Hélen Spadari

EFEITOS AGUDOS DE EXERCÍCIOS PARA A MUSCULATURA INTRÍNSECA DO PÉ NA BIOMECÂNICA DA CORRIDA E NA FUNCIONALIDADE DE MEMBROS INFERIORES DE CORREDORES DE LONGA DISTÂNCIA

Dissertação apresentada à Universidade de Caxias do Sul, para obtenção do Título de Mestre em Ciências da Saúde.

Caxias do Sul

2024

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Orientador:
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Coorientador:
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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

COORDENADOR DO PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

Prof. Dr. José Mauro Madi

Hélen Spadari

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Abreviações

1-β	poder estatístico observado
CECLIN	Centro Clínico
CI	contato inicial
COP	centro de pressão
DP	desvio padrão
F	razão estatística ANOVA F
GC	grupo controle
GE	grupo experimental
Km	quilômetros
PL	posterolateral
PM	posteromedial
Sig	valor de p encontrado no teste ANOVA misto
SPSS	Statistical Package for the Social Sciences
TCLE	Termo de consentimento livre e esclarecido
UCS	Universidade de Caxias do Sul
UK	United Kingdom
η^2	tamanho do efeito

Sumário

Esta dissertação de mestrado acadêmico stricto sensu é apresentada no formato exigido pelo programa de pós-graduação em ciências da saúde da Universidade de Caxias do Sul. Ela é constituída da secção de “introdução com referências bibliográficas”, a inclusão do artigo original submetido/publicado em periódico qualis a na classificação da coordenação de aperfeiçoamento de pessoal em nível superior (CAPES), e as “considerações finais e perspectivas”.

1. INTRODUÇÃO

O crescente aumento no número de praticantes da corrida é notório mundialmente. No Brasil, se tornou a segunda modalidade esportiva mais praticada, destacando-se pela democratização; além de ser uma habilidade motora base de várias modalidades esportivas (OLIVEIRA, LOPES & HESPANHOL, 2021). A corrida realizada de forma regular traz inúmeros benefícios à saúde, como aumento da atividade cardiovascular, na densidade mineral óssea, diminuição de marcadores inflamatórios e melhora na qualidade de vida. Porém, com a expansão no número de praticantes houve crescimento proporcional na incidência de lesões (TADDEI et al., 2020).

Por isso destaca-se a importância do complexo articular do pé, pois é uma estrutura que trabalha na sustentação e locomoção do corpo humano e muitas vezes é negligenciada. O pé possui uma complexa rede de ossos, ligamentos e músculos que funcionam em sincronismo para conservar sua forma e permitir movimentos (GOODING et al., 2016). É um sistema complexo com múltiplos graus de liberdade que exerce função essencial na corrida, enquanto a musculatura intrínseca do pé é a principal estabilizadora e esses músculos se contraem excentricamente durante a fase de apoio da corrida antes de se contraírem concentricamente na fase de propulsão, à medida que o arco recua paralelamente à fáscia plantar (TOURILLON, GOJANOVIC & FOURCHET, 2019).

Tendo em vista que o arco longitudinal medial colabora para a absorção de choque e a atenuação de forças transmitidas ao corpo durante a corrida (KELLY et al., 2014), é possível inferir que se um praticante de corrida possui fraqueza nos músculos do pé, pode ter maior risco de lesão na região, assim como em outras articulações como joelho e quadril.

Moon, Kim & Lee (2014) avaliaram indivíduos com pronação excessiva, fazendo exercícios de ativação da musculatura intrínseca do pé, e foi verificada uma melhora imediata do equilíbrio dinâmico. Já Gooding et al. (2016) avaliaram atletas de *cross country* e pista com a ressonância magnética antes e após realizar os exercícios de ativação para o *footcore* de forma aguda, sendo que os exercícios foram randomizados, feitos de forma alternada e em dois dias. Os autores demonstraram que esses exercícios melhorou as atividades musculares voluntárias do quadrado plantar, abdutor, adutor e flexor do hálux (GOODING et al., 2016). Inclusive, tem influência em dor patelofemoral, como visto por Kisacik et al. (2021) quando um protocolo de "exercícios de pé curto" foi utilizado e foram encontrados efeitos positivos em dor no joelho, na posição do navicular, na postura do retropé, também podendo estar associado a estabilização do quadril.

Alterações no pé também podem influenciar a dinâmica, cinética e cinemática de todo membro inferior e tronco. O arco do pé desabado (pé plano) por fraqueza ou inativação da musculatura intrínseca pode gerar lesões como fasciíte plantar, estresse tibial medial, tendinopatia do tendão do tríceps sural, e de tibial posterior (JAMES et al., 2013; McKEON et al., 2015). Invariavelmente, essas lesões levam ao afastamento dos treinamentos, podendo ocasionar ansiedade, estresse, compulsões alimentares, ganho de peso entre outros aspectos emocionais que geram gatilhos. Outra questão bem importante está relacionada à diminuição do desempenho de corredores com alterações no pé.

Assim sendo, a estabilidade na locomoção se refere à capacidade de um indivíduo manter o equilíbrio quando está em movimento e é reconhecida como inerente ao sistema de controle motor de preservar seu estado inicial, mesmo com fatores internos e perturbações ambientais, sendo crucial para compreensão da mecânica da corrida (PROMSRI et al., 2024).

Os estudos em biomecânica foram construídos de forma multidisciplinar ao longo dos anos e atinge diferenciados contextos. McGinnis (2013) relata que a biomecânica é a compreensão das forças e suas implicações nos seres vivos. Essas forças são constituídas pelas internas produzidas pelo sistema muscular, neural e esquelético e as forças externas que interagem com o corpo. De igual maneira, Côrrea