a round table to talk about challenges for the early career scientist workforce in the Multicenter Graduate Program in Physiological Sciences Meeting 2021, part of the Annual Conference of the Brazilian Society of Physiology. This round table originated a meeting report submitted to *Advances in Physiology Education*.

10.3 Supervision of students

During my Ph.D. I had the opportunity to cosupervise undergraduate students doing research and also help master's student develop their projects. I have worked closely with three undergraduate students from Universidade Federal de Santa Maria and three from Universidade Federal do Pampa, including cosupervision of senior projects. Parallel to my research, I provided support with technical issues and concepts for two master's students. In addition, I delivered technical training for my labmates throughout the graduation period.

10.4 Events and awards

I was able to attend several events. Table 6 summarizes the list of international and national conferences attended.

Table 6 – Conferences attended during graduation.

Type of conference	Conferences attended
International	39th Congress of the International Society of Biomechanics in Sports (2021)*
	XXVIII Congress of the International Society of Biomechanics (2021)*
	Annual Meeting & World Congress of American College Sports Medicine (2021)
	2nd International Knee Day (2021)*
	1st International Knee Day (2020)
	XXVII Congress of the International Society of Biomechanics (2019)*
National	XIX Congresso Brasileiro de Biomecânica (2021)*

56º Congresso Anual da SBFIS OnLine (2021)*
Congresso Internacional da SONAFE Brasil (2021)
I Encontro Online do Programa de Pós-Graduação Multicêntrico em Ciências Fisiológicas (2021)*
X Congresso Brasileiro de Comportamento Motor (2020)*
55º Congresso Anual da SBFIS OnLine (2020)*
Simpósio Internacional de Transparência da Pesquisa em Saúde (2019)
X Simpósio em Neuromecânica Aplicada (2019)*
XVIII Congresso Brasileiro de Biomecânica (2019)*
IX Simpósio em Neuromecânica Aplicada: Populações Especiais (2018)*

* Conferences where I presented at least one abstract.

I was involved in the organization committee of seven events and participated six times in scientific board reviews. I was invited to deliver five lectures and three workshops on topics related to my research and presented a total of seven abstracts at international conferences and seven at national conferences.

The enrollment in the different activities and the abstract presented in events allowed me to receive ten awards as listed below:

- LatinX in Biomechanics Outreach Through National Biomechanics Day Grant Program (2022);
- Melhor trabalho na Categoria Biomecânica do Esporte do XIX Congresso Brasileiro de Biomecânica (2021);
- Apoio à participação de estudantes de graduação e pós-graduação em eventos científicos ou cursos de curta duração da Sociedade Brasileira de Comportamento Motor (2021);
- International Society of Biomechanics Congress Travel Grant (2021);
- Auxílio viagem internacional da Sociedade Brasileira de Biomecânica (2021);
- 3º melhor trabalho na área de Ciências Fisiológicas, no IV Simpósio Integrado dos PPGs (2020);
- Delsys Developing Country Student Grant (2019);
- International Society of Biomechanics Congress Travel Grant (2019);
- Auxílio viagem internacional da Sociedade Brasileira de Biomecânica (2019);
- Menção honrosa no X Simpósio em Neuromecânica Aplicada (2019).

10.5 Research achievements

As a young scientist I developed several skills during graduation, including advanced skills in 3D and 2D kinematic data collection and processing; 3D kinetic data collection and processing; EMG data collection; inferential statistical analysis; systematic review methodology and analysis; methodological procedures conducting transversal and longitudinal projects; strength measures in isokinetic and hand-held dynamometers. In addition, I developed moderate skills in EMG data analysis, Matlab, and ultrasound data collection and analysis, and initial skills in Python.

10.6 Other activities

Teaching: Adjunct professor position at the Universidade Federal do Pampa from 2017 to 2018 and Universidade Franciscana in 2021. My teaching training during the Ph.D. included activities in the courses of Kinesiology for Physical Education students and Biomechanics for Physical Education and Physiotherapy students at the Universidade Federal do Pampa.

Society memberships: Brazilian Society of Biomechanics, Brazilian Society of Physiology, International Society of Biomechanics, American College of Sports Medicine, and International Society of Biomechanics in Sports.

Participation in executive councils: student representative in the Teaching Committee of the Brazilian Society of Biomechanics, and member of the Executive Team of Latinx in Biomechanix organization (@latinxbiomechanix), an initiative aiming to include Latinx and allies in a supportive environment.

Networking: collaborations with researchers from Universidade Federal de Santa Maria, Chile and Universidade Federal do Rio Grande do Sul originating two publications. One original paper published in *Clinical Biomechanics* (Steadiness training improves the quadriceps strength and self-reported outcomes in persistent quadriceps weakness following nine months of anterior cruciate ligament reconstruction and failed conventional physiotherapy) and other paper submitted to *Journal of Sport Rehabilitation* (Lower limb kinematic analysis during lateral step down in female adolescents with and without patellofemoral pain).

Reviewer: served as a reviewer in four journals and completed ten reviews during the Ph.D. period.

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APPENDIX A – Correlation matrix between clinical and biomechanical outcomes – Unilateral landings

Correlation matrix of clinical and biomehcanical outcomes for preferred leg

Biomechanical outcome			Correlation information	Clinical outcomes																					
Joint	Instant	Outcome		Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add	Strength Abd/Add
Knee	IC	Sagittal plane angle	r	0.13	0.141	-0.212	-0.086	-0.089	-0.074	-0.355	-0.057	-0.198	0.000	-0.17	-0.388	-0.279	0.003	-0.299	-0.079	-0.207	0.002	0.168	-0.015	-0.101	0.032
			p	0.383	0.346	0.153	0.567	0.55	0.62	0.014	0.705	0.181	0.999	0.255	0.007	0.058	0.986	0.041	0.6	0.163	0.988	0.26	0.922	0.498	0.829
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	IC	Frontal plane angle	r	0.058	0.33	0.311	0.376	0.409	-0.095	0.035	0.115	0.057	-0.281	0.167	0.194	0.216	-0.352	-0.258	-0.224	0.207	0.159	0.014	0.197	0.187	0.025
			p	0.697	0.023	0.033	0.009	0.004	0.526	0.818	0.442	0.702	0.056	0.263	0.192	0.144	0.015	0.08	0.13	0.163	0.285	0.923	0.184	0.208	0.866
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Ankle	IC	Sagittal plane angle	r	0.045	-0.064	-0.315	-0.269	-0.281	0.069	-0.243	-0.16	-0.175	-0.045	-0.064	-0.244	-0.157	0.042	-0.07	0.126	-0.032	0.054	0.06	0.015	0.084	-0.088
			p	0.765	0.67	0.031	0.068	0.055	0.643	0.1	0.282	0.239	0.762	0.669	0.099	0.291	0.782	0.639	0.397	0.833	0.72	0.689	0.922	0.572	0.558
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Sagittal plane angle	r	0.209	0.273	-0.182	-0.062	-0.029	-0.115	-0.025	0.117	0.025	-0.117	0.012	-0.142	-0.055	0.005	-0.353	-0.069	-0.145	0.128	0.235	-0.199	-0.195	0.019
			p	0.159	0.064	0.22	0.68	0.847	0.44	0.865	0.433	0.87	0.435	0.935	0.34	0.712	0.973	0.015	0.643	0.33	0.392	0.111	0.181	0.19	0.899
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Frontal plane angle	r	-0.102	-0.072	-0.01	-0.111	-0.081	-0.101	-0.032	-0.166	-0.136	-0.050	0	-0.055	-0.073	-0.017	0.066	-0.068	0.176	0.134	-0.056	0.327	0.293	0.027
			p	0.495	0.631	0.949	0.456	0.587	0.498	0.83	0.266	0.363	0.737	0.999	0.714	0.625	0.911	0.658	0.652	0.236	0.371	0.709	0.025	0.046	0.859
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Transverse plane angle	r	-0.001	0.18	0.067	0.035	0.094	-0.173	0.039	0.022	-0.01	-0.207	0.002	-0.013	-0.081	-0.055	0.061	-0.034	0.321	0.239	-0.061	0.186	0.265	-0.125
			p	0.994	0.226	0.653	0.816	0.528	0.246	0.795	0.881	0.947	0.162	0.99	0.933	0.589	0.716	0.683	0.818	0.028	0.106	0.686	0.211	0.072	0.402
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Sagittal plane angle	r	0.130	0.312	0.114	0.155	0.211	0.01	0.169	0.157	0.154	-0.072	0.207	0.123	0.151	-0.031	-0.277	0.065	0.045	0.153	0.096	-0.168	-0.070	-0.002
			p	0.384	0.033	0.447	0.298	0.154	0.948	0.255	0.293	0.302	0.631	0.163	0.411	0.312	0.838	0.06	0.666	0.762	0.304	0.52	0.258	0.642	0.990
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Frontal plane angle	r	-0.202	0.112	0.162	0.07	0.131	-0.109	0.042	-0.064	-0.051	-0.136	0.15	0.02	0.1	-0.302	-0.317	-0.139	0.095	-0.003	-0.081	0.353	0.117	0.273
			p	0.174	0.453	0.276	0.639	0.379	0.464	0.777	0.669	0.733	0.361	0.315	0.892	0.504	0.039	0.03	0.351	0.524	0.983	0.589	0.015	0.434	0.063
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Transverse plane angle*	r	-0.126	0.218	0.167	0.077	0.183	0.107	0.181	0.083	0.118	0.011	0.102	0.042	0.106	-0.171	-0.264	-0.061	-0.175	-0.241	-0.035	0.005	-0.233	0.287
			p	0.400	0.141	0.262	0.608	0.219	0.474	0.224	0.581	0.428	0.943	0.496	0.782	0.478	0.252	0.073	0.683	0.240	0.102	0.818	0.971	0.116	0.051
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Sagittal plane angle	r	-0.072	0.135	-0.207	-0.099	-0.096	-0.164	0.103	0.144	0.083	0.129	0.006	-0.102	-0.004	-0.029	-0.253	0.034	-0.291	0.008	0.257	-0.019	-0.175	0.159
			p	0.633	0.364	0.164	0.506	0.522	0.271	0.491	0.333	0.579	0.387	0.966	0.497	0.981	0.848	0.087	0.821	0.047	0.955	0.081	0.900	0.240	0.286
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Frontal plane angle*	r	-0.296	0.024	0.261	0.007	0.126	-0.117	0.292	-0.105	0.045	-0.003	0.122	-0.033	0.070	-0.058	-0.118	0.174	0.180	-0.076	-0.190	0.244	0.217	0.029
			p	0.043	0.873	0.076	0.962	0.400	0.434	0.046	0.482	0.765	0.983	0.412	0.825	0.641	0.701	0.430	0.241	0.226	0.611	0.201	0.098	0.143	0.846
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Transverse plane angle*	r	-0.200	0.122	0.151	0.038	0.130	0.082	0.161	0.044	0.088	0.058	-0.021	0.013	0.039	-0.213	-0.162	-0.019	-0.169	-0.222	-0.028	0.065	-0.244	0.359
			p	0.178	0.412	0.312	0.800	0.383	0.583	0.281	0.767	0.558	0.698	0.891	0.929	0.797	0.151	0.275	0.899	0.257	0.134	0.854	0.665	0.099	0.013
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	IC	Sagittal plane moment	r	-0.233	-0.215	-0.205	-0.371	-0.331	0.002	0.176	-0.103	0.013	0.099	0.013	0.013	0.036	-0.026	0.054	0.119	-0.01	-0.061	-0.032	0.04	-0.002	-0.016
			p	0.119	0.151	0.171	0.011	0.025	0.988	0.241	0.494	0.93	0.514	0.934	0.932	0.81	0.864	0.723	0.431	0.947	0.688	0.833	0.791	0.987	0.915
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Knee	IC	Frontal plane moment	r	-0.148	0.014	0.037	-0.056	-0.01	0.130	0.124	0.115	0.151	0.083	-0.010	-0.080	-0.015	0.067	0.198	0.348	0.107	-0.052	-0.12	-0.063	0.045	-0.069
			p	0.327	0.928	0.809	0.71	0.946	0.390	0.412	0.445	0.317	0.585	0.947	0.599	0.923	0.659	0.188	0.018	0.480	0.730	0.425	0.676	0.767	0.647
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Hip	IC	Frontal plane moment	r	-0.086	0.095	-0.028	-0.019	0.005	0.215	0.138	0.140	0.198	-0.083	-0.026	-0.037	-0.015	0.237	0.148	0.123	-0.004	-0.022	-0.017	-0.014	-0.009	0.012
			p	0.570	0.530	0.851	0.898	0.973	0.152	0.360	0.352	0.187	0.583	0.864	0.806	0.922	0.113	0.325	0.414	0.980	0.882	0.909	0.924	0.952	0.939
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Knee	MF	Sagittal plane angle	r	0.137	0.155	0.029	0.130	0.122	-0.029	-0.009	0.095	0.043	-0.169	0.217	0.175	0.307	-0.088	-0.220	-0.054	-0.100	0.217	0.268	-0.041	0.125	-0.140
			p	0.358	0.297	0.845	0.385	0.416	0.848	0.950	0.527	0.772	0.256	0.142	0.240	0.036	0.558	0.137	0.720	0.504	0.144	0.069	0.783	0.402	0.347
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	MF	Frontal plane angle	r	0.011	0.072	0.037	0.044	0.057	-0.114	-0.027	-0.206	-0.162	-0.279	-0.069	-0.099	-0.099	-0.246	-0.226	-0.315	-0.122	0.118	0.176	0.048	-0.003	0.092
			p	0.940	0.632	0.806	0.767	0.702	0.444	0.859	0.165	0.276	0.058	0.643	0.510	0.509	0.095	0.127	0.031	0.413	0.430	0.235	0.748	0.985	0.540
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47

Ankle	MF	Sagittal plane angle	r	0.218	0.215	-0.018	0.050	0.078	-0.154	-0.252	-0.119	-0.210	-0.200	0.051	-0.023	0.046	-0.106	-0.302	-0.246	0.072	0.124	0.067	0.147	0.313	-0.221
			p	0.140	0.147	0.906	0.740	0.603	0.302	0.088	0.424	0.157	0.177	0.735	0.876	0.757	0.476	0.039	0.095	0.632	0.406	0.653	0.323	0.032	0.136
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	MF	Sagittal plane angle*	r	0.078	0.012	-0.086	0.035	0.009	-0.014	0.227	0.224	0.178	-0.022	0.129	0.038	0.164	-0.005	-0.261	-0.031	-0.234	0.111	0.266	-0.271	-0.146	-0.136
			p	0.601	0.935	0.565	0.816	0.953	0.923	0.125	0.131	0.232	0.885	0.389	0.798	0.270	0.974	0.077	0.836	0.113	0.456	0.071	0.066	0.328	0.364
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	MF	Frontal plane angle	r	-0.082	-0.030	0.166	0.074	0.096	-0.105	-0.047	-0.078	-0.088	0.092	0.191	0.173	0.123	-0.003	0.074	0.007	0.209	0.076	-0.110	0.276	0.395	-0.053
			p	0.584	0.840	0.264	0.620	0.522	0.484	0.753	0.604	0.555	0.540	0.198	0.245	0.408	0.985	0.622	0.963	0.159	0.612	0.463	0.060	0.006	0.723
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	MF	Transverse plane angle	r	0.052	0.014	-0.025	-0.043	-0.028	-0.182	-0.028	-0.216	-0.183	-0.084	-0.087	-0.099	-0.163	-0.049	0.045	-0.033	0.059	0.089	-0.019	-0.053	0.117	-0.157
			p	0.727	0.926	0.866	0.774	0.850	0.221	0.853	0.145	0.219	0.575	0.561	0.508	0.274	0.744	0.766	0.827	0.695	0.554	0.900	0.725	0.434	0.293
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Sagittal plane angle	r	0.110	0.163	0.069	0.118	0.133	0.057	0.191	0.097	0.140	-0.021	0.233	0.209	0.231	0.132	-0.163	0.098	-0.121	0.119	0.194	-0.219	-0.098	-0.013
			p	0.462	0.274	0.647	0.431	0.373	0.703	0.199	0.516	0.347	0.890	0.115	0.159	0.118	0.377	0.274	0.513	0.418	0.427	0.192	0.140	0.511	0.932
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Frontal plane angle	r	-0.202	0.128	0.337	0.234	0.290	-0.039	0.146	0.004	0.049	-0.075	0.375	0.282	0.326	-0.215	-0.316	-0.129	-0.013	0.004	0.002	0.259	0.162	0.135
			p	0.173	0.392	0.021	0.114	0.048	0.794	0.328	0.979	0.741	0.619	0.009	0.054	0.025	0.146	0.031	0.389	0.931	0.981	0.987	0.079	0.277	0.366
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Transverse plane angle*	r	-0.108	0.265	0.133	0.042	0.162	0.149	0.183	0.085	0.145	0.042	0.056	0.023	0.100	-0.181	-0.239	-0.048	-0.153	-0.198	-0.005	0.053	-0.175	0.282
			p	0.470	0.072	0.374	0.779	0.277	0.318	0.219	0.571	0.330	0.777	0.706	0.880	0.504	0.223	0.106	0.748	0.303	0.183	0.976	0.724	0.238	0.055
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Sagittal plane angle*	r	-0.037	0.187	-0.066	0.097	0.080	-0.042	0.221	0.134	0.099	0.121	0.171	0.122	0.230	-0.021	-0.243	-0.095	-0.368	0.024	0.333	-0.028	-0.107	0.034
			p	0.805	0.208	0.659	0.518	0.593	0.778	0.136	0.371	0.509	0.417	0.251	0.415	0.120	0.890	0.099	0.524	0.011	0.871	0.022	0.854	0.474	0.820
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Frontal plane angle	r	-0.241	0.060	0.308	0.173	0.228	-0.054	0.120	-0.031	0.016	0.101	0.214	0.105	0.156	-0.204	-0.178	0.116	0.267	0.019	-0.185	0.293	0.382	0.100
			p	0.102	0.686	0.035	0.245	0.123	0.720	0.420	0.838	0.917	0.499	0.148	0.483	0.295	0.169	0.230	0.439	0.070	0.900	0.213	0.046	0.008	0.505
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Transverse plane angle*	r	-0.150	0.172	0.154	0.043	0.142	0.097	0.135	0.040	0.084	0.033	0.006	0.001	0.055	-0.211	-0.190	-0.016	-0.128	-0.212	-0.056	0.106	-0.194	0.349
			p	0.314	0.246	0.301	0.773	0.343	0.517	0.366	0.788	0.573	0.826	0.966	0.996	0.713	0.154	0.201	0.913	0.392	0.152	0.710	0.477	0.191	0.016
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	MF	Sagittal plane moment	r	-0.016	0.042	0.035	-0.117	-0.034	0.079	-0.202	-0.083	-0.108	0.118	-0.037	0.025	-0.090	0.064	0.272	0.218	0.512	0.052	-0.330	0.315	0.303	-0.015
			p	0.917	0.782	0.817	0.437	0.821	0.601	0.178	0.586	0.474	0.434	0.809	0.870	0.551	0.671	0.068	0.145	0.000	0.732	0.025	0.033	0.041	0.921
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Knee	MF	Frontal plane moment	r	0.147	0.143	-0.101	-0.051	-0.027	0.055	-0.122	-0.037	-0.052	-0.481	-0.113	-0.093	-0.145	-0.059	-0.125	-0.286	0.111	0.180	0.090	0.202	0.119	0.046
			p	0.331	0.343	0.505	0.736	0.861	0.714	0.418	0.809	0.733	0.001	0.456	0.538	0.336	0.695	0.408	0.054	0.463	0.231	0.551	0.179	0.431	0.762
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Hip	MF	Frontal plane moment	r	0.010	0.056	0.034	-0.026	0.016	0.067	-0.063	-0.013	-0.015	-0.138	-0.089	-0.081	-0.094	-0.096	0.028	-0.081	0.294	0.077	-0.150	0.338	0.289	-0.003
			p	0.945	0.709	0.823	0.866	0.915	0.659	0.679	0.934	0.924	0.361	0.557	0.593	0.536	0.525	0.856	0.594	0.047	0.610	0.321	0.022	0.051	0.987
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
N/A	MF	Ground reaction force	r	-0.083	0.056	-0.058	-0.189	-0.104	0.153	-0.061	-0.086	-0.031	0.049	-0.079	-0.032	-0.210	0.145	0.272	0.127	0.408	0.157	-0.153	0.267	0.194	0.042
			p	0.585	0.709	0.703	0.209	0.493	0.311	0.686	0.570	0.837	0.746	0.602	0.832	0.161	0.337	0.067	0.402	0.005	0.296	0.311	0.073	0.197	0.781
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Knee	Range	Frontal plane angle*	r	-0.003	-0.056	-0.046	-0.031	-0.050	0.127	-0.044	-0.225	-0.113	-0.011	-0.084	-0.172	-0.054	0.096	-0.054	-0.099	-0.306	-0.048	0.211	-0.057	-0.182	0.059
			p	0.985	0.711	0.758	0.838	0.739	0.393	0.767	0.129	0.448	0.943	0.574	0.247	0.719	0.522	0.721	0.506	0.037	0.749	0.155	0.704	0.222	0.696
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
N/A	Peak	Ground reaction force	r	-0.184	-0.132	0.206	0.146	0.120	0.214	0.265	0.213	0.285	0.194	0.352	0.294	0.249	0.316	0.296	0.357	0.306	0.060	-0.186	-0.132	0.159	-0.246
			p	0.221	0.382	0.169	0.335	0.427	0.152	0.075	0.155	0.055	0.197	0.016	0.047	0.095	0.032	0.046	0.015	0.038	0.691	0.217	0.381	0.292	0.099
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
N/A	Rate	Ground reaction force*	r	-0.082	-0.117	-0.033	-0.070	-0.097	0.243	0.076	0.175	0.251	0.080	0.251	0.181	0.199	0.276	0.262	0.503	0.162	0.116	-0.119	-0.244	0.108	-0.261
			p	0.588	0.438	0.830	0.643	0.520	0.104	0.616	0.245	0.092	0.595	0.093	0.230	0.184	0.064	0.079	0.000	0.282	0.442	0.432	0.103	0.473	0.080
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
Knee	Peak valgus	Frontal plane angle	r	0.058	0.198	0.129	0.164	0.190	-0.194	-0.046	-0.099	-0.128	-0.356	-0.003	-0.027	-0.036	-0.393	-0.337	-0.331	0.114	0.167	0.065	0.120	0.109	-0.004
			p	0.697	0.182	0.388	0.271	0.200	0.192	0.757	0.506	0.391	0.014	0.985	0.857	0.808	0.006	0.021	0.023	0.445	0.260	0.666	0.423	0.468	0.977
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	Peak abductor	Frontal plane moment	r	-0.254	-0.001	0.059	-0.037	0.004	0.154	0.188	0.130	0.192	0.086	-0.004	-0.038	0.026	-0.061	0.106	0.272	0.090	-0.084	-0.128	-0.046	-0.018	0.026
			p	0.088	0.994	0.699	0.807	0.978	0.306	0.210	0.389	0.201	0.569	0.979	0.804	0.862	0.688	0.483	0.067	0.552	0.580	0.396	0.762	0.907	0.863
			n	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46

* Spearmann correlation; Cells highligthed in green are p values ≤ 0.20; Cells highligthed in blue are the clinical outcomes inserted in each model.

Correlation matrix of clinical and biomehcanical outcomes for non-preferred leg

Biomechanical outcome: Joint	Instant	Outcome	Correlation information	Clinical outcomes: Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add	Strength Abd/Add
Knee	IC	Sagittal plane angle	r	0.257	0.250	-0.223	-0.333	-0.182	-0.028	-0.115	0.089	0.005	-0.087	-0.278	-0.283	-0.297	0.108	-0.176	-0.061	-0.078	-0.081	0.034	-0.076	-0.095	0.045
			p	0.081	0.090	0.132	0.022	0.221	0.849	0.440	0.550	0.971	0.560	0.059	0.054	0.043	0.472	0.237	0.686	0.602	0.587	0.820	0.612	0.527	0.763
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	IC	Frontal plane angle	r	0.061	0.178	0.211	0.329	0.307	0.038	0.054	-0.002	0.027	-0.297	0.290	0.393	0.351	-0.191	-0.212	-0.118	-0.049	0.216	0.192	0.163	-0.132	0.198
			p	0.683	0.231	0.155	0.024	0.036	0.801	0.720	0.989	0.859	0.042	0.048	0.006	0.016	0.199	0.153	0.429	0.745	0.146	0.195	0.274	0.376	0.182
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Ankle	IC	Sagittal plane angle*	r	0.111	-0.120	-0.244	-0.188	-0.231	0.178	-0.038	0.013	0.039	-0.018	-0.062	-0.157	-0.156	0.141	0.026	0.175	0.030	-0.007	-0.035	-0.052	-0.098	0.062
			p	0.457	0.420	0.098	0.205	0.117	0.230	0.798	0.929	0.793	0.903	0.681	0.292	0.295	0.345	0.861	0.241	0.839	0.961	0.816	0.731	0.513	0.679
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Sagittal plane angle	r	0.209	0.229	-0.218	-0.174	-0.106	-0.035	0.001	-0.024	-0.022	-0.273	-0.086	-0.049	-0.130	0.108	-0.195	-0.059	-0.248	0.002	0.169	-0.145	-0.141	0.055
			p	0.159	0.121	0.141	0.241	0.480	0.818	0.993	0.872	0.882	0.063	0.564	0.745	0.382	0.471	0.188	0.694	0.092	0.989	0.257	0.331	0.346	0.712
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Frontal plane angle	r	-0.066	-0.194	-0.085	-0.076	-0.133	-0.151	-0.213	-0.223	-0.252	-0.090	-0.022	-0.001	0.042	-0.040	0.072	-0.152	0.029	0.083	0.031	0.268	0.091	0.132
			p	0.659	0.192	0.568	0.614	0.374	0.312	0.150	0.132	0.088	0.550	0.882	0.995	0.777	0.787	0.629	0.308	0.848	0.581	0.834	0.068	0.542	0.378
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	IC	Transverse plane angle	r	0.027	0.066	0.122	0.208	0.175	0.041	-0.027	0.012	-0.004	-0.154	0.212	0.319	0.217	-0.108	-0.285	-0.219	-0.066	0.051	0.050	-0.024	-0.311	0.281
			p	0.855	0.660	0.412	0.161	0.239	0.787	0.855	0.936	0.979	0.302	0.152	0.029	0.143	0.470	0.052	0.138	0.657	0.735	0.741	0.873	0.033	0.055
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Sagittal plane angle	r	0.115	0.136	-0.062	0.097	0.066	-0.033	0.065	-0.125	-0.055	-0.132	0.062	0.099	0.084	-0.048	-0.214	-0.273	-0.228	-0.056	0.106	0.077	-0.183	0.230
			p	0.443	0.362	0.678	0.516	0.658	0.824	0.666	0.404	0.713	0.376	0.677	0.506	0.572	0.749	0.150	0.064	0.122	0.708	0.480	0.606	0.219	0.120
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Frontal plane angle*	r	-0.089	-0.009	-0.253	-0.077	-0.191	-0.034	0.156	-0.149	-0.002	-0.215	0.050	-0.057	0.069	0.131	0.021	-0.259	-0.169	0.023	0.167	0.131	-0.022	0.151
			p	0.551	0.950	0.087	0.607	0.198	0.819	0.296	0.317	0.990	0.146	0.736	0.701	0.643	0.379	0.887	0.079	0.256	0.880	0.262	0.379	0.881	0.310
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	IC	Transverse plane angle*	r	0.174	0.078	-0.082	0.000	-0.011	-0.072	0.139	-0.026	-0.024	-0.094	0.018	-0.009	0.097	0.039	-0.030	-0.177	-0.174	0.007	0.112	0.137	-0.282	0.286
			p	0.241	0.604	0.586	0.998	0.944	0.629	0.350	0.863	0.874	0.528	0.906	0.952	0.517	0.797	0.841	0.233	0.241	0.962	0.453	0.358	0.055	0.052
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Sagittal plane angle	r	-0.081	0.013	-0.405	-0.339	-0.331	-0.146	0.080	-0.036	-0.022	-0.140	0.006	0.013	0.041	-0.035	-0.136	-0.171	-0.434	0.126	0.443	-0.182	-0.233	0.107
			p	0.588	0.929	0.005	0.020	0.023	0.327	0.592	0.810	0.884	0.349	0.966	0.933	0.786	0.818	0.362	0.251	0.002	0.398	0.002	0.220	0.115	0.472
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Frontal plane angle	r	0.109	0.169	-0.017	0.105	0.099	0.060	0.125	-0.097	0.012	-0.041	0.029	-0.093	-0.069	-0.100	-0.071	0.028	0.105	-0.022	-0.097	0.081	-0.213	0.222
			p	0.467	0.255	0.912	0.483	0.508	0.687	0.402	0.519	0.936	0.786	0.845	0.534	0.647	0.503	0.635	0.851	0.484	0.882	0.518	0.588	0.151	0.134
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	IC	Transverse plane angle*	r	0.217	0.076	-0.007	0.003	0.029	-0.061	-0.013	0.035	-0.050	0.063	-0.025	-0.071	0.027	0.055	-0.074	-0.075	0.034	-0.055	-0.079	0.180	-0.188	0.251
			p	0.142	0.611	0.962	0.982	0.849	0.684	0.933	0.816	0.739	0.673	0.869	0.634	0.856	0.716	0.623	0.617	0.819	0.713	0.599	0.227	0.205	0.089
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	IC	Sagittal plane moment	r	-0.136	-0.160	-0.168	-0.165	-0.205	0.048	0.236	-0.091	0.062	0.018	-0.108	-0.111	0.007	0.133	0.140	0.064	0.106	-0.161	-0.240	0.015	-0.139	0.110
			p	0.374	0.295	0.269	0.280	0.177	0.755	0.118	0.554	0.686	0.906	0.480	0.467	0.964	0.385	0.359	0.678	0.488	0.289	0.113	0.923	0.362	0.470
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Knee	IC	Frontal plane moment	r	0.153	0.133	-0.030	-0.058	0.003	0.041	0.019	-0.014	0.014	-0.131	-0.141	-0.129	-0.172	0.199	0.065	0.301	0.238	-0.010	-0.149	0.171	0.138	-0.014
			p	0.315	0.384	0.847	0.706	0.983	0.791	0.904	0.928	0.930	0.390	0.356	0.398	0.258	0.190	0.673	0.045	0.116	0.946	0.329	0.262	0.364	0.929
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Hip	IC	Frontal plane moment	r	0.034	0.187	0.181	0.051	0.162	-0.083	-0.091	-0.059	-0.089	-0.031	-0.147	-0.119	-0.238	0.089	-0.046	0.138	0.167	-0.118	-0.201	0.005	0.062	-0.022
			p	0.823	0.219	0.234	0.740	0.288	0.588	0.553	0.700	0.560	0.842	0.336	0.435	0.116	0.560	0.766	0.366	0.271	0.441	0.185	0.976	0.686	0.885
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Knee	MF	Sagittal plane angle	r	0.221	0.317	0.104	0.129	0.205	0.045	-0.023	0.101	0.062	-0.347	0.263	0.346	0.373	0.000	-0.223	-0.015	-0.059	0.281	0.269	0.151	-0.172	0.156
			p	0.135	0.030	0.488	0.387	0.166	0.762	0.879	0.499	0.677	0.017	0.074	0.017	0.010	0.998	0.132	0.921	0.695	0.055	0.067	0.312	0.248	0.295
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	MF	Frontal plane angle	r	0.042	-0.081	0.115	0.269	0.158	-0.066	-0.118	-0.277	-0.233	-0.282	0.132	0.278	0.181	-0.129	-0.314	-0.214	-0.201	-0.018	0.059	-0.049	-0.331	0.248
			p	0.777	0.590	0.441	0.067	0.289	0.659	0.430	0.059	0.114	0.055	0.376	0.059	0.223	0.388	0.032	0.149	0.175	0.905	0.692	0.742	0.023	0.093
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Ankle	MF	Sagittal plane angle	r	0.297	0.295	0.222	0.127	0.245	0.065	-0.237	0.020	-0.068	-0.150	0.095	0.176	0.075	0.099	-0.210	0.065	0.134	0.142	0.003	0.161	-0.234	0.277
			p	0.043	0.044	0.134	0.395	0.096	0.666	0.109	0.895	0.648	0.315	0.526	0.236	0.616	0.506	0.156	0.662	0.371	0.343	0.984	0.280	0.114	0.060
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47

Hip	MF	Sagittal plane angle*	r	0.077	0.086	-0.074	0.053	0.016	0.121	0.120	0.156	0.152	-0.226	0.160	0.194	0.181	0.073	-0.227	-0.020	-0.285	0.183	0.355	-0.028	-0.323	0.234
			p	0.606	0.566	0.619	0.722	0.915	0.418	0.423	0.294	0.306	0.126	0.282	0.192	0.223	0.624	0.125	0.893	0.052	0.219	0.014	0.854	0.027	0.113
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	MF	Frontal plane angle*	r	-0.059	-0.049	-0.106	-0.037	-0.077	-0.096	0.025	-0.035	-0.037	-0.077	0.255	0.190	0.211	-0.039	0.029	-0.026	-0.071	0.243	0.298	0.303	0.202	0.030
			p	0.691	0.746	0.476	0.807	0.607	0.521	0.865	0.814	0.806	0.605	0.084	0.201	0.154	0.797	0.849	0.862	0.633	0.100	0.042	0.039	0.174	0.842
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Hip	MF	Transverse plane angle	r	-0.002	-0.109	0.119	0.251	0.141	0.073	-0.067	-0.126	-0.096	-0.126	0.158	0.268	0.161	-0.082	-0.240	-0.124	-0.179	-0.070	-0.002	-0.099	-0.37	0.274
			p	0.991	0.465	0.426	0.089	0.343	0.627	0.656	0.400	0.519	0.400	0.288	0.068	0.279	0.582	0.104	0.408	0.229	0.641	0.988	0.509	0.010	0.062
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Sagittal plane angle	r	-0.037	-0.151	-0.026	0.164	0.026	0.114	0.044	-0.120	-0.027	-0.098	0.129	0.213	0.161	-0.027	-0.184	-0.205	-0.320	-0.028	0.158	0.065	-0.249	0.292
			p	0.803	0.309	0.862	0.272	0.864	0.444	0.769	0.423	0.856	0.511	0.389	0.150	0.281	0.859	0.216	0.167	0.028	0.854	0.289	0.662	0.091	0.047
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Frontal plane angle*	r	0.083	0.086	-0.173	-0.062	-0.082	-0.187	0.025	-0.084	-0.090	-0.226	0.214	0.104	0.204	0.058	-0.037	-0.217	-0.202	0.213	0.324	0.121	-0.002	0.098
			p	0.578	0.565	0.246	0.678	0.585	0.209	0.867	0.576	0.546	0.126	0.149	0.485	0.170	0.701	0.804	0.142	0.173	0.150	0.026	0.419	0.990	0.514
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Pelvis	MF	Transverse plane angle*	r	0.124	0.035	-0.132	-0.105	-0.076	-0.079	0.111	0.054	0.027	0.128	-0.125	-0.213	-0.086	0.089	0.052	-0.015	-0.016	0.012	0.027	0.020	-0.243	0.182
			p	0.407	0.814	0.378	0.484	0.614	0.600	0.456	0.720	0.856	0.391	0.401	0.151	0.566	0.552	0.730	0.920	0.917	0.936	0.856	0.892	0.100	0.221
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Sagittal plane angle*	r	-0.085	0.004	-0.348	-0.174	-0.234	0.005	0.174	0.150	0.164	-0.135	0.191	0.202	0.269	0.003	-0.150	-0.177	-0.484	0.295	0.588	-0.057	-0.334	0.191
			p	0.571	0.981	0.016	0.242	0.113	0.972	0.242	0.315	0.270	0.367	0.198	0.172	0.067	0.986	0.314	0.234	0.001	0.044	0.000	0.705	0.022	0.198
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Frontal plane angle*	r	0.027	0.199	0.078	0.161	0.208	0.019	0.114	0.004	0.020	0.039	0.010	-0.165	-0.106	-0.022	-0.036	0.115	0.136	0.003	-0.084	0.197	-0.013	0.136
			p	0.856	0.180	0.603	0.279	0.161	0.901	0.445	0.977	0.893	0.795	0.946	0.268	0.480	0.883	0.810	0.441	0.363	0.985	0.574	0.185	0.932	0.364
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Trunk	MF	Transverse plane angle*	r	0.155	0.065	-0.019	-0.015	0.016	-0.029	0.077	0.079	0.037	0.132	-0.076	-0.147	-0.034	0.071	0.015	0.023	0.094	-0.055	-0.113	0.135	-0.199	0.239
			p	0.299	0.662	0.897	0.920	0.915	0.845	0.605	0.599	0.804	0.376	0.612	0.323	0.819	0.636	0.921	0.879	0.529	0.714	0.451	0.364	0.179	0.106
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	MF	Sagittal plane moment	r	0.167	0.129	-0.156	-0.187	-0.115	-0.016	0.125	0.054	0.087	-0.159	-0.203	-0.108	-0.016	0.143	0.109	-0.016	0.189	0.049	-0.062	0.133	0.382	-0.294
			p	0.274	0.400	0.307	0.219	0.453	0.915	0.414	0.726	0.571	0.297	0.181	0.481	0.919	0.349	0.474	0.915	0.214	0.752	0.685	0.385	0.010	0.050
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Knee	MF	Frontal plane moment*	r	0.015	0.050	0.005	-0.033	0.022	-0.199	-0.070	-0.280	-0.220	0.048	-0.209	-0.255	-0.314	0.066	0.030	0.126	0.274	-0.218	-0.297	0.093	0.399	-0.231
			p	0.922	0.743	0.975	0.828	0.884	0.190	0.646	0.062	0.147	0.753	0.169	0.091	0.036	0.667	0.843	0.410	0.069	0.149	0.048	0.542	0.007	0.126
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Hip	MF	Frontal plane moment	r	-0.091	-0.092	0.065	-0.010	-0.009	0.022	0.045	-0.036	0.004	0.197	-0.029	-0.242	-0.203	0.043	0.293	0.256	0.329	-0.169	-0.358	0.155	0.445	-0.240
			p	0.551	0.547	0.669	0.946	0.952	0.886	0.769	0.815	0.979	0.194	0.851	0.109	0.181	0.780	0.051	0.089	0.027	0.268	0.016	0.308	0.002	0.113
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
N/A	MF	Ground reaction force	r	-0.053	-0.175	-0.243	-0.263	-0.290	0.026	0.143	-0.028	0.053	0.151	-0.234	-0.290	-0.272	0.156	0.223	0.119	0.139	-0.185	-0.226	-0.013	0.410	-0.302
			p	0.727	0.251	0.108	0.081	0.054	0.865	0.350	0.855	0.731	0.321	0.123	0.053	0.070	0.306	0.142	0.435	0.362	0.224	0.135	0.930	0.005	0.044
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Knee	Range	Frontal plane angle*	r	-0.041	-0.125	-0.261	-0.123	-0.204	0.039	0.012	-0.170	-0.073	-0.019	-0.064	-0.112	-0.045	-0.157	-0.111	-0.250	-0.318	0.146	0.292	-0.169	-0.169	0.080
			p	0.785	0.401	0.077	0.410	0.169	0.797	0.938	0.255	0.627	0.899	0.669	0.455	0.764	0.293	0.456	0.090	0.030	0.327	0.047	0.256	0.255	0.592
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
N/A	Peak	Ground reaction force	r	-0.319	-0.308	-0.098	-0.163	-0.225	0.166	0.286	0.312	0.338	0.468	0.043	0.024	0.075	0.082	0.237	0.187	0.334	-0.041	-0.249	-0.006	0.175	-0.118
			p	0.033	0.040	0.521	0.283	0.138	0.275	0.057	0.037	0.023	0.001	0.779	0.874	0.624	0.592	0.117	0.218	0.025	0.787	0.099	0.967	0.249	0.441
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
N/A	Rate	Ground reaction force*	r	-0.134	-0.233	-0.140	-0.180	-0.229	0.280	0.091	0.218	0.246	0.326	0.130	0.010	0.080	0.046	0.240	0.309	0.216	-0.143	-0.275	-0.036	0.022	-0.076
			p	0.381	0.123	0.360	0.236	0.131	0.063	0.551	0.151	0.103	0.029	0.394	0.947	0.600	0.763	0.112	0.039	0.155	0.347	0.067	0.814	0.888	0.620
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Knee	Peak valgus	Frontal plane angle	r	0.095	0.038	0.215	0.349	0.276	-0.036	-0.066	-0.169	-0.141	-0.297	0.242	0.394	0.305	-0.138	-0.295	-0.172	-0.101	0.048	0.059	0.043	-0.239	0.210
			p	0.527	0.798	0.147	0.016	0.061	0.809	0.660	0.257	0.344	0.042	0.101	0.006	0.037	0.353	0.044	0.248	0.500	0.748	0.695	0.776	0.105	0.157
			n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Knee	Peak abductor	Frontal plane moment	r	0.124	0.114	-0.035	-0.052	-0.002	0.043	0.041	-0.022	0.019	-0.124	-0.134	-0.145	-0.182	0.194	0.078	0.316	0.242	-0.016	-0.162	0.160	0.145	-0.024
			p	0.416	0.455	0.820	0.736	0.989	0.777	0.789	0.884	0.904	0.418	0.381	0.342	0.231	0.201	0.612	0.035	0.110	0.916	0.288	0.294	0.342	0.874
			n	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45

* Spearmann correlation; Cells highligthed in green are p values ≤ 0.20; Cells highligthed in blue are the clinical outcomes inserted in each model.

APPENDIX B – Correlation matrix between clinical outcomes – Unilateral landings

Correlation matrix between clinical outcomes for prefered leg.

Clinical outcome	Correlation information	Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add
SEBT A	r	0.429																				
	p	0.003																				
	n	47																				
SEBT M	r	-0.129	0.371																			
	p	0.386	0.010																			
	n	47	47																			
SEBT L	r	-0.075	0.311	0.807																		
	p	0.615	0.033	0.000																		
	n	47	47	47																		
SEBT T	r	0.028	0.583	0.915	0.922																	
	p	0.851	0.000	0.000	0.000																	
	n	47	47	47	47																	
Ass SEBT A	r	-0.112	0.200	0.137	0.188	0.207																
	p	0.455	0.177	0.359	0.205	0.163																
	n	47	47	47	47	47																
Ass SEBT M	r	-0.324	0.077	0.381	0.233	0.293	0.265															
	p	0.026	0.607	0.008	0.115	0.046	0.072															
	n	47	47	47	47	47	47															
Ass SEBT L	r	-0.156	0.232	0.239	0.455	0.394	0.339	0.577														
	p	0.295	0.116	0.106	0.001	0.006	0.020	0.000														
	n	47	47	47	47	47	47	47														
Ass SEBT T	r	-0.260	0.217	0.332	0.404	0.400	0.560	0.816	0.900													
	p	0.077	0.144	0.023	0.005	0.005	0.000	0.000	0.000													
	n	47	47	47	47	47	47	47	47													
LSD*	r	-0.252	-0.343	-0.282	-0.274	-0.351	-0.148	0.062	-0.081	-0.080												
	p	0.088	0.018	0.055	0.062	0.016	0.320	0.677	0.586	0.593												
	n	47	47	47	47	47	47	47	47	47												
Single hop	r	-0.042	0.243	0.534	0.589	0.583	0.149	0.321	0.311	0.346	-0.315											
	p	0.778	0.101	0.000	0.000	0.000	0.319	0.028	0.033	0.017	0.031											
	n	47	47	47	47	47	47	47	47	47	47											
Triple hop	r	-0.012	0.153	0.504	0.539	0.520	0.227	0.259	0.302	0.337	-0.208	0.796										
	p	0.935	0.306	0.000	0.000	0.000	0.126	0.079	0.039	0.021	0.160	0.000										
	n	47	47	47	47	47	47	47	47	47	47	47										
Cross hop	r	0.007	0.272	0.498	0.576	0.570	0.212	0.399	0.454	0.476	-0.241	0.859	0.894									
	p	0.963	0.064	0.000	0.000	0.000	0.153	0.006	0.001	0.001	0.102	0.000	0.000									
	n	47	47	47	47	47	47	47	47	47	47	47	47									
Ass Single	r	0.244	0.023	-0.134	-0.181	-0.140	0.247	0.201	0.192	0.260	0.042	0.107	0.055	0.064								
	p	0.098	0.880	0.370	0.223	0.347	0.094	0.176	0.197	0.078	0.780	0.474	0.715	0.668								
	n	47	47	47	47	47	47	47	47	47	47	47	47	47								
Ass Triple	r	0.061	0.003	0.112	-0.044	0.022	0.344	0.130	0.115	0.214	-0.070	0.033	0.293	0.110	0.484							
	p	0.684	0.983	0.453	0.768	0.881	0.018	0.386	0.443	0.148	0.640	0.825	0.045	0.461	0.001							
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47							
Ass Cross	r	0.115	0.152	0.085	0.050	0.101	0.188	0.296	0.351	0.371	0.085	0.206	0.198	0.326	0.557	0.434						
	p	0.443	0.309	0.572	0.738	0.498	0.205	0.043	0.016	0.010	0.569	0.165	0.182	0.025	0.000	0.002						
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47						

Strength Quad	r	0.053	0.125	0.327	0.198	0.267	-0.013	-0.056	0.012	-0.018	-0.050	0.141	0.317	0.186	-0.012	0.200	0.202					
	p	0.723	0.403	0.025	0.181	0.070	0.930	0.707	0.937	0.904	0.740	0.343	0.030	0.210	0.936	0.177	0.173					
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47					
Strength Hams	r	0.340	0.267	-0.092	0.039	0.057	0.097	0.015	0.131	0.105	-0.278	0.243	0.256	0.255	0.183	0.208	0.312	0.264				
	p	0.019	0.069	0.538	0.796	0.702	0.519	0.918	0.379	0.481	0.058	0.099	0.083	0.084	0.219	0.160	0.033	0.073				
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47				
Strength H/Q	r	0.271	0.129	-0.350	-0.127	-0.168	0.101	0.050	0.129	0.119	-0.170	0.093	-0.007	0.085	0.203	0.018	0.133	-0.502	0.680			
	p	0.065	0.389	0.016	0.396	0.258	0.498	0.738	0.389	0.424	0.253	0.535	0.961	0.571	0.171	0.903	0.373	0.000	0.000			
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47			
Strength Abd	r	-0.183	0.098	-0.066	-0.210	-0.107	0.081	-0.159	-0.113	-0.105	0.018	-0.139	-0.001	-0.044	-0.075	0.112	-0.086	0.312	0.073	-0.165		
	p	0.219	0.510	0.661	0.157	0.473	0.590	0.285	0.451	0.482	0.904	0.352	0.994	0.770	0.617	0.454	0.567	0.033	0.625	0.269		
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47		
Strength Add	r	0.020	0.132	0.163	0.141	0.174	-0.127	-0.086	-0.116	-0.131	-0.046	0.311	0.246	0.272	0.084	-0.004	0.151	0.561	0.361	-0.114	0.366	
	p	0.896	0.375	0.274	0.343	0.242	0.396	0.565	0.439	0.381	0.761	0.034	0.096	0.064	0.573	0.977	0.309	0.000	0.013	0.444	0.011	
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	
Strength Abd/Add	r	-0.179	-0.029	-0.154	-0.287	-0.171	0.188	-0.099	0.058	0.019	0.001	-0.310	-0.158	-0.222	-0.162	0.071	-0.230	-0.275	-0.275	-0.057	0.500	-0.581
	p	0.230	0.849	0.301	0.051	0.249	0.206	0.506	0.700	0.897	0.995	0.034	0.290	0.134	0.276	0.636	0.120	0.062	0.062	0.706	0.000	0.000
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47

* Spearmann correlation; Cells highligthed in orange are correlation coefficients < 0.7.

Correlation matrix between clinical outcomes for non-prefered leg.

Clinical outcome	Correlation information	Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add
SEBT A	r	0.543																				
	p	0.000																				
	n	47																				
SEBT M	r	0.079	0.342																			
	p	0.597	0.019																			
	n	47	47																			
SEBT L	r	-0.026	0.173	0.840																		
	p	0.865	0.244	0.000																		
	n	47	47	47																		
SEBT T	r	0.187	0.535	0.936	0.900																	
	p	0.209	0.000	0.000	0.000																	
	n	47	47	47	47																	
Ass SEBT A	r	-0.188	-0.354	-0.013	-0.013	-0.121																
	p	0.207	0.015	0.930	0.932	0.417																
	n	47	47	47	47	47																
Ass SEBT M	r	-0.362	-0.069	-0.237	-0.120	-0.178	0.265															
	p	0.012	0.644	0.109	0.423	0.232	0.072															
	n	47	47	47	47	47	47															
Ass SEBT L	r	-0.161	0.039	-0.103	-0.182	-0.122	0.339	0.577														
	p	0.279	0.794	0.490	0.220	0.414	0.020	0.000														
	n	47	47	47	47	47	47	47														
Ass SEBT T	r	-0.296	-0.098	-0.161	-0.160	-0.176	0.560	0.816	0.900													
	p	0.043	0.514	0.281	0.283	0.236	0.000	0.000	0.000													
	n	47	47	47	47	47	47	47	47													
LSD*	r	-0.279	-0.375	-0.212	-0.114	-0.254	0.070	-0.078	0.101	0.020												
	p	0.058	0.009	0.152	0.447	0.085	0.642	0.603	0.498	0.896												
	n	47	47	47	47	47	47	47	47	47												
Single hop	r	-0.135	0.192	0.456	0.572	0.534	-0.021	0.165	0.179	0.161	-0.075											
	p	0.365	0.195	0.001	0.000	0.000	0.887	0.267	0.228	0.279	0.616											
	n	47	47	47	47	47	47	47	47	47	47											
Triple hop	r	0.000	0.162	0.356	0.462	0.428	0.013	0.178	0.232	0.204	-0.097	0.825										
	p	0.999	0.278	0.014	0.001	0.003	0.929	0.230	0.117	0.168	0.518	0.000										
	n	47	47	47	47	47	47	47	47	47	47	47										
Cross hop	r	-0.030	0.137	0.338	0.424	0.394	0.141	0.298	0.340	0.351	-0.195	0.831	0.905									
	p	0.844	0.358	0.020	0.003	0.006	0.345	0.042	0.019	0.016	0.190	0.000	0.000									
	n	47	47	47	47	47	47	47	47	47	47	47	47									
Ass Single	r	0.183	-0.107	-0.269	-0.339	-0.314	0.247	0.201	0.192	0.260	-0.201	-0.508	-0.235	-0.172								
	p	0.219	0.473	0.067	0.020	0.032	0.094	0.176	0.197	0.078	0.175	0.000	0.113	0.247								
	n	47	47	47	47	47	47	47	47	47	47	47	47	47								
Ass Triple	r	-0.084	-0.183	0.035	-0.125	-0.106	0.344	0.130	0.115	0.214	-0.188	-0.283	-0.303	-0.071	0.484							
	p	0.576	0.218	0.814	0.402	0.478	0.018	0.386	0.443	0.148	0.205	0.054	0.039	0.635	0.001							
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47							
Ass Cross	r	0.095	0.043	-0.110	-0.191	-0.128	0.188	0.296	0.351	0.371	-0.098	-0.183	-0.068	-0.071	0.557	0.434						
	p	0.526	0.773	0.463	0.198	0.392	0.205	0.043	0.016	0.010	0.510	0.218	0.650	0.635	0.000	0.002						
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47						

Strength Quad	r	-0.061	0.170	0.358	0.234	0.316	0.111	0.005	0.026	0.047	-0.003	0.192	0.188	0.167	-0.017	0.232	0.333					
	p	0.682	0.253	0.013	0.114	0.031	0.459	0.975	0.860	0.756	0.982	0.196	0.207	0.261	0.910	0.116	0.022					
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47					
Strength Hams	r	0.191	0.090	-0.246	-0.184	-0.165	0.002	0.022	0.300	0.182	-0.255	0.156	0.227	0.294	0.141	0.161	0.212	0.151				
	p	0.198	0.546	0.096	0.215	0.268	0.989	0.884	0.040	0.222	0.083	0.296	0.125	0.045	0.343	0.280	0.153	0.311				
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47				
Strength H/Q	r	0.207	-0.014	-0.417	-0.313	-0.331	-0.059	-0.002	0.227	0.116	-0.189	-0.017	0.038	0.118	0.109	-0.026	-0.080	-0.556	0.709			
	p	0.163	0.926	0.004	0.032	0.023	0.696	0.991	0.125	0.437	0.204	0.910	0.800	0.430	0.467	0.862	0.593	0.000	0.000			
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47			
Strength Abd	r	-0.031	0.076	0.279	0.255	0.266	0.197	-0.163	-0.057	-0.047	-0.121	0.260	0.300	0.252	-0.326	-0.005	-0.014	0.483	0.101	-0.193		
	p	0.837	0.613	0.057	0.084	0.071	0.184	0.273	0.702	0.755	0.418	0.077	0.040	0.087	0.025	0.974	0.927	0.001	0.501	0.194		
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47		
Strength Add	r	-0.091	0.039	0.006	-0.084	-0.028	-0.098	-0.061	-0.026	-0.065	-0.024	0.029	0.021	0.011	0.080	0.267	0.189	0.495	0.235	-0.140	0.291	
	p	0.542	0.796	0.969	0.574	0.850	0.513	0.682	0.864	0.666	0.873	0.846	0.887	0.943	0.592	0.069	0.203	0.000	0.112	0.349	0.047	
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	
Strength Abd/Add	r	-0.049	-0.076	0.140	0.222	0.146	0.270	-0.036	0.035	0.076	-0.102	0.157	0.161	0.139	-0.351	-0.257	-0.236	-0.161	-0.154	0.015	0.429	-0.703
	p	0.745	0.611	0.347	0.134	0.329	0.066	0.810	0.815	0.613	0.497	0.292	0.279	0.350	0.016	0.081	0.110	0.279	0.301	0.919	0.003	0.000
	n	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47

* Spearmann correlation; Cells highligthed in orange are correlation coefficients < 0.7.

APPENDIX C – Linear regression models – Unilateral landings

Linear regression analyses outcomes for unilateral jump landings with the preferred and non-preferred legs.

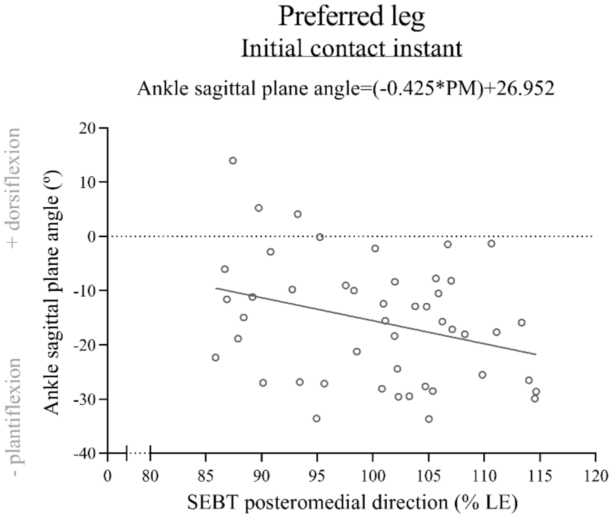
Dependent variable	Independent variable	r	r^2	p	f^2
Preferred leg					
Ankle					
Dorsi/plantarflexion angle at IC	SEBT M	0.315	0.100	0.031	0.111
Dorsiflexion angle at MF	Hip adductor strength, triple hop asymmetry, and lateral step down	0.510	0.260	0.004	0.351
Knee					
Flexion angle at IC	Triple hop	0.388	0.151	0.007	0.178
Flexion angle at MF	Cross hop	0.307	0.094	0.036	0.104
Extensor moment at IC	SEBT L	0.371	0.138	0.011	0.160
Flexor moment at MF	Knee extensor strength	0.590	0.349	<0.001	0.536
Varus/valgus angle at IC	SEBT T and single hop asymmetry	0.506	0.256	0.002	0.344
Varus/valgus angle at MF	Crossover hop asymmetry and lateral step down	0.421	0.178	0.014	0.217
Valgus peak angle	Single hop asymmetry and lateral step down	0.511	0.261	0.001	0.353
Adductor/abductor moment at IC	Crossover hop asymmetry	0.349	0.122	0.019	0.139
Adductor moment at MF	Lateral step down	0.455	0.207	0.002	0.261
Hip					
Flexion angle at IC	Triple hop asymmetry and SEBT A	0.446	0.199	0.008	0.248
Abduction angle at IC	Hip abductor strength	0.327	0.107	0.025	0.120
Adduction/abduction angle at MF	Hip adductor strength	0.395	0.156	0.006	0.185
Adductor moment angle at MF	Hip abductor strength	0.338	0.114	0.022	0.129
Internal/external rotation angle at IC	Knee extensor strength	0.321	0.103	0.028	0.115
Pelvis					
Anterior/posterior tilt at IC	SEBT A and triple hop asymmetry	0.417	0.174	0.015	0.211
Obliquity at IC	Hip abductor strength, triple hop asymmetry	0.503	0.253	0.002	0.339
Obliquity at MF	Single hop, triple hop asymmetry, and hip abductor strength	0.612	0.374	<0.001	0.597
Trunk					
Forward/backward tilt at IC	Knee extensor strength	0.291	0.085	0.047	0.093
Forward/backward tilt at MF	Knee flexor/extensor strength ratio	0.398	0.158	0.006	0.188
Frontal plane angle at IC	Hip abductor strength and SEBT M asymmetry	0.483	0.233	0.003	0.304
Frontal plane angle at MF	Hip abductor strength	0.512	0.262	<0.001	0.355
vGRF					
vGRF peak	Crossover hop asymmetry and single hop	0.457	0.209	0.007	0.264
vGRF at MF	Knee extensor strength and crossover hop	0.501	0.251	0.002	0.335
vGRF rate	Crossover hop asymmetry	0.401	0.161	0.006	0.192

Non-preferred leg					
Knee					
Flexion angle at IC	SEBT L and SEBT A	0.457	0.209	0.006	0.264
Flexion angle at MF	Lateral step down and triple hop asymmetry	0.545	0.297	<0.001	0.422
Flexor/extensor moment at MF	Hip adductor strength	0.382	0.146	0.010	1.171
Varus/valgus angle at IC	Triple hop	0.393	0.154	0.006	0.182
Valgus peak angle	Triple hop	0.394	0.155	0.006	1.183
Adductor/abductor moment at IC	Crossover hop asymmetry	0.301	0.091	0.045	0.100
Adductor moment at MF	Hip adductor strength and crossover hop	0.498	0.248	0.003	0.330
Abductor peak moment	Crossover hop asymmetry	0.326	0.106	0.033	0.119
Hip					
Flexion angle at MF	Triple hop and knee extensor strength	0.442	0.195	0.008	0.242
Adduction/abduction angle at MF	Hip abductor strength and knee flexor/extensor strength ratio	0.534	0.285	0.001	0.399
Adductor moment at MF	Hip adductor strength and knee flexor/extensor strength ratio	0.536	0.287	0.001	0.403
Internal/external rotation angle at IC	Triple hop and hip adductor strength	0.450	0.203	0.007	0.255
Internal/external rotation angle at MF	Hip adductor strength and triple hop	0.462	0.213	0.005	0.271
Pelvis					
Anterior tilt at MF	Hip abductor/adductor strength ratio	0.292	0.085	0.047	0.093
Trunk					
Forward/backward tilt at IC	Knee flexor/extensor strength ratio	0.443	0.196	0.002	0.244
Forward/backward tilt at MF	Knee flexor/extensor strength ratio, crossover hop, and hip adductor strength	0.681	0.463	<0.001	0.862
vGRF					
vGRF at MF	Hip adductor strength and triple hop	0.507	0.257	0.002	0.346
vGRF peak	Lateral step down, knee extensor strength, and SEBT T asymmetry	0.637	0.406	<0.001	0.684
vGRF rate	Lateral step down and crossover hop asymmetry	0.472	0.223	0.005	0.287

A: anterior direction of SEBT; IC: initial contact instant; L: posterolateral direction of SEBT; M: posteromedial direction of SEBT; MF: maximal knee flexion instant; SEBT: Star Excursion Balance Test; T: total score of SEBT; vGRF: vertical component of ground reaction force.

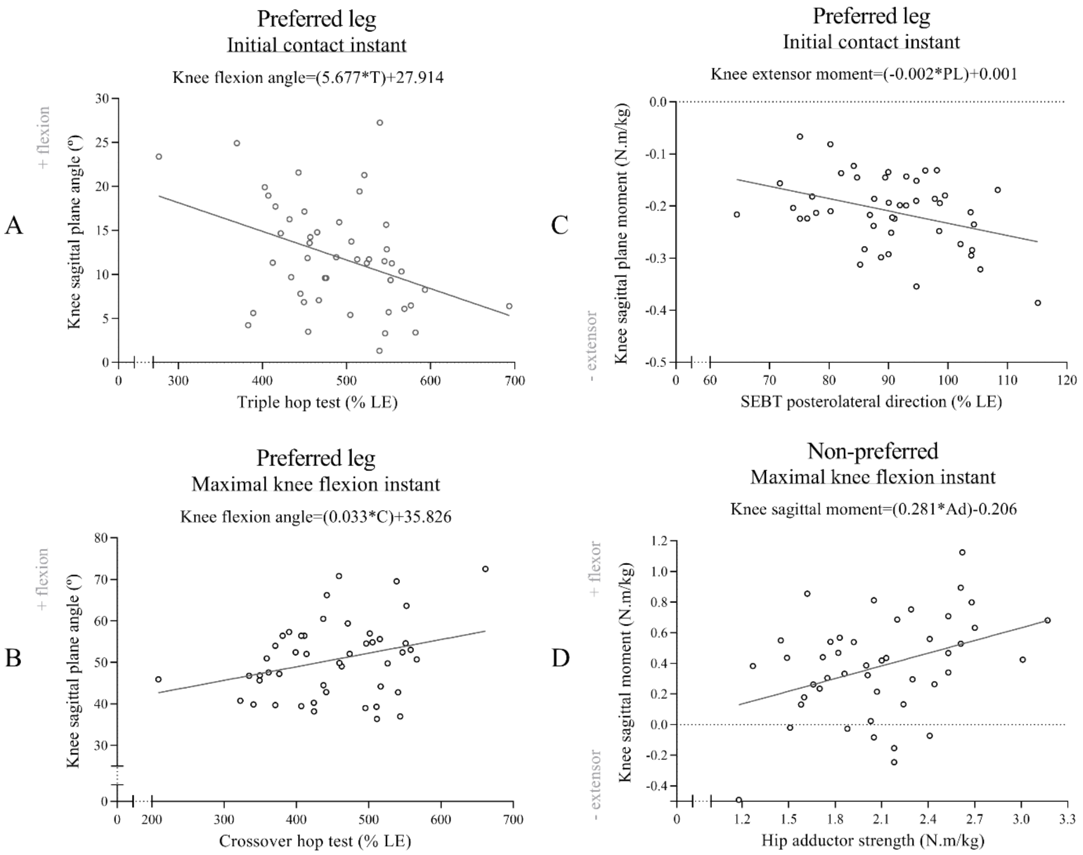
APPENDIX D – Figures from regression models – Unilateral landings

Figure A 1 – Sagittal plane angle of ankle at initial contact when landing with the preferred leg being predicted by the clinical tests.



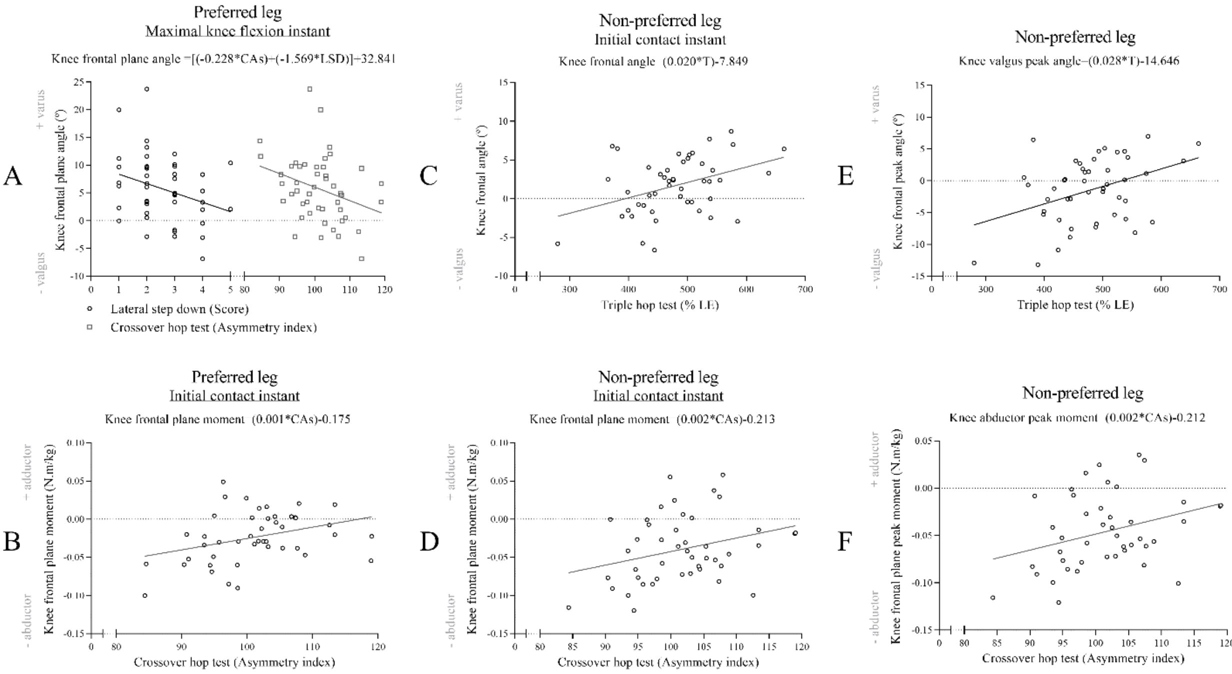
LE: lower extremity; PM: SEBT posteromedial direction; SEBT: star excursion balance test.

Figure A 2 – Knee sagittal plane angle (A-B) and moment (C-D) when landing with the preferred and non-preferred legs being predicted by the clinical tests.



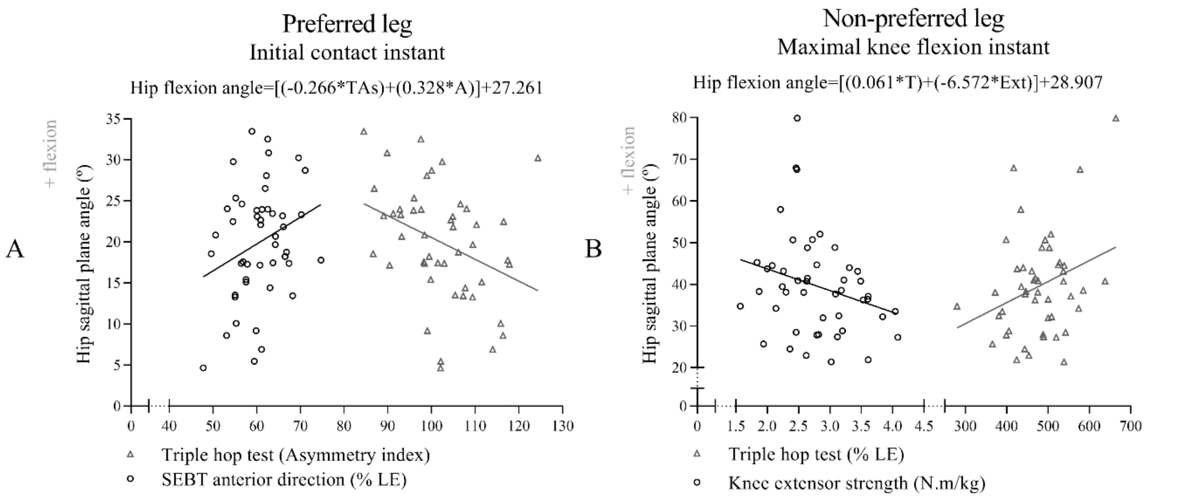
Ad: hip adductor strength; C: crossover hop test; LE: lower extremity; PL: SEBT posterolateral direction; SEBT: star excursion balance test; T: triple hop test.

Figure A 3 – Knee frontal plane angle (A, C, E) and moment (B, D, F) when landing with the preferred and non-preferred legs being predicted by the clinical tests.



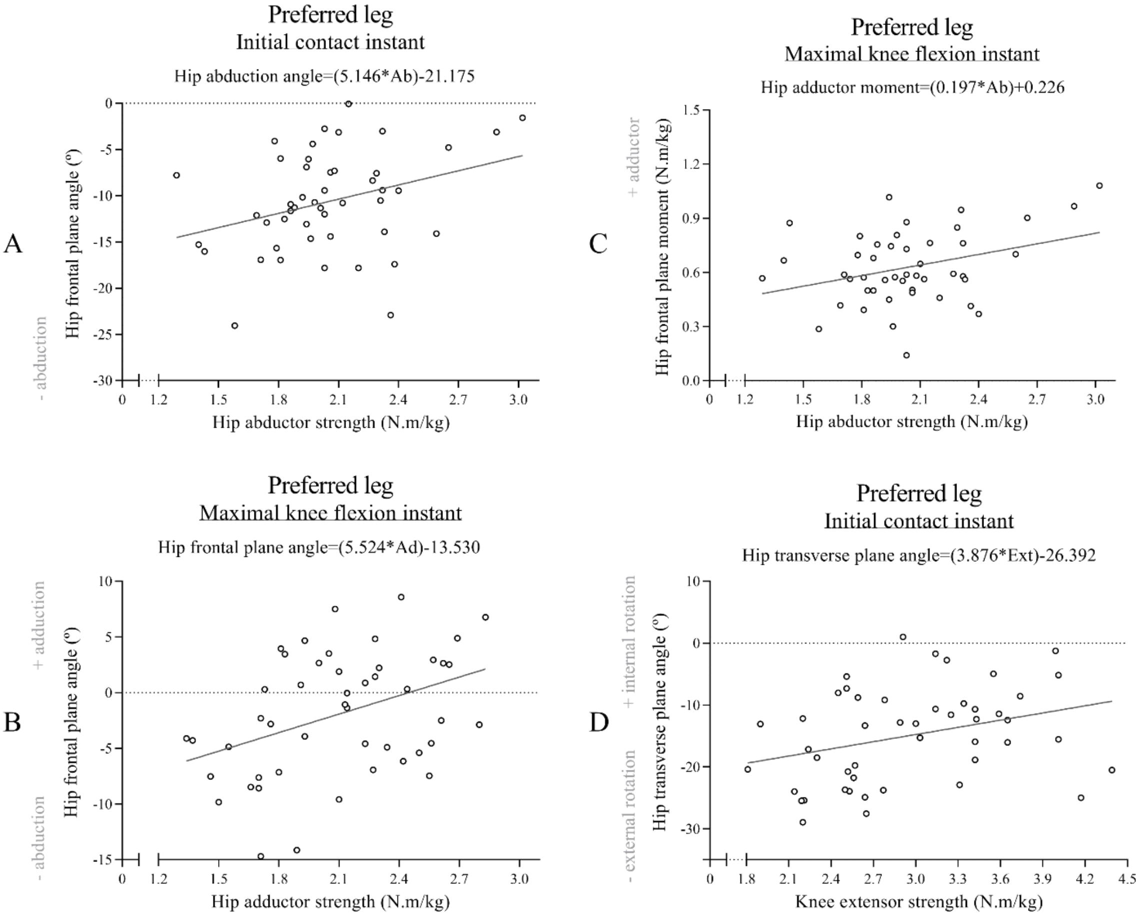
CAs: asymmetry index in crossover hop test; LE: lower extremity; LSD: lateral step down; T: triple hop test.

Figure A 4 – Hip flexion angle at initial contact (A) and maximal knee flexion (B) when landing with the preferred and non-preferred legs being predicted by the clinical tests.



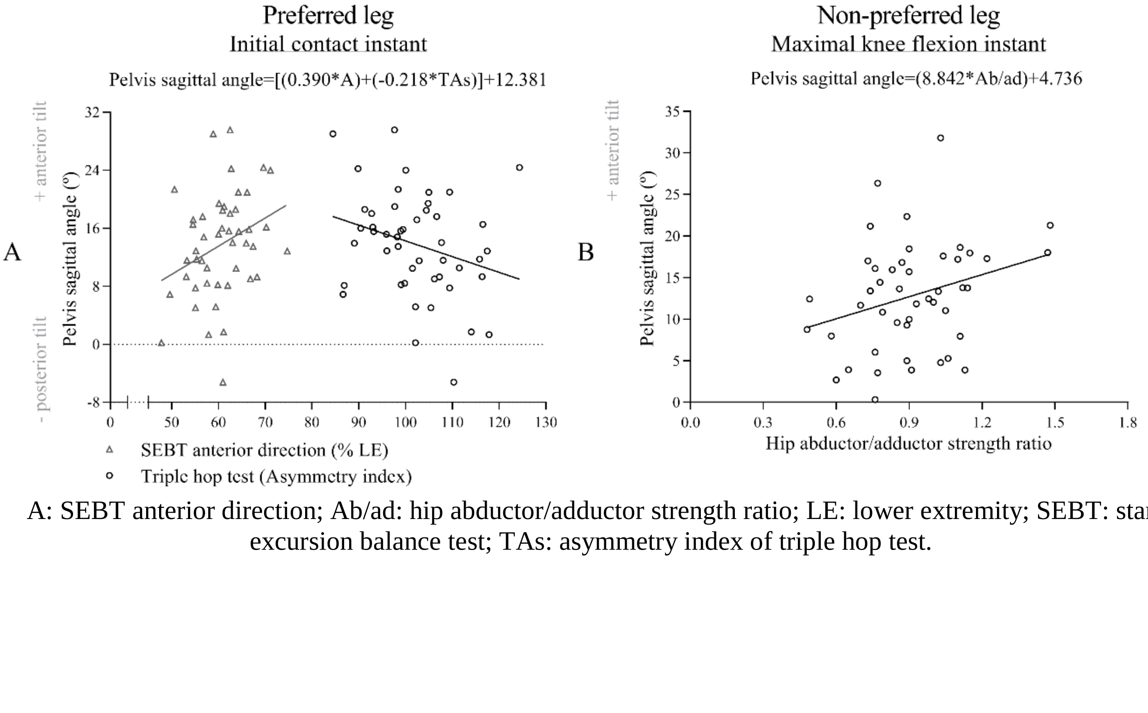
A: SEBT anterior direction; Ext: knee extensor strength; LE: lower extremity; SEBT: star excursion balance test; T: triple hop test; TAs: asymmetry index of triple hop test.

Figure A 5 – Hip frontal plane angle (A-B) and moment (C) and transverse plane angle (D) when landing with the preferred leg being predicted by the clinical tests.



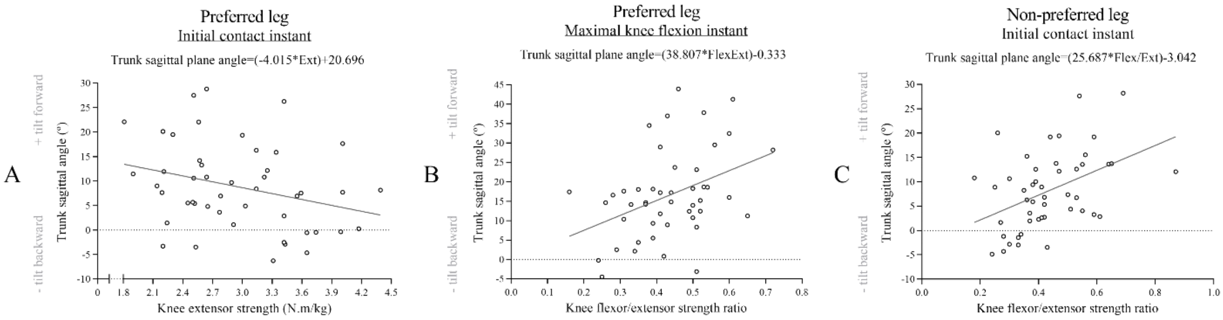
Ab: hip abductor strength; Ad: hip adductor strength; Ext: knee extensor strength.

Figure A 6 – Pelvis sagittal plane angle at initial contact (A) and knee maximal flexion (B) when landing with the preferred and non-preferred legs being predicted by the clinical tests.



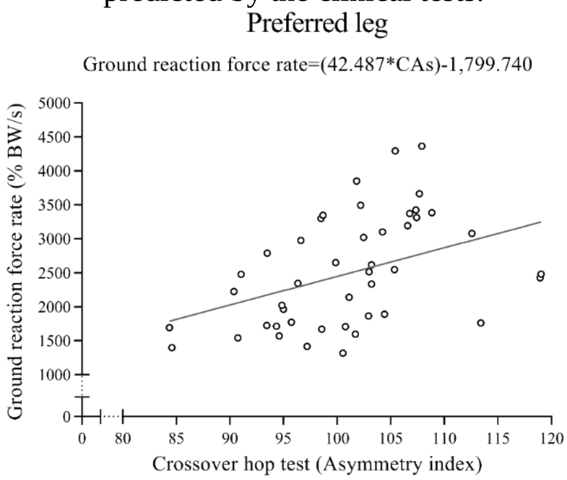
A: SEBT anterior direction; Ab/ad: hip abductor/adductor strength ratio; LE: lower extremity; SEBT: star excursion balance test; TAs: asymmetry index of triple hop test.

Figure A 7 – Trunk sagittal plane angle at initial contact (A, C) and maximal knee flexion (B) when landing with the preferred and non-preferred legs being predicted by the clinical tests.



Ext: knee extensor strength; Flex/Ext: knee flexor/extensor strength ratio.

Figure A 8 – Vertical ground reaction force rate when landing with the preferred leg being predicted by the clinical tests.



CAs: asymmetry index in crossover hop test.

APPENDIX E – Correlation matrix between clinical and biomechanical outcomes – Bilateral landings

Correlation matrix of clinical and biomechanical outcomes for preferred leg

Biomechanical outcome			Correlation information	Clinical outcomes																					
Joint	Instant	Outcome		Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add	Strength Abd/Add
Knee	IC	Sagittal plane angle	r	0.120	0.219	0.054	0.128	0.129	0.023	-0.122	0.050	-0.019	-0.218	0.089	-0.099	0.056	-0.233	-0.383	0.003	-0.161	0.019	-0.156	-0.052	-0.079	0.054
			p	0.401	0.122	0.705	0.371	0.368	0.870	0.394	0.728	0.894	0.124	0.532	0.491	0.696	0.101	0.006	0.984	0.260	0.893	0.274	0.720	0.583	0.708
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	IC	Frontal plane angle	r	0.040	0.312	0.242	0.353	0.368	-0.031	-0.067	0.064	0.001	-0.294	0.153	0.100	0.164	-0.289	-0.321	-0.190	0.040	0.106	-0.006	0.103	0.241	-0.123
			p	0.783	0.026	0.087	0.011	0.008	0.828	0.639	0.657	0.995	0.036	0.282	0.484	0.250	0.040	0.022	0.183	0.781	0.459	0.966	0.473	0.088	0.389
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Ankle	IC	Sagittal plane angle*	r	-0.012	0.038	-0.142	-0.160	-0.109	0.249	-0.054	0.068	0.132	-0.141	0.116	-0.155	0.017	0.012	-0.318	0.128	-0.071	0.059	-0.029	-0.043	0.082	0.000
			p	0.935	0.791	0.322	0.262	0.445	0.078	0.705	0.637	0.355	0.322	0.416	0.277	0.905	0.935	0.023	0.370	0.619	0.680	0.843	0.766	0.566	0.999
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Sagittal plane angle	r	0.103	0.176	0.119	0.190	0.186	0.078	0.112	0.042	0.087	-0.273	0.203	0.125	0.153	0.003	-0.132	0.100	-0.030	0.181	-0.167	-0.146	-0.019	0.038
			p	0.470	0.217	0.404	0.182	0.192	0.587	0.434	0.772	0.544	0.052	0.153	0.382	0.284	0.985	0.356	0.485	0.836	0.203	0.242	0.308	0.896	0.789
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Frontal plane angle	r	0.218	-0.062	-0.140	-0.313	-0.235	-0.114	-0.065	-0.325	-0.243	0.125	-0.082	-0.242	-0.263	0.205	-0.042	-0.072	0.043	0.037	0.180	0.037	0.042	0.150
			p	0.125	0.666	0.326	0.025	0.097	0.425	0.652	0.020	0.085	0.380	0.569	0.087	0.062	0.149	0.771	0.614	0.762	0.795	0.207	0.797	0.770	0.294
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Transverse plane angle	r	0.063	0.145	0.038	-0.036	0.033	-0.066	0.051	0.072	0.049	-0.198	0.025	-0.086	-0.097	-0.026	0.021	0.036	0.208	0.227	-0.059	0.141	0.192	0.147
			p	0.662	0.310	0.793	0.804	0.820	0.644	0.723	0.618	0.732	0.163	0.860	0.547	0.499	0.855	0.881	0.801	0.143	0.109	0.680	0.322	0.177	0.303
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Sagittal plane angle	r	-0.116	0.025	0.139	0.084	0.099	0.129	0.233	-0.008	0.125	-0.174	0.213	0.232	0.170	0.004	0.010	0.073	0.099	0.219	-0.080	0.000	0.127	-0.007
			p	0.418	0.860	0.330	0.559	0.488	0.366	0.099	0.958	0.384	0.221	0.134	0.102	0.234	0.979	0.943	0.610	0.490	0.122	0.578	0.997	0.376	0.963
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Frontal plane angle*	r	0.239	0.120	0.040	0.100	0.094	-0.066	-0.053	0.019	-0.068	0.002	0.116	0.005	0.074	-0.214	-0.485	-0.247	-0.252	-0.117	0.009	-0.121	-0.047	-0.014
			p	0.092	0.402	0.783	0.487	0.511	0.646	0.711	0.894	0.633	0.989	0.417	0.972	0.607	0.132	0.000	0.081	0.074	0.413	0.951	0.396	0.744	0.922
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Transverse plane angle*	r	-0.074	-0.119	-0.010	0.106	0.013	-0.089	-0.008	0.011	-0.039	0.011	-0.127	0.004	-0.062	-0.133	-0.090	-0.161	-0.198	-0.240	-0.171	0.037	-0.089	-0.168
			p	0.607	0.407	0.945	0.458	0.930	0.533	0.954	0.939	0.784	0.937	0.374	0.980	0.664	0.351	0.529	0.259	0.164	0.090	0.229	0.797	0.533	0.240
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Sagittal plane angle	r	-0.020	0.180	0.078	0.184	0.188	0.031	0.089	0.092	0.099	-0.175	0.212	0.237	0.254	-0.109	-0.056	-0.037	-0.025	0.066	0.096	0.198	0.065	0.048
			p	0.891	0.206	0.585	0.196	0.186	0.831	0.533	0.521	0.489	0.219	0.135	0.094	0.073	0.445	0.698	0.798	0.861	0.646	0.504	0.163	0.649	0.738
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Frontal plane angle	r	0.189	-0.124	-0.127	-0.106	-0.119	-0.229	0.066	-0.060	-0.065	0.039	0.109	0.094	0.120	0.082	-0.131	-0.166	-0.144	-0.003	0.180	0.067	0.161	-0.016
			p	0.183	0.385	0.374	0.461	0.404	0.106	0.645	0.676	0.652	0.785	0.448	0.512	0.403	0.566	0.360	0.243	0.313	0.985	0.206	0.642	0.258	0.912
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Transverse plane angle*	r	-0.176	-0.053	0.107	0.195	0.116	-0.206	0.054	0.027	-0.034	0.047	-0.102	0.072	0.023	-0.192	-0.087	-0.102	-0.124	-0.230	-0.164	0.021	-0.084	-0.124
			p	0.216	0.713	0.456	0.169	0.418	0.148	0.705	0.851	0.814	0.745	0.478	0.615	0.873	0.177	0.542	0.476	0.388	0.104	0.251	0.884	0.557	0.384
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	IC	Sagittal plane moment	r	-0.267	-0.161	-0.189	-0.183	-0.197	-0.108	0.019	-0.063	-0.053	0.027	0.040	-0.134	-0.008	-0.168	-0.297	-0.023	-0.142	-0.150	-0.022	0.189	0.030	0.348
			p	0.067	0.275	0.199	0.212	0.179	0.464	0.896	0.671	0.720	0.855	0.790	0.364	0.955	0.254	0.041	0.879	0.337	0.309	0.882	0.199	0.837	0.015
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Knee	IC	Frontal plane moment	r	-0.175	0.030	0.004	0.073	0.046	0.070	0.018	0.201	0.135	-0.021	0.242	0.275	0.282	0.150	0.072	0.320	0.168	0.188	0.177	-0.139	0.231	-0.052
			p	0.233	0.837	0.980	0.624	0.756	0.637	0.904	0.171	0.362	0.890	0.098	0.059	0.052	0.310	0.628	0.027	0.253	0.201	0.230	0.346	0.115	0.724
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Hip	IC	Frontal plane moment	r	0.008	-0.002	-0.133	-0.029	-0.094	0.115	0.041	0.211	0.168	-0.209	0.010	0.048	0.083	0.159	-0.197	-0.166	-0.198	0.099	-0.138	-0.154	-0.168	0.010
			p	0.956	0.990	0.369	0.844	0.526	0.435	0.782	0.149	0.254	0.153	0.947	0.746	0.574	0.280	0.180	0.258	0.178	0.502	0.349	0.297	0.252	0.945
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Knee	MF	Sagittal plane angle*	r	0.145	0.274	0.134	0.177	0.230	0.033	-0.017	0.075	0.033	-0.282	0.171	0.106	0.201	-0.075	-0.057	0.019	-0.091	-0.019	-0.091	0.132	-0.006	0.043
			p	0.310	0.052	0.350	0.214	0.105	0.820	0.905	0.599	0.816	0.045	0.230	0.458	0.158	0.599	0.693	0.893	0.525	0.895	0.525	0.357	0.968	0.767
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	MF	Frontal plane angle	r	-0.233	-0.129	0.052	0.151	0.061	0.048	-0.017	-0.089	-0.045	-0.059	-0.143	-0.213	-0.240	-0.071	0.032	-0.149	-0.155	-0.015	-0.110	-0.071	-0.054	0.151
			p	0.100	0.367	0.718	0.289	0.670	0.738	0.905	0.534	0.752	0.682	0.318	0.133	0.090	0.622	0.825	0.295	0.276	0.917	0.441	0.621	0.707	0.289
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51

Ankle	MF	Sagittal plane angle	r	0.375	0.432	-0.019	-0.047	0.078	-0.051	-0.080	0.017	-0.029	-0.234	-0.035	-0.149	-0.030	0.017	-0.169	-0.039	-0.096	0.012	-0.035	0.092	-0.054	0.055
			p	0.007	0.002	0.895	0.741	0.588	0.721	0.578	0.905	0.838	0.098	0.806	0.297	0.837	0.904	0.235	0.784	0.502	0.931	0.806	0.520	0.705	0.704
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	MF	Sagittal plane angle*	r	0.032	0.159	0.075	0.212	0.197	0.224	0.153	0.164	0.187	-0.162	0.203	0.222	0.254	-0.022	-0.020	0.052	-0.087	0.112	-0.084	0.037	-0.054	-0.015
			p	0.825	0.265	0.603	0.136	0.165	0.114	0.283	0.250	0.190	0.255	0.152	0.118	0.072	0.876	0.887	0.716	0.543	0.432	0.557	0.796	0.707	0.918
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	MF	Frontal plane angle	r	0.151	-0.023	-0.162	-0.354	-0.259	-0.215	-0.109	-0.271	-0.255	0.282	-0.214	-0.363	-0.366	0.175	0.045	0.120	0.170	0.092	0.213	0.128	0.122	0.025
			p	0.291	0.872	0.256	0.011	0.066	0.130	0.445	0.054	0.071	0.045	0.132	0.009	0.008	0.220	0.754	0.400	0.233	0.522	0.134	0.371	0.395	0.862
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	MF	Transverse plane angle	r	-0.090	0.043	-0.034	0.084	0.056	0.072	0.084	0.076	0.097	-0.102	0.001	-0.050	-0.045	0.070	0.131	0.112	-0.032	0.200	-0.120	0.015	0.030	0.092
			p	0.529	0.763	0.814	0.559	0.694	0.615	0.559	0.595	0.500	0.477	0.996	0.728	0.753	0.624	0.361	0.433	0.826	0.159	0.403	0.914	0.832	0.522
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Sagittal plane angle	r	-0.156	-0.031	0.040	0.241	0.168	0.243	0.150	0.085	0.168	-0.059	0.259	0.344	0.274	-0.079	-0.014	-0.030	-0.023	0.136	-0.093	0.013	-0.014	-0.062
			p	0.274	0.832	0.780	0.089	0.238	0.086	0.295	0.551	0.240	0.683	0.067	0.014	0.051	0.582	0.922	0.834	0.875	0.340	0.518	0.929	0.925	0.668
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Frontal plane angle*	r	0.059	0.051	0.126	0.207	0.169	-0.140	0.030	0.148	0.012	-0.008	0.011	-0.031	0.030	-0.019	-0.185	-0.081	-0.111	-0.228	-0.078	0.112	0.034	0.001
			p	0.679	0.723	0.377	0.145	0.237	0.327	0.835	0.302	0.932	0.957	0.940	0.827	0.832	0.892	0.193	0.570	0.438	0.107	0.588	0.433	0.813	0.995
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Transverse plane angle*	r	-0.001	-0.130	0.013	0.184	0.057	-0.022	-0.047	0.058	-0.014	-0.052	-0.074	0.104	0.023	-0.187	-0.051	-0.155	-0.181	-0.223	-0.153	-0.081	-0.132	-0.155
			p	0.997	0.365	0.927	0.196	0.690	0.879	0.742	0.688	0.925	0.716	0.605	0.467	0.875	0.189	0.722	0.279	0.205	0.115	0.283	0.572	0.357	0.278
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Sagittal plane angle*	r	-0.105	0.170	0.067	0.210	0.174	0.172	0.159	0.121	0.155	-0.213	0.284	0.334	0.351	-0.089	0.001	-0.066	-0.077	0.144	0.054	0.233	-0.021	0.153
			p	0.464	0.232	0.640	0.139	0.222	0.227	0.266	0.398	0.279	0.133	0.044	0.017	0.011	0.533	0.994	0.644	0.592	0.312	0.708	0.101	0.886	0.284
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Frontal plane angle*	r	0.216	-0.124	-0.109	-0.047	-0.133	-0.172	0.053	0.040	0.008	0.048	0.075	0.142	0.168	0.075	-0.026	-0.094	-0.136	-0.149	0.098	0.166	0.125	-0.132
			p	0.128	0.386	0.447	0.745	0.352	0.227	0.713	0.780	0.955	0.736	0.600	0.320	0.238	0.602	0.854	0.512	0.340	0.298	0.496	0.243	0.383	0.355
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Transverse plane angle*	r	-0.090	-0.031	0.144	0.242	0.164	-0.175	0.021	0.042	-0.038	-0.030	-0.093	0.107	0.035	-0.199	0.017	-0.073	-0.121	-0.192	-0.144	-0.003	-0.130	-0.137
			p	0.532	0.827	0.314	0.088	0.250	0.220	0.884	0.772	0.793	0.832	0.517	0.454	0.808	0.162	0.904	0.610	0.399	0.176	0.314	0.984	0.364	0.338
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	MF	Sagittal plane moment	r	0.148	0.021	-0.018	-0.103	-0.047	-0.224	-0.221	-0.111	-0.215	0.132	-0.007	-0.090	-0.058	-0.028	0.004	0.150	0.316	0.068	0.120	0.070	0.332	-0.232
			p	0.315	0.887	0.904	0.485	0.751	0.126	0.132	0.454	0.142	0.370	0.962	0.544	0.697	0.850	0.980	0.309	0.029	0.648	0.416	0.637	0.021	0.112
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Knee	MF	Frontal plane moment*	r	0.353	0.028	-0.240	-0.147	-0.160	0.007	-0.346	-0.041	-0.149	-0.287	-0.180	-0.344	-0.262	0.022	-0.268	-0.261	-0.169	0.068	-0.245	-0.237	-0.108	0.101
			p	0.014	0.851	0.100	0.318	0.278	0.965	0.016	0.782	0.312	0.048	0.220	0.017	0.071	0.880	0.065	0.074	0.251	0.648	0.093	0.105	0.467	0.494
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Hip	MF	Frontal plane moment	r	0.277	-0.090	-0.145	-0.170	-0.187	-0.040	-0.068	0.041	-0.021	0.055	-0.134	-0.213	-0.116	0.102	-0.288	-0.084	0.073	0.004	-0.031	-0.011	0.048	0.017
			p	0.057	0.544	0.326	0.248	0.202	0.789	0.645	0.783	0.890	0.709	0.364	0.146	0.431	0.490	0.047	0.570	0.622	0.977	0.834	0.940	0.744	0.911
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
N/A	MF	Ground reaction force	r	0.080	0.058	0.028	-0.039	0.020	0.013	-0.042	-0.077	-0.060	0.055	0.095	0.039	0.009	0.185	0.148	0.183	0.268	0.247	0.243	0.009	0.344	-0.190
			p	0.587	0.694	0.851	0.795	0.894	0.929	0.776	0.602	0.688	0.708	0.523	0.792	0.950	0.209	0.315	0.213	0.066	0.091	0.096	0.954	0.017	0.196
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Knee	Range	Frontal plane angle*	r	0.075	0.160	0.084	0.226	0.157	-0.219	-0.166	-0.013	-0.104	0.027	0.252	0.176	0.288	0.168	0.096	0.216	0.029	0.009	0.100	-0.070	0.143	-0.150
			p	0.599	0.262	0.559	0.111	0.273	0.122	0.245	0.930	0.468	0.851	0.074	0.216	0.041	0.240	0.504	0.128	0.841	0.950	0.484	0.624	0.317	0.293
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
N/A	Peak	Ground reaction force	r	0.019	-0.001	0.002	0.076	0.067	0.119	0.002	0.008	0.035	0.051	0.234	0.193	0.109	0.249	0.261	0.315	0.258	0.164	0.066	-0.073	0.242	-0.044
			p	0.897	0.994	0.989	0.608	0.649	0.420	0.992	0.957	0.811	0.731	0.109	0.190	0.459	0.088	0.073	0.029	0.077	0.265	0.655	0.624	0.097	0.765
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
N/A	Rate	Ground reaction force*	r	-0.007	0.020	0.001	-0.031	-0.025	0.117	0.046	0.033	0.125	-0.044	0.294	0.228	0.170	0.293	0.189	0.464	0.170	0.285	0.021	-0.205	0.219	-0.165
			p	0.965	0.890	0.995	0.832	0.867	0.428	0.757	0.824	0.399	0.768	0.043	0.119	0.249	0.043	0.199	0.001	0.247	0.050	0.889	0.163	0.134	0.262
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Knee	Peak valgus	Frontal plane angle*	r	-0.192	-0.073	0.053	0.090	0.075	0.007	-0.002	-0.111	-0.078	-0.120	-0.139	-0.207	-0.196	-0.164	-0.179	-0.193	-0.116	0.022	-0.132	0.128	0.040	0.155
			p	0.178	0.612	0.714	0.531	0.601	0.962	0.990	0.438	0.587	0.400	0.330	0.145	0.167	0.252	0.210	0.176	0.418	0.880	0.357	0.372	0.779	0.277
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	Peak abductor	Frontal plane moment*	r	-0.101	0.042	-0.054	0.098	-0.003	-0.052	-0.110	-0.017	-0.026	-0.231	0.222	0.111	0.124	0.058	-0.175	0.034	0.029	0.210	0.087	-0.324	0.231	0.056
			p	0.493	0.778	0.715	0.509	0.982	0.727	0.456	0.909	0.860	0.114	0.129	0.451	0.401	0.693	0.235	0.816	0.847	0.152	0.557	0.024	0.115	0.704
			n	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

* Spearmann correlation; Cells highligthed in green are p values ≤ 0.20; Cells highligthed in blue are the clinical outcomes inserted in each model.

Correlation matrix of clinical and biomechanical outcomes for non-preferred leg

Biomechanical outcome			Correlation information	Clinical outcomes																					
Joint	Instant	Outcome		Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add	Strength Abd/Add
Knee	IC	Sagittal plane angle	r	0.211	0.335	0.135	0.134	0.221	-0.070	-0.066	0.026	-0.024	-0.250	0.154	0.019	-0.034	-0.225	-0.189	0.042	0.054	-0.016	-0.275	0.220	-0.178	0.304
			p	0.138	0.016	0.346	0.349	0.119	0.625	0.647	0.855	0.865	0.076	0.279	0.897	0.814	0.113	0.183	0.768	0.706	0.909	0.050	0.122	0.212	0.030
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	IC	Frontal plane angle*	r	-0.053	0.243	0.148	0.226	0.239	0.035	0.072	0.138	0.104	-0.039	0.220	0.345	0.231	-0.152	-0.324	-0.133	0.004	0.197	0.023	0.066	-0.009	0.021
			p	0.711	0.086	0.299	0.111	0.092	0.807	0.617	0.333	0.467	0.785	0.121	0.013	0.102	0.288	0.020	0.351	0.979	0.165	0.872	0.643	0.950	0.882
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Ankle	IC	Sagittal plane angle*	r	-0.095	-0.033	-0.175	-0.121	-0.125	0.116	0.015	0.029	0.118	-0.187	0.010	-0.015	-0.100	0.033	-0.194	0.122	0.092	-0.040	-0.212	0.071	-0.096	0.170
			p	0.505	0.819	0.219	0.399	0.382	0.419	0.916	0.839	0.408	0.189	0.945	0.915	0.484	0.819	0.172	0.394	0.522	0.780	0.136	0.619	0.503	0.232
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Sagittal plane angle	r	0.084	0.205	0.083	0.245	0.219	0.002	0.119	0.053	0.080	-0.304	0.232	0.243	0.173	-0.072	-0.157	0.033	-0.085	0.026	-0.275	0.131	-0.164	0.229
			p	0.557	0.148	0.561	0.084	0.123	0.988	0.407	0.713	0.576	0.030	0.102	0.086	0.225	0.615	0.271	0.819	0.554	0.855	0.050	0.360	0.249	0.105
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Frontal plane angle	r	-0.056	-0.373	-0.382	-0.472	-0.504	0.110	0.067	-0.008	0.052	0.222	-0.398	-0.369	-0.297	0.308	0.299	0.159	0.033	-0.055	0.045	-0.116	0.116	-0.149
			p	0.695	0.007	0.006	0.000	0.000	0.442	0.641	0.955	0.716	0.118	0.004	0.008	0.034	0.028	0.033	0.266	0.819	0.702	0.753	0.416	0.418	0.298
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	IC	Transverse plane angle*	r	0.098	0.127	0.111	0.129	0.135	0.112	-0.035	0.036	0.020	0.015	0.206	0.309	0.175	-0.118	-0.409	-0.117	-0.061	0.045	-0.180	-0.002	-0.263	0.205
			p	0.496	0.376	0.438	0.369	0.346	0.436	0.808	0.802	0.892	0.914	0.147	0.027	0.219	0.408	0.003	0.412	0.670	0.752	0.207	0.990	0.062	0.149
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Sagittal plane angle	r	-0.162	-0.042	-0.021	0.099	0.030	0.135	0.238	0.002	0.133	-0.226	0.176	0.235	0.165	0.009	0.010	0.082	0.074	0.074	-0.120	0.146	0.064	0.031
			p	0.255	0.767	0.886	0.491	0.836	0.346	0.093	0.986	0.351	0.111	0.218	0.097	0.247	0.952	0.946	0.566	0.608	0.604	0.402	0.308	0.655	0.827
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Frontal plane angle*	r	-0.238	-0.151	-0.070	-0.109	-0.130	0.068	0.062	-0.021	0.072	-0.133	-0.193	-0.260	-0.185	0.210	0.487	0.245	0.382	0.141	0.067	0.085	0.283	-0.199
			p	0.093	0.289	0.624	0.447	0.364	0.634	0.664	0.882	0.614	0.352	0.176	0.065	0.194	0.140	0.000	0.083	0.006	0.325	0.638	0.552	0.044	0.161
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	IC	Transverse plane angle*	r	0.127	0.085	0.023	-0.031	0.038	0.086	0.010	-0.010	0.040	-0.042	-0.029	-0.045	-0.026	0.128	0.080	0.161	0.36	0.185	0.021	0.050	0.184	-0.089
			p	0.375	0.555	0.875	0.829	0.792	0.549	0.944	0.944	0.783	0.772	0.838	0.753	0.854	0.372	0.576	0.259	0.010	0.193	0.883	0.730	0.196	0.533
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Sagittal plane angle	r	-0.059	0.166	0.058	0.114	0.131	0.030	0.088	0.095	0.100	-0.255	0.249	0.257	0.275	-0.112	-0.055	-0.039	-0.097	0.171	0.153	0.147	-0.096	0.200
			p	0.680	0.245	0.687	0.425	0.361	0.834	0.538	0.508	0.485	0.071	0.078	0.069	0.051	0.436	0.704	0.784	0.498	0.230	0.283	0.304	0.501	0.160
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Frontal plane angle	r	-0.167	-0.014	0.141	0.078	0.092	0.233	-0.066	0.055	0.063	0.041	-0.041	-0.164	-0.177	-0.086	0.128	0.167	0.172	-0.042	-0.198	0.032	0.058	-0.035
			p	0.242	0.924	0.322	0.586	0.521	0.099	0.644	0.699	0.660	0.775	0.773	0.250	0.215	0.550	0.370	0.243	0.226	0.770	0.164	0.821	0.686	0.809
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	IC	Transverse plane angle*	r	0.225	-0.024	-0.059	-0.098	-0.094	0.214	-0.047	-0.024	0.041	-0.033	-0.097	-0.122	-0.086	0.197	0.088	0.117	0.262	0.132	0.040	0.071	0.136	-0.004
			p	0.112	0.866	0.680	0.493	0.513	0.132	0.744	0.866	0.774	0.819	0.499	0.394	0.549	0.165	0.540	0.413	0.063	0.355	0.781	0.620	0.340	0.975
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	IC	Sagittal plane moment	r	0.022	0.063	-0.238	-0.207	-0.180	-0.081	-0.003	-0.058	-0.055	-0.246	-0.154	-0.100	-0.114	0.030	-0.058	0.034	0.055	-0.073	-0.124	0.089	-0.068	0.113
			p	0.877	0.665	0.096	0.149	0.212	0.574	0.983	0.689	0.703	0.085	0.286	0.488	0.429	0.838	0.689	0.815	0.703	0.614	0.391	0.541	0.641	0.435
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Knee	IC	Frontal plane moment	r	0.036	0.118	-0.276	-0.300	-0.224	0.025	0.138	0.222	0.199	-0.138	-0.139	-0.099	-0.070	0.165	-0.028	0.100	0.062	0.171	0.180	0.161	0.263	-0.178
			p	0.802	0.414	0.052	0.034	0.118	0.862	0.338	0.120	0.165	0.338	0.336	0.492	0.627	0.253	0.849	0.491	0.667	0.235	0.212	0.263	0.065	0.217
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Hip	IC	Frontal plane moment	r	-0.114	0.028	-0.075	-0.153	-0.099	-0.073	0.043	0.238	0.145	-0.156	-0.067	-0.028	-0.074	0.141	-0.120	0.091	-0.027	0.138	0.203	-0.092	-0.007	-0.041
			p	0.431	0.849	0.607	0.288	0.496	0.617	0.766	0.096	0.314	0.280	0.642	0.845	0.611	0.328	0.408	0.531	0.853	0.340	0.158	0.527	0.962	0.779
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Knee	MF	Sagittal plane angle*	r	0.137	0.244	0.212	0.175	0.233	0.052	-0.082	0.080	0.014	-0.358	0.208	0.134	0.161	-0.076	-0.094	0.026	-0.073	0.175	-0.120	0.147	-0.216	0.312
			p	0.339	0.085	0.136	0.219	0.099	0.718	0.566	0.576	0.924	0.010	0.144	0.350	0.260	0.596	0.511	0.859	0.612	0.219	0.400	0.302	0.128	0.026
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	MF	Frontal plane angle	r	-0.066	-0.136	0.097	0.192	0.096	0.116	-0.053	-0.079	-0.046	0.018	0.092	0.151	0.095	-0.046	-0.221	-0.118	-0.062	-0.009	-0.086	-0.222	-0.314	0.148
			p	0.644	0.340	0.498	0.177	0.502	0.419	0.711	0.584	0.749	0.901	0.519	0.292	0.509	0.750	0.120	0.410	0.667	0.952	0.550	0.118	0.025	0.300
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Ankle	MF	Sagittal plane angle	r	0.347	0.327	0.089	-0.007	0.128	-0.009	-0.147	-0.016	-0.071	-0.159	0.075	0.049	-0.043	-0.038	-0.273	0.006	-0.065	0.087	-0.148	0.145	-0.252	0.306
			p	0.013	0.019	0.536	0.959	0.369	0.951	0.302	0.910	0.620	0.266	0.603	0.735	0.767	0.793	0.053	0.967	0.649	0.542	0.301	0.309	0.074	0.029
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51

Hip	MF	Sagittal plane angle*	r	-0.045	0.052	0.087	0.197	0.136	0.231	0.135	0.167	0.178	-0.214	0.244	0.222	0.239	-0.076	-0.053	0.009	-0.133	0.212	-0.049	0.145	-0.242	0.300
			p	0.752	0.716	0.544	0.166	0.342	0.102	0.345	0.242	0.212	0.132	0.084	0.117	0.091	0.595	0.711	0.949	0.352	0.136	0.731	0.309	0.087	0.032
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	MF	Frontal plane angle	r	0.038	-0.239	-0.304	-0.280	-0.334	0.060	0.098	0.007	0.053	0.300	-0.133	-0.082	-0.092	0.087	0.066	-0.007	-0.112	0.055	-0.027	-0.113	0.048	-0.058
			p	0.792	0.092	0.030	0.047	0.016	0.678	0.493	0.962	0.710	0.033	0.353	0.567	0.519	0.546	0.643	0.963	0.434	0.702	0.849	0.430	0.739	0.686
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Hip	MF	Transverse plane angle*	r	-0.020	-0.034	0.194	0.266	0.193	0.147	0.016	0.044	0.058	-0.072	0.190	0.258	0.184	-0.033	-0.288	-0.068	-0.190	0.039	-0.027	-0.041	-0.351	0.243
			p	0.891	0.815	0.173	0.059	0.174	0.303	0.909	0.760	0.686	0.614	0.181	0.067	0.196	0.818	0.041	0.635	0.183	0.785	0.851	0.773	0.012	0.086
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Sagittal plane angle	r	-0.215	-0.156	0.047	0.211	0.080	0.241	0.148	0.083	0.165	-0.092	0.281	0.348	0.314	-0.077	-0.014	-0.032	-0.069	0.161	-0.049	0.159	-0.116	0.216
			p	0.130	0.275	0.746	0.137	0.577	0.089	0.300	0.562	0.247	0.522	0.045	0.012	0.025	0.590	0.924	0.823	0.632	0.258	0.733	0.264	0.419	0.128
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Frontal plane angle*	r	-0.041	-0.065	-0.086	-0.153	-0.121	0.151	-0.025	-0.134	0.003	0.033	-0.049	-0.079	-0.090	0.038	0.180	0.086	0.284	0.156	-0.005	-0.072	0.209	-0.200
			p	0.773	0.649	0.549	0.283	0.398	0.291	0.863	0.348	0.983	0.816	0.732	0.581	0.531	0.790	0.205	0.548	0.043	0.275	0.973	0.614	0.141	0.160
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Pelvis	MF	Transverse plane angle*	r	0.075	0.118	-0.045	-0.105	-0.014	0.023	0.053	-0.054	0.018	-0.064	-0.104	-0.106	-0.102	0.182	0.051	0.159	0.312	0.159	0.072	0.018	0.199	-0.130
			p	0.602	0.408	0.754	0.464	0.924	0.874	0.711	0.705	0.901	0.655	0.466	0.459	0.475	0.202	0.722	0.264	0.026	0.265	0.615	0.899	0.162	0.363
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Sagittal plane angle*	r	-0.129	0.098	0.037	0.109	0.066	0.167	0.158	0.113	0.149	-0.274	0.329	0.335	0.370	-0.095	-0.005	-0.074	-0.138	0.314	0.134	0.216	-0.146	0.253
			p	0.366	0.493	0.797	0.447	0.645	0.242	0.268	0.431	0.295	0.051	0.018	0.016	0.008	0.508	0.970	0.604	0.335	0.025	0.348	0.128	0.306	0.073
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Frontal plane angle*	r	-0.129	0.001	0.099	0.073	0.109	0.170	-0.049	-0.039	-0.006	0.087	-0.052	-0.155	-0.223	-0.079	0.021	0.092	0.225	0.020	-0.116	0.004	0.088	-0.058
			p	0.368	0.995	0.492	0.612	0.445	0.232	0.735	0.788	0.967	0.544	0.715	0.278	0.116	0.583	0.884	0.521	0.112	0.888	0.416	0.980	0.539	0.687
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Trunk	MF	Transverse plane angle*	r	0.154	-0.022	-0.170	-0.175	-0.168	0.172	0.003	-0.029	0.056	-0.003	-0.111	-0.109	-0.095	0.208	-0.013	0.081	0.218	0.104	0.005	0.009	0.128	-0.028
			p	0.281	0.879	0.233	0.219	0.240	0.226	0.982	0.841	0.694	0.984	0.436	0.448	0.506	0.144	0.926	0.572	0.125	0.466	0.971	0.951	0.369	0.848
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	MF	Sagittal plane moment	r	0.370	0.232	-0.148	-0.269	-0.121	-0.131	-0.192	0.056	-0.083	0.031	-0.192	-0.184	-0.085	0.082	0.030	0.047	0.179	-0.025	-0.026	0.103	0.311	-0.255
			p	0.008	0.104	0.306	0.059	0.403	0.364	0.181	0.699	0.565	0.830	0.181	0.201	0.559	0.572	0.838	0.743	0.214	0.864	0.860	0.476	0.028	0.074
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Knee	MF	Frontal plane moment*	r	0.087	0.031	0.085	0.057	0.067	-0.205	-0.247	-0.303	-0.304	0.338	-0.042	-0.103	-0.191	-0.075	-0.133	0.036	0.200	-0.366	-0.120	-0.058	0.123	-0.122
			p	0.549	0.830	0.556	0.693	0.642	0.154	0.084	0.032	0.032	0.017	0.775	0.475	0.185	0.603	0.358	0.804	0.165	0.009	0.407	0.690	0.394	0.399
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Hip	MF	Frontal plane moment	r	-0.128	-0.114	-0.077	-0.133	-0.135	-0.172	0.023	-0.118	-0.103	0.198	-0.149	-0.208	-0.234	0.078	0.155	0.151	0.208	-0.248	0.095	0.030	0.370	-0.292
			p	0.375	0.430	0.594	0.357	0.351	0.231	0.877	0.415	0.476	0.168	0.301	0.147	0.102	0.589	0.284	0.294	0.146	0.083	0.512	0.838	0.008	0.039
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
N/A	MF	Ground reaction force	r	-0.006	0.057	-0.025	0.062	0.039	-0.240	0.008	-0.084	-0.113	0.278	0.089	0.082	0.065	-0.009	-0.030	-0.045	0.140	-0.023	0.013	-0.008	0.284	-0.261
			p	0.966	0.695	0.862	0.670	0.785	0.093	0.957	0.562	0.434	0.051	0.537	0.571	0.654	0.948	0.838	0.759	0.331	0.875	0.931	0.954	0.045	0.068
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Knee	Range	Frontal plane angle	r	-0.104	-0.115	-0.082	-0.064	-0.100	0.318	0.115	0.181	0.236	0.009	0.037	-0.121	-0.012	-0.138	0.189	-0.084	-0.089	0.073	0.009	0.170	-0.022	0.209
			p	0.469	0.423	0.566	0.655	0.487	0.023	0.422	0.204	0.095	0.952	0.795	0.400	0.933	0.335	0.183	0.557	0.534	0.610	0.952	0.234	0.876	0.142
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
N/A	Peak	Ground reaction force	r	-0.050	-0.119	-0.037	-0.028	-0.067	0.162	0.109	0.196	0.195	0.277	0.032	0.106	0.073	0.332	0.175	0.282	0.295	0.088	0.022	0.000	0.083	-0.063
			p	0.732	0.412	0.797	0.849	0.645	0.262	0.452	0.173	0.175	0.051	0.823	0.463	0.613	0.018	0.223	0.047	0.037	0.542	0.880	0.998	0.567	0.664
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
N/A	Rate	Ground reaction force*	r	-0.098	-0.098	-0.068	-0.064	-0.072	0.155	0.115	0.225	0.263	0.155	0.076	0.181	0.122	0.287	0.105	0.327	0.286	0.011	-0.089	0.052	0.067	-0.099
			p	0.501	0.500	0.638	0.661	0.617	0.281	0.426	0.117	0.066	0.282	0.600	0.208	0.399	0.043	0.469	0.021	0.044	0.939	0.541	0.718	0.646	0.493
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Knee	Peak valgus	Frontal plane angle	r	0.001	0.007	0.118	0.182	0.142	-0.009	-0.086	-0.083	-0.094	-0.001	0.087	0.210	0.117	-0.035	-0.307	-0.074	-0.002	0.031	-0.077	-0.191	-0.204	0.036
			p	0.994	0.961	0.411	0.202	0.322	0.949	0.548	0.564	0.513	0.997	0.544	0.139	0.412	0.806	0.029	0.606	0.991	0.831	0.589	0.180	0.150	0.804
			n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Knee	Peak abductor	Frontal plane moment	r	0.024	0.102	-0.270	-0.309	-0.232	0.058	0.132	0.209	0.198	-0.146	-0.148	-0.112	-0.086	0.175	-0.012	0.103	0.058	0.118	0.216	0.147	0.246	-0.171
			p	0.869	0.480	0.057	0.029	0.106	0.688	0.362	0.146	0.169	0.312	0.304	0.438	0.552	0.223	0.935	0.476	0.687	0.416	0.132	0.309	0.085	0.236
			n	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50

* Spearmann correlation; Cells highligthed in green are p values ≤ 0.20; Cells highligthed in blue are the clinical outcomes inserted in each model.

APPENDIX F – Correlation matrix between clinical outcomes – Bilateral landings

Correlation matrix between clinical outcomes for prefered leg.

Clinical outcome	Correlation information	Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M*	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add
SEBT A	r	0.426																				
	p	0.002																				
	n	51																				
SEBT M*	r	-0.136	0.422																			
	p	0.340	0.002																			
	n	51	51																			
SEBT L	r	-0.103	0.316	0.817																		
	p	0.471	0.024	0.000																		
	n	51	51	51																		
SEBT T	r	0.012	0.587	0.918	0.922																	
	p	0.935	0.000	0.000	0.000																	
	n	51	51	51	51																	
Ass SEBT A	r	-0.064	0.203	0.071	0.126	0.160																
	p	0.656	0.154	0.622	0.377	0.262																
	n	51	51	51	51	51																
Ass SEBT M	r	-0.300	0.105	0.449	0.257	0.324	0.254															
	p	0.033	0.465	0.001	0.068	0.020	0.072															
	n	51	51	51	51	51	51															
Ass SEBT L	r	-0.145	0.226	0.205	0.413	0.355	0.349	0.558														
	p	0.310	0.110	0.148	0.003	0.010	0.012	0.000														
	n	51	51	51	51	51	51	51														
Ass SEBT T	r	-0.234	0.226	0.320	0.376	0.381	0.567	0.807	0.896													
	p	0.099	0.111	0.022	0.007	0.006	0.000	0.000	0.000													
	n	51	51	51	51	51	51	51	51													
LSD*	r	-0.224	-0.378	-0.354	-0.306	-0.402	-0.135	-0.014	-0.068	-0.099												
	p	0.113	0.006	0.011	0.029	0.003	0.345	0.923	0.634	0.490												
	n	51	51	51	51	51	51	51	51	51												
Single hop	r	-0.003	0.284	0.567	0.568	0.594	0.164	0.353	0.289	0.352	-0.369											
	p	0.983	0.043	0.000	0.000	0.000	0.252	0.011	0.039	0.011	0.008											
	n	51	51	51	51	51	51	51	51	51	51											
Triple hop	r	0.012	0.196	0.488	0.539	0.548	0.222	0.299	0.280	0.341	-0.291	0.815										
	p	0.934	0.167	0.000	0.000	0.000	0.118	0.033	0.046	0.014	0.038	0.000										
	n	51	51	51	51	51	51	51	51	51	51	51										
Cross hop	r	0.027	0.305	0.510	0.576	0.592	0.207	0.428	0.428	0.474	-0.304	0.867	0.903									
	p	0.851	0.030	0.000	0.000	0.000	0.146	0.002	0.002	0.000	0.030	0.000	0.000									
	n	51	51	51	51	51	51	51	51	51	51	51	51									
Ass Single	r	0.201	0.023	-0.128	-0.141	-0.109	0.220	0.204	0.192	0.255	0.022	0.094	0.053	0.062								
	p	0.158	0.872	0.369	0.323	0.445	0.122	0.152	0.177	0.070	0.877	0.512	0.713	0.666								
	n	51	51	51	51	51	51	51	51	51	51	51	51	51								
Ass Triple	r	0.022	0.001	0.143	0.020	0.068	0.266	0.142	0.090	0.188	-0.080	0.022	0.278	0.113	0.479							
	p	0.880	0.992	0.318	0.891	0.637	0.059	0.319	0.531	0.187	0.575	0.879	0.048	0.428	0.000							
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51							

Ass Cross	r	0.077	0.163	0.181	0.104	0.152	0.143	0.300	0.327	0.349	0.017	0.215	0.215	0.333	0.560	0.444							
	p	0.590	0.254	0.205	0.466	0.288	0.317	0.033	0.019	0.012	0.906	0.131	0.129	0.017	0.000	0.001							
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51							
Strength Quad	r	0.050	0.120	0.322	0.206	0.267	-0.059	-0.069	-0.026	-0.057	-0.087	0.136	0.295	0.178	-0.046	0.207	0.207						
	p	0.725	0.403	0.021	0.147	0.058	0.683	0.631	0.857	0.689	0.544	0.343	0.036	0.210	0.750	0.144	0.145						
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51						
Strength Hams	r	0.323	0.270	-0.124	0.041	0.065	0.093	0.006	0.128	0.098	-0.274	0.242	0.251	0.248	0.182	0.186	0.319	0.261					
	p	0.021	0.056	0.387	0.774	0.653	0.514	0.967	0.370	0.493	0.052	0.087	0.076	0.079	0.201	0.192	0.023	0.064					
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51					
Strength H/Q	r	-0.015	0.192	-0.039	-0.237	-0.078	0.234	0.066	-0.114	0.023	0.031	0.137	0.131	0.135	0.025	0.126	0.042	-0.024	0.156				
	p	0.917	0.176	0.788	0.093	0.588	0.098	0.643	0.427	0.874	0.829	0.336	0.360	0.346	0.862	0.378	0.772	0.867	0.274				
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51				
Strength Abd	r	-0.173	0.124	0.049	-0.115	-0.012	0.026	-0.114	-0.139	-0.115	-0.069	-0.062	0.064	0.020	-0.076	0.153	-0.028	0.366	0.080	0.224			
	p	0.225	0.387	0.733	0.420	0.935	0.854	0.427	0.331	0.420	0.631	0.664	0.655	0.889	0.596	0.285	0.845	0.008	0.577	0.114			
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51			
Strength Add	r	0.000	0.165	0.211	0.199	0.242	-0.140	-0.043	-0.121	-0.121	-0.121	0.349	0.293	0.311	0.105	0.023	0.203	0.529	0.370	0.116	0.401		
	p	0.999	0.248	0.137	0.162	0.088	0.328	0.764	0.396	0.399	0.396	0.012	0.037	0.027	0.462	0.871	0.152	0.000	0.008	0.418	0.004		
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51		
Strength Abd/Add*	r	-0.191	-0.067	-0.016	-0.014	-0.019	0.057	-0.066	-0.043	-0.054	-0.115	-0.060	-0.134	-0.186	-0.212	0.018	-0.373	-0.006	0.041	-0.073	0.052	-0.125	
	p	0.179	0.639	0.909	0.920	0.896	0.691	0.645	0.765	0.706	0.421	0.678	0.348	0.192	0.135	0.900	0.007	0.969	0.775	0.610	0.716	0.383	
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	

* Spearmann correlation; Cells highligthed in red are correlation coefficients < 0.7.

Correlation matrix between clinical outcomes for non-prefered leg.

Clinical outcome	Correlation information	Lunge	SEBT A	SEBT M	SEBT L	SEBT T	Ass SEBT A	Ass SEBT M	Ass SEBT L	Ass SEBT T	LSD*	Single hop	Triple hop	Cross hop	Ass Single	Ass Triple	Ass Cross	Strength Quad	Strength Hams	Strength H/Q	Strength Abd	Strength Add
SEBT A	r	0.508																				
	p	0.000																				
	n	51																				
SEBT M	r	0.055	0.372																			
	p	0.700	0.007																			
	n	51	51																			
SEBT L	r	-0.073	0.218	0.838																		
	p	0.613	0.124	0.000																		
	n	51	51	51																		
SEBT T	r	0.136	0.556	0.935	0.908																	
	p	0.343	0.000	0.000	0.000																	
	n	51	51	51	51																	
Ass SEBT A	r	-0.145	-0.357	-0.039	-0.076	-0.161																
	p	0.311	0.010	0.785	0.594	0.260																
	n	51	51	51	51	51																
Ass SEBT M	r	-0.360	-0.038	-0.188	-0.066	-0.119	0.254															
	p	0.009	0.792	0.187	0.645	0.404	0.072															
	n	51	51	51	51	51	51															
Ass SEBT L	r	-0.150	0.026	-0.117	-0.198	-0.140	0.349	0.558														
	p	0.292	0.859	0.414	0.164	0.327	0.012	0.000														
	n	51	51	51	51	51	51	51														
Ass SEBT T	r	-0.281	-0.095	-0.156	-0.162	-0.173	0.567	0.807	0.896													
	p	0.046	0.507	0.274	0.255	0.225	0.000	0.000	0.000													
	n	51	51	51	51	51	51	51	51													
LSD*	r	-0.198	-0.404	-0.267	-0.201	-0.326	0.114	-0.114	0.106	0.016												
	p	0.163	0.003	0.058	0.157	0.020	0.426	0.424	0.461	0.910												
	n	51	51	51	51	51	51	51	51	51												
Single hop	r	-0.107	0.215	0.470	0.533	0.522	0.010	0.199	0.164	0.175	-0.099											
	p	0.455	0.130	0.001	0.000	0.000	0.943	0.162	0.251	0.220	0.491											
	n	51	51	51	51	51	51	51	51	51	51											
Triple hop	r	0.018	0.180	0.371	0.422	0.417	0.056	0.211	0.226	0.225	-0.112	0.835										
	p	0.902	0.205	0.007	0.002	0.002	0.696	0.138	0.111	0.112	0.432	0.000										
	n	51	51	51	51	51	51	51	51	51	51	51										
Cross hop	r	-0.022	0.160	0.354	0.411	0.398	0.155	0.331	0.325	0.362	-0.195	0.838	0.902									
	p	0.880	0.263	0.011	0.003	0.004	0.277	0.018	0.020	0.009	0.170	0.000	0.000									
	n	51	51	51	51	51	51	51	51	51	51	51	51									
Ass Single	r	0.148	-0.094	-0.244	-0.283	-0.2694	0.220	0.204	0.192	0.255	-0.251	-0.494	-0.225	-0.171								
	p	0.299	0.510	0.084	0.044	0.056	0.122	0.152	0.177	0.070	0.076	0.000	0.113	0.229								
	n	51	51	51	51	51	51	51	51	51	51	51	51	51								
Ass Triple	r	-0.119	-0.147	0.065	-0.037	-0.037	0.266	0.142	0.090	0.188	-0.228	-0.274	-0.306*	-0.068	0.479							
	p	0.405	0.303	0.652	0.795	0.796	0.059	0.319	0.531	0.187	0.107	0.052	0.029	0.635	0.000							
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51							
Ass Cross	r	0.060	0.076	-0.051	-0.105	-0.051	0.143	0.300	0.327	0.349	-0.174	-0.158	-0.050	-0.058	0.560	0.444						
	p	0.674	0.594	0.720	0.462	0.720	0.317	0.033	0.019	0.012	0.223	0.267	0.728	0.688	0.000	0.001						
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51						

Strength Quad	r	-0.079	0.201	0.389	0.283	0.358	0.076	0.034	0.008	0.040	-0.072	0.213	0.197	0.188	-0.010	0.257	0.354					
	p	0.581	0.157	0.005	0.045	0.010	0.596	0.810	0.954	0.778	0.617	0.134	0.166	0.187	0.946	0.069	0.011					
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51					
Strength Hams	r	0.215	0.086	-0.214	-0.207	-0.165	0.069	0.034	0.302	0.203	-0.220	0.210	0.291	0.316	0.117	0.083	0.183	0.129				
	p	0.129	0.550	0.132	0.145	0.247	0.632	0.810	0.031	0.152	0.122	0.140	0.038	0.024	0.413	0.563	0.198	0.366				
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51				
Strength H/Q	r	-0.123	-0.032	-0.121	-0.208	-0.164	0.130	0.056	0.025	0.073	-0.141	0.037	0.059	0.119	0.042	0.068	-0.112	-0.149	0.163			
	p	0.389	0.826	0.396	0.143	0.250	0.364	0.695	0.862	0.610	0.323	0.794	0.681	0.405	0.769	0.636	0.435	0.298	0.252			
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51			
Strength Abd	r	-0.049	0.111	0.322	0.294	0.311	0.161	-0.137	-0.066	-0.051	-0.164	0.270	0.31	0.254	-0.288	0.015	0.041	0.494	0.108	0.141		
	p	0.733	0.437	0.021	0.036	0.026	0.260	0.337	0.643	0.723	0.249	0.055	0.027	0.072	0.040	0.919	0.777	0.000	0.452	0.325		
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51		
Strength Add	r	-0.121	0.091	0.089	0.023	0.074	-0.125	-0.023	-0.038	-0.064	-0.125	0.063	0.063	0.037	0.113	0.280	0.249	0.508	0.218	0.125	0.351	
	p	0.396	0.524	0.535	0.874	0.606	0.382	0.874	0.793	0.657	0.382	0.663	0.659	0.794	0.431	0.047	0.078	0.000	0.124	0.384	0.011	
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	
Strength Abd/Add	r	-0.022	-0.100	0.094	0.154	0.086	0.278	-0.051	0.039	0.074	-0.018	0.138	0.134	0.124	-0.366	-0.267	-0.268	-0.180	-0.142	0.017	0.363	-0.711
	p	0.878	0.486	0.512	0.282	0.548	0.048	0.720	0.788	0.604	0.899	0.333	0.347	0.386	0.008	0.059	0.057	0.207	0.320	0.903	0.009	0.000
	n	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51

* Spearmann correlation; Cells highligthed in orange are correlation coefficients < 0.7.

APPENDIX G – Linear regression models – Bilateral landings

Linear regression analyses outcomes for unilateral jump landings with the preferred and non-preferred legs.

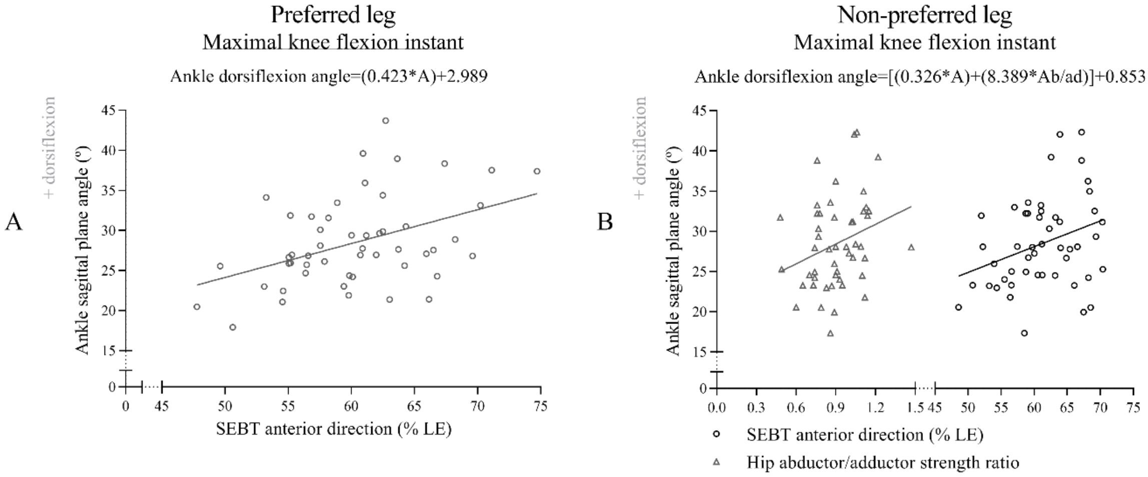
Dependent variable	Independent variable	r	r^2	p	f^2
Preferred					
Ankle					
Dorsiflexion angle at MF	SEBT A	0.432	0.187	0.002	0.230
Knee					
Flexion/extension angle at IC	Triple hop asymmetry	0.383	0.147	0.006	0.172
Flexion angle at MF	Lateral step down	0.347	0.121	0.013	0.138
Extensor moment at IC	Hip abductor/adductor strength ratio and triple hop asymmetry	0.468	0.219	0.004	0.280
Flexor moment at MF	Hip adductor strength	0.332	0.110	0.021	0.124
Varus/valgus angle at IC	SEBT T and triple hop asymmetry	0.506	0.256	0.001	0.344
Adductor/abductor moment at IC	Crossover hop asymmetry	0.320	0.102	0.027	0.114
Adductor moment at MF	Triple hop, lateral step down and lunge	0.674	0.454	<0.001	0.831
Hip					
Flexion angle at IC	Lateral step down	0.282	0.080	0.045	0.087
Flexion angle at MF	Crossover hop	0.353	0.124	0.011	0.142
Abduction angle at IC	SEBT L asymmetry and single hop asymmetry	0.424	0.180	0.009	0.220
Adduction/abduction angle at MF	Crossover hop and knee flexor/extensor strength ratio	0.452	0.204	0.004	0.256
Adductor moment at MF	Triple hop asymmetry and lunge	0.404	0.163	0.018	0.195
Pelvis					
Anterior/posterior tilt at MF	Triple hop	0.344	0.118	0.014	0.134
Obliquity at IC	Triple hop asymmetry	0.472	0.222	0.001	0.285
Trunk					
Forward/backward tilt at MF	Crossover hop	0.428	0.183	0.002	0.224
GRF vertical component					
GRF at MF	Hip adductor strength	0.344	0.118	0.017	0.134
GRF peak	Crossover hop asymmetry	0.315	0.100	0.029	0.111
GRF rate	Crossover hop asymmetry and single hop	0.436	0.190	0.009	0.235

Non-preferred					
Ankle					
Dorsi/plantarflexion angle at MF	SEBT A and hip abductor/adductor strength ratio	0.426	0.182	0.010	0.222
Knee					
Flexion angle at IC	Hip abductor/adductor strength ratio, knee flexor/extensor strength ratio and lateral step down	0.596	0.356	<0.001	0.553
Flexion angle at MF	Lateral step down and hip abductor/adductor strength ratio	0.506	0.256	0.001	0.344
Flexor/extensor moment at MF	Lunge and hip adductor strength	0.542	0.294	<0.001	0.416
Varus/valgus angle at IC	Triple hop asymmetry	0.308	0.095	0.028	0.105
Varus/valgus angle at MF	Hip adductor strength	0.314	0.099	0.025	0.110
Valgus angle range	SEBT A asymmetry	0.318	0.101	0.023	0.112
Adductor/abductor moment at IC	SEBT L and hip adductor strength	0.403	0.163	0.015	0.195
Adductor moment at MF	SEBT T asymmetry and lateral step down	0.529	0.280	0.001	0.389
Abductor peak moment	SEBT L	0.292	0.085	0.042	0.093
Hip					
Flexion angle at MF	Lateral step down and hip abductor/adductor strength ratio	0.423	0.179	0.010	0.218
Abduction angle at IC	SEBT T and triple hop asymmetry	0.576	0.332	<0.001	0.497
Adduction/abduction angle at MF	SEBT T	0.334	0.112	0.016	0.126
Adductor moment at MF	Hip adductor strength and knee flexor strength	0.613	0.375	<0.001	0.600
Internal/external rotation angle at IC	Triple hop asymmetry	0.429	0.184	0.002	0.225
Internal/external rotation angle at MF	Hip adductor strength and triple hop	0.453	0.205	0.005	0.258
Pelvis					
Anterior tilt at MF	Triple hop	0.348	0.121	0.012	0.138
Obliquity at IC	Triple hop asymmetry	0.476	0.227	0.001	0.294
Trunk					
Forward/backward tilt at MF	Crossover hop	0.464	0.215	0.001	0.274
GRF vertical component					
GRF at MF	Hip adductor strength and lateral step down	0.411	0.169	0.013	0.203
GRF peak	Knee extensor strength	0.378	0.143	0.007	0.167
GRF rate	Single hop asymmetry and knee extensor strength	0.431	0.186	0.009	0.228

A: anterior direction of SEBT; GRF: ground reaction force; IC: initial contact instant; L: posterolateral direction of SEBT; MF: maximal knee flexion instant; SEBT: Star Excursion Balance Test; T: total score of SEBT.

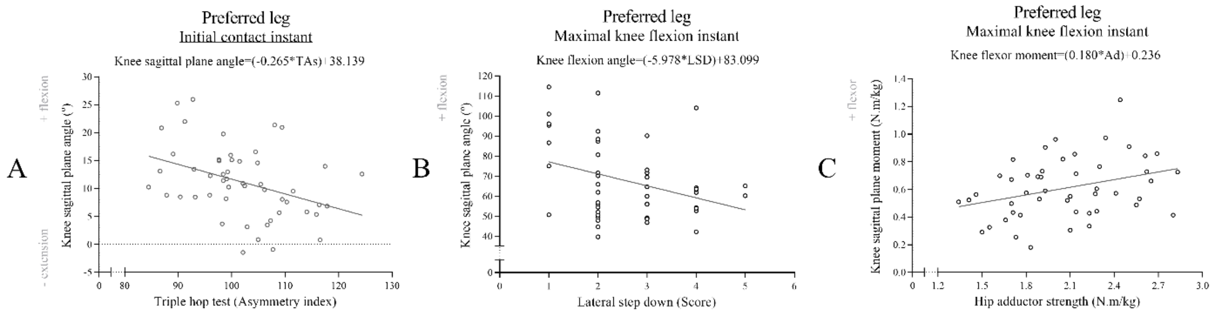
APPENDIX H – Figures from regression models – Bilateral landings

Figure A 9 – Sagittal plane angle of ankle at maximal knee flexion (A-B) in the preferred leg and non-preferred leg being predicted by the clinical tests.



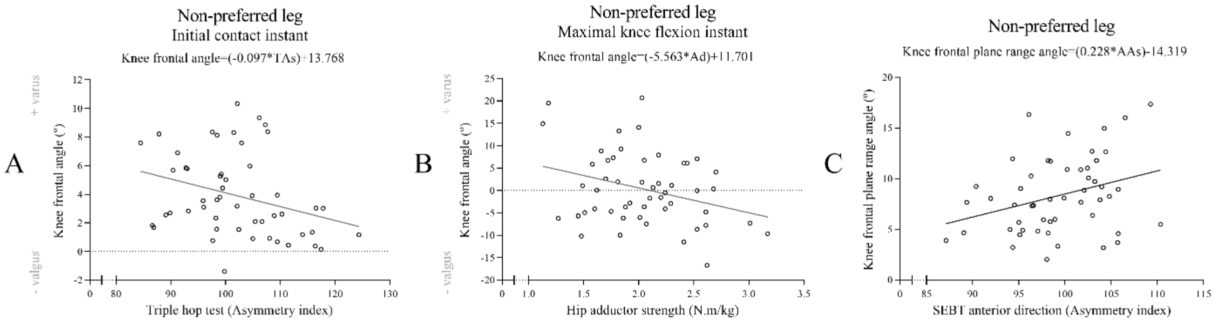
A: anterior direction of SEBT; SEBT: star excursion balance test; Ab/Ad: hip abductor/adductor strength ratio; LE: lower extremity.

Figure A 10 – Knee flexion angle and moment at initial contact (A) and maximal knee flexion (B-C) in the preferred and non-preferred legs being predicted by the clinical tests.



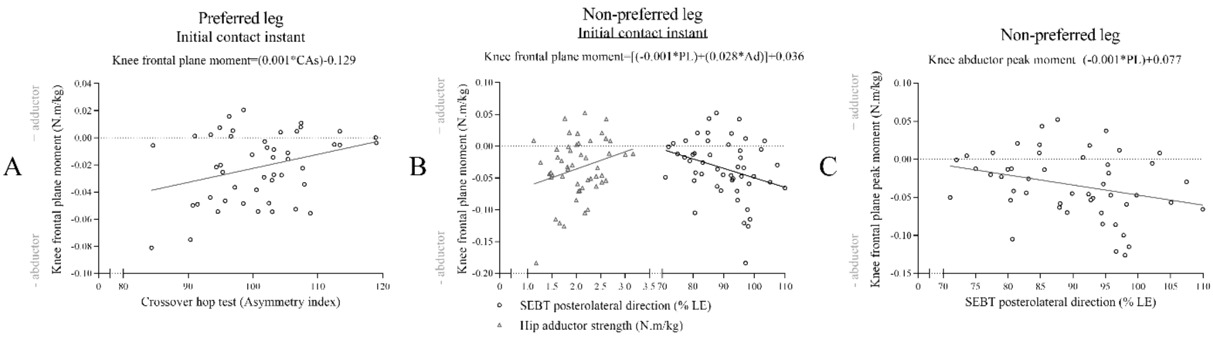
TAs: asymmetry index in the triple hop test; LSD: lateral step down; Ad: hip adductor strength.

Figure A 11 – Knee varus/valgus angle at initial contact (A), maximal knee flexion (B) and range value (C) in the non-preferred leg being predicted by the clinical tests.



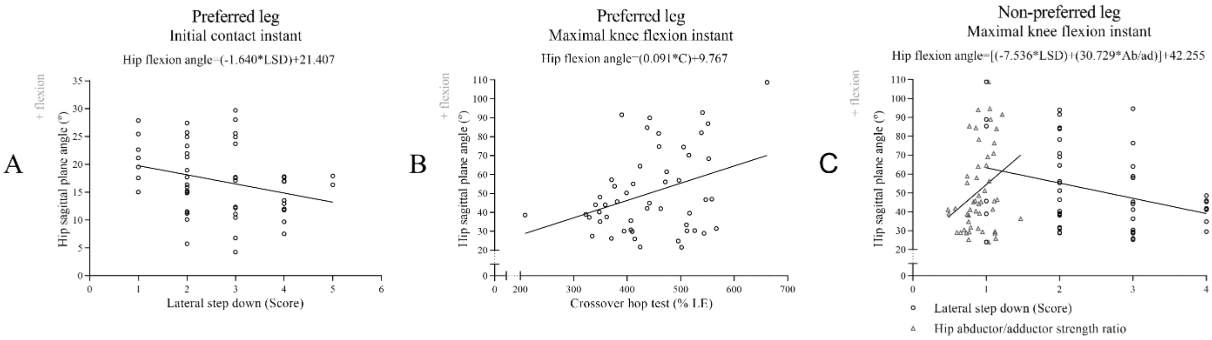
TAs: asymmetry index in the triple hop test; Ad: hip adductor strength; AAS: asymmetry index of SEBT anterior direction; SEBT: star excursion balance test.

Figure A 12 – Knee adductor/abductor moment at initial contact (A-B) and peak value (C) in the preferred and non-preferred legs being predicted by the clinical tests.



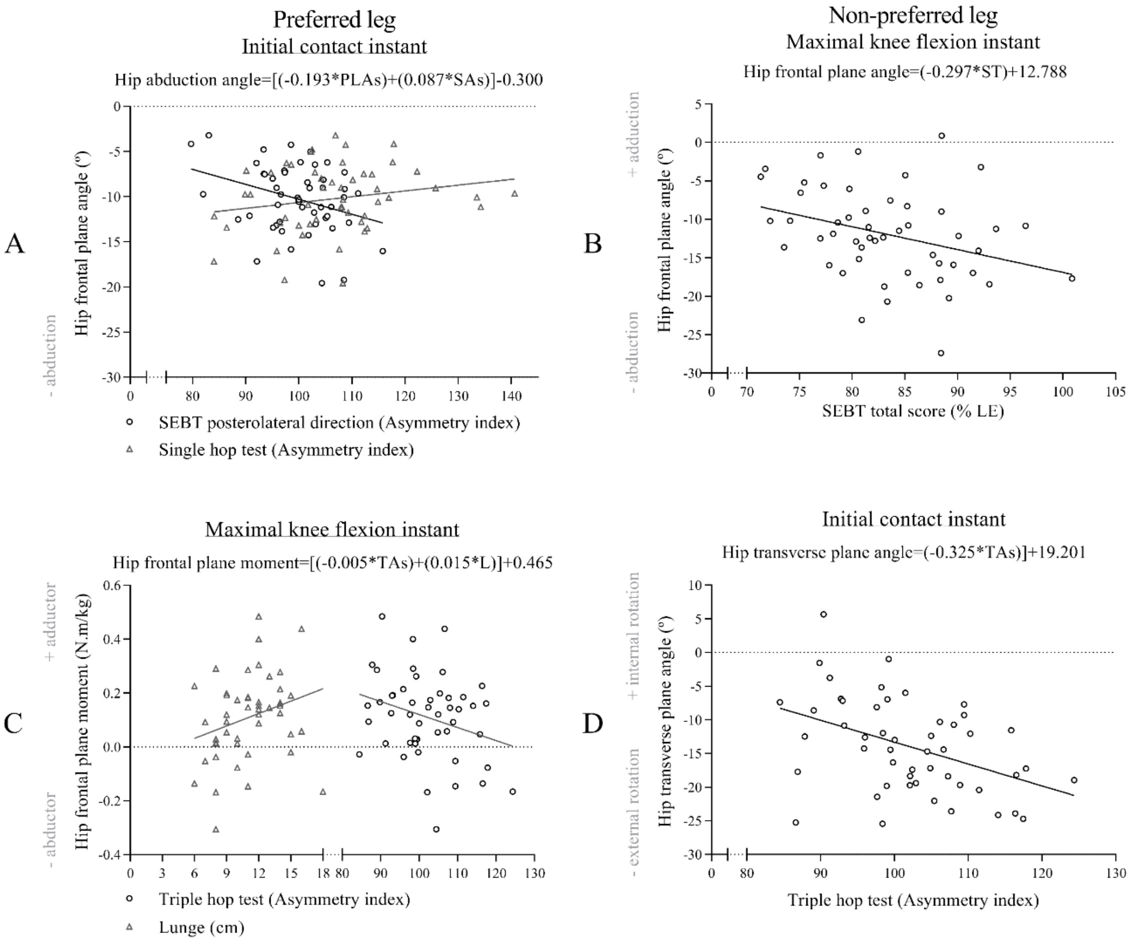
CAs: asymmetry index of crossover hop test; PL: SEBT posterolateral direction; SEBT: star excursion balance test; Ad: hip adductor strength; LE: lower extremity.

Figure A 13 – Hip flexion angle at initial contact (A) and maximal knee flexion (B-C) in the preferred and non-preferred legs being predicted by the clinical tests.



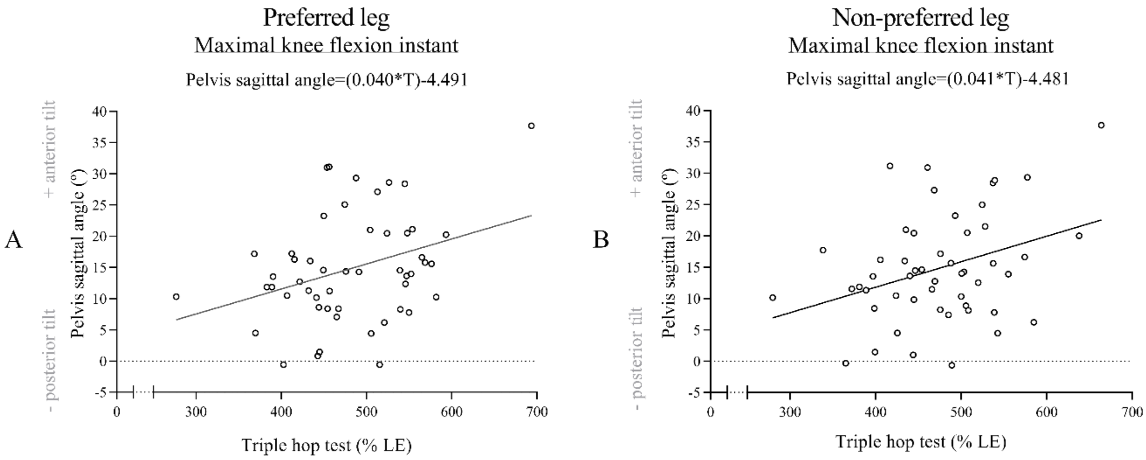
LSD: lateral step down; C: crossover hop test; Ab/ad: hip abductor/adductor strength ratio; LE: lower extremity.

Figure A 14 – Frontal and transverse plane hip angles and moment at initial contact (A, D) and knee maximal flexion (B-C) in the preferred and non-preferred legs being predicted by the clinical tests.



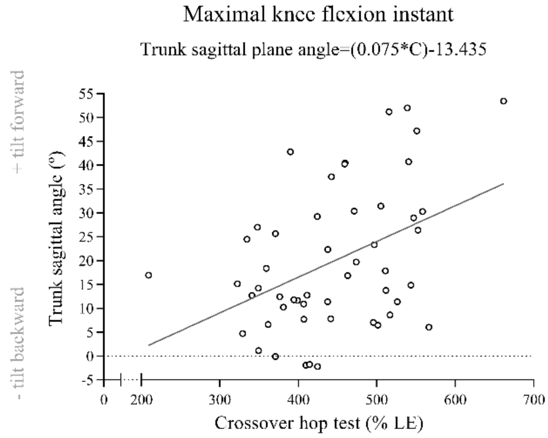
PLAs: asymmetry index of SEBT posterolateral direction; SEBT: star excursion balance test; SAs: asymmetry index of single hop test; ST: SEBT total score; TAs: asymmetry index of triple hop test; L: lunge; LE: lower extremity.

Figure A 15 – Sagittal plane pelvis angles at maximal knee flexion (A-B) in preferred and non-preferred legs being predicted by the clinical tests.



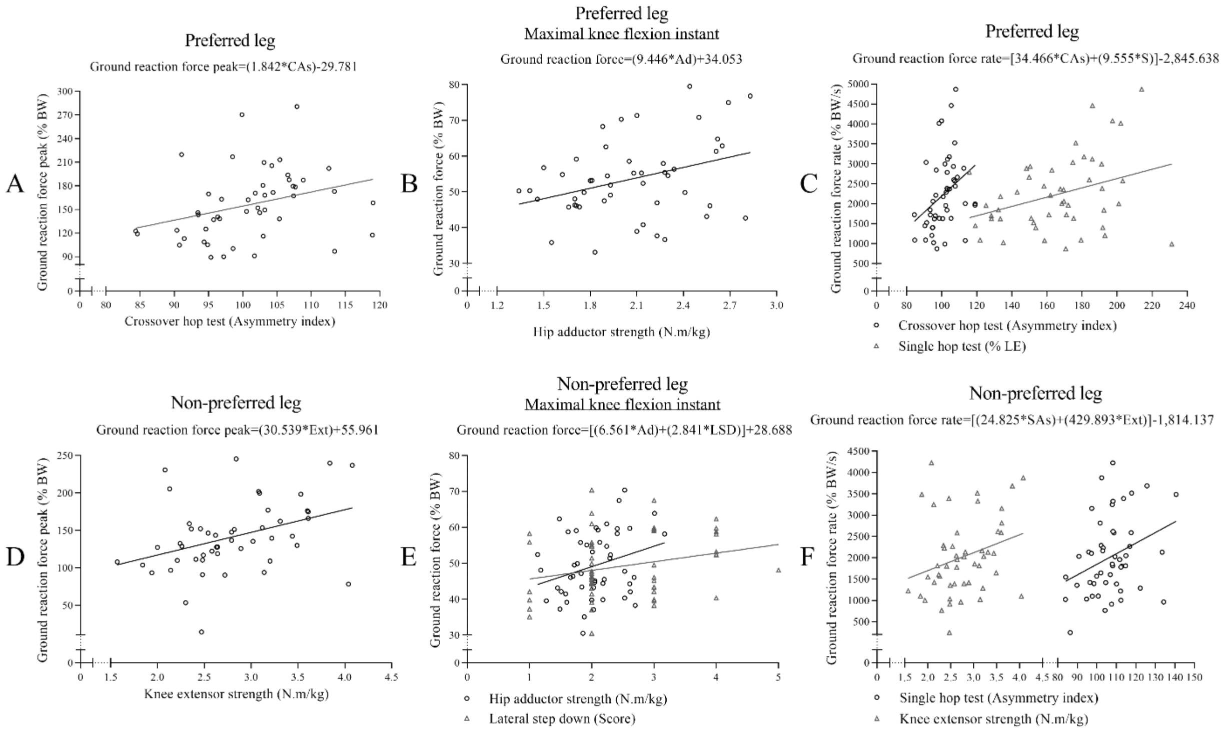
T: triple hop test; LE: lower extremity.

Figure A 16 – Sagittal plane trunk angle at maximal knee flexion in the preferred leg being predicted by the clinical tests.



C: crossover hop test; LE: lower extremity.

Figure A 17 – Ground reaction force peak value (A, D), value at maximal knee flexion (B, E) and rate (C, F) in the preferred and non-preferred legs being predicted by the clinical tests.



CAs: asymmetry index of crossover hop test; Ad: hip adductor strength; S: single hop test; Ext: knee extensor strength; LSD: lateral step down; SAs: asymmetry index of single hop test; LE: lower extremity.

ANNEX 1 - Ethics committee approval

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FUNDAÇÃO UNIVERSIDADE
FEDERAL DO PAMPA -
UNIPAMPA

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Adaptações ao treinamento de força e potência
Pesquisador: Felipe Pivetta Carpes
Área Temática:
Versão: 3
CAAE: 96793518.3.0000.5323
Instituição Proponente: Fundação Universidade Federal do Pampa UNIPAMPA
Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.052.941

Apresentação do Projeto:
De acordo com o pesquisador
A combinação de estímulos que aumentem a força e a velocidade de movimento podem ser efetivos para prevenção de lesões, especialmente na
articulação do joelho, uma das mais acometidas na prática esportiva. Neste estudo realizaremos um ensaio clínico controlado aleatorizado para
determinar o efeito agudo e crônico de um treinamento que combina exercícios de força e potência sobre a neuromecânica dos membros inferiores
em tarefas de saltos, que servem como ferramenta para avaliar riscos de lesão de joelho. Participarão indivíduos do sexo masculino com idade entre
18 e 30 anos que não pratiquem atividade física regular. Eles serão classificados com ou sem risco de lesão e após randomizados em grupo
intervenção e controle. O treinamento consistirá em exercícios de força e potência com duração de 8 semanas, 2 sessões por semana. As
avaliações incluirão anamnese, questionários, medidas antropométricas, avaliação funcional, avaliação de força, avaliação da mecânica muscular,
ativação elétrica neuromuscular e avaliação cinemática e cinética durante a realização de saltos. A avaliação funcional incluirá o Star Excursion
Balance Test, Single Leg Hop for Distance, Triple Leg Hop for Distance e Crossover Hop for

Distance, Lateral Step Down e Lunge Test. A força de
músculos extensores e flexores de joelho será avaliada com dinamômetro isocinético. A mecânica muscular será avaliada por ultrassonografia para
os músculos reto femoral, vasto medial e lateral, bíceps femoral e semitendíneo. Na realização de saltos unilateral e bilateral Drop vertical jump e
forward jump será determinada a ativação neuromuscular com um eletromiógrafo, as forças de reação do solo e cinemática com um sistema de
cinemetria e plataformas de força. As avaliações serão realizadas em duas etapas: na primeira será verificado o efeito de uma sessão de exercício e
na segunda o efeito do treinamento. As variáveis dos testes funcionais serão o escore total de cada perna e índice de assimetria entre as pernas.
Quanto a força muscular, serão analisados a força máxima, a assimetria entre extensores e flexores de joelho e a taxa de produção de força. A
avaliação da mecânica muscular consistirá na análise do ângulo de penação, comprimento de fascículo e a espessura muscular dos músculos
avaliados. Na avaliação dos saltos será determinado o instante do toque inicial e o instante de máxima flexão do joelho na aterrissagem. Nos dois
instantes serão consideradas as variáveis de momentos articulares das articulações do membro inferior e sua contribuição relativa; ângulo do joelho
no plano frontal; ângulo do tronco no plano sagital e frontal. Além dessas variáveis, serão analisados os picos de momentos articulares do joelho no
plano frontal; stiffness articular; magnitude, sequência e assimetrias na ativação dos músculos analisados; sempre no intervalo entre o instante de
contato inicial e o pico da flexão do joelho. Comparações entre os grupos e condições pré e pós treinamento serão conduzidas.Este projeto foi
registrado no Sistema de Informação de Projetos de Pesquisa, Ensino e Extensão (SIPPEE) da Universidade Federal do Pampa sob o número
20180702141429.

Objetivo da Pesquisa:

De acordo com o pesquisador:

Objetivo Primário:

Determinar o efeito agudo e crônico de um treinamento que combina exercícios de força e potência sobre a neuromecânica dos membros inferiores.

Objetivo Secundário:
- Verificar a predição de testes funcionais sobre os fatores de risco biomecânicos para lesão de LCA.- Verificar os efeitos de uma sessão de
exercício de potência sobre a neuromecânica dos membros inferiores.- Verificar os efeitos de 8 semanas de treinamento combinado sobre a
neuromecânica dos membros inferiores.- Verificar a duração dos efeitos de um treinamento de 8 semanas sobre a neuromecânica dos membros
inferiores.

Avaliação dos Riscos e Benefícios:
De acordo com o pesquisador:
Riscos:
Os riscos atrelados a participação serão os mesmos que o envolvimento em sessões de exercício fisico normalmente realizadas em programas de
treinamento: dor muscular tardia e fadiga após as sessões de exercícios de força e potência, em nível similar ao experimentado na prática de
qualquer atividade física requerendo essas valências e durante a realização das avaliações há, ainda que remotamente, a possibilidade de alguma
queda ou entorse. Todos os procedimentos serão conduzidos seguindo os preceitos para prevenção destes riscos por uma equipe que há quase 10
anos realiza esse tipo de avaliação. Os participantes serão orientados a utilizar gelo caso o desconforto pela dor muscular tardia e fadiga for muito
grande e a não realizar outras atividades extenuantes. No caso de algum evento durante a realização das avaliações o serviço de atendimento
médico de urgência será acionado e os pesquisadores acompanharão o participante até que o caso seja resolvido. As demais fases do estudo
envolvem riscos mínimos, uma vez que são questionários e avaliação verbal e antropométrica. Nessas fases, você poderá sentir cansaço por
responder os questionários e perguntas, e ficar constrangido durante a mensuração dos dados antropométricos por estar com trajes de banho.
Esses riscos serão minimizados por um intervalo entre os questionários e por colocação de biombo para proteger a sua privacidade durante as
medidas. Você terá todo o acompanhamento pelos pesquisadores em todas as fases do estudo.
Benefícios:

Os benefícios que os indivíduos terão ao participar deste estudo serão: receber resultados detalhados de sua condição física, incluindo medidas
antropométricas, nível de força, potencia, preferencia lateral e uma estimava preciso de riscos de lesão de membros inferiores na prática esportiva.
Ao se engajar no protocolo de treinamento, terão como benefício a possibilidade de aumentar os níveis de força e potência e melhorar o controle
motor ao realizar movimentos multiarticulares. No caso de serem identificados fatores de risco para lesão, os indivíduos serão orientados quanto a
estratégias para prevenção.

Comentários e Considerações sobre a Pesquisa:

Pesquisa de relevância científica na área das ciências da saúde

Considerações sobre os Termos de apresentação obrigatória:

Cata-resposta: OK

Folha de rosto: OK

Autorização de co-participante: não se aplica

Termo de confidencialidade: OK

TCLE: OK

Projeto: OK

Recomendações:

Não há recomendações

Conclusões ou Pendências e Lista de Inadequações:

Não há pendências

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1171992.pdf	26/11/2018 14:21:50		Aceito
Declaração de Pesquisadores	CartaRespostaPendenciasNovembro.pdf	26/11/2018 14:21:07	Karine Josibel Velasques Stoelben	Aceito
TCLE / Termos de Assentimento /	Tclecorrigido.pdf	26/11/2018 14:20:55	Karine Josibel Velasques Stoelben	Aceito

FUNDAÇÃO UNIVERSIDADE FEDERAL DO PAMPA - UNIPAMPA

Continuação do Parecer: 3.052.941

Justificativa de Ausência	Tclecorrigido.pdf	26/11/2018 14:20:55	Karine Josibel Velasques Stoelben	Aceito
Declaração de Pesquisadores	cartaresposta.pdf	24/09/2018 08:06:45	Felipe Pivetta Carpes	Aceito
Brochura Pesquisa	Questionarios.docx	23/09/2018 22:13:31	Karine Josibel Velasques Stoelben	Aceito
Brochura Pesquisa	Procedimentos_Instrumentos.docx	23/09/2018 22:12:43	Karine Josibel Velasques Stoelben	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_CEP.docx	09/08/2018 11:41:14	Karine Josibel Velasques Stoelben	Aceito
Declaração de Pesquisadores	TC_assinadoKarine.pdf	09/08/2018 11:38:20	Karine Josibel Velasques Stoelben	Aceito
Declaração de Pesquisadores	TC_assinadoAndressa.pdf	09/08/2018 11:38:05	Karine Josibel Velasques Stoelben	Aceito
Folha de Rosto	folhaDeRostoKarineAssinada.pdf	09/08/2018 11:37:41	Karine Josibel Velasques Stoelben	Aceito
Brochura Pesquisa	PROJETO_SIPPEE.pdf	06/08/2018 21:28:45	Felipe Pivetta Carpes	Aceito
Declaração de Pesquisadores	TCF_felipecarpes.pdf	06/08/2018 21:28:19	Felipe Pivetta Carpes	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

URUGUAIANA, 03 de Dezembro de 2018

Assinado por:
Fabiana Ernestina Barcellos da Silva
(Coordenador(a))

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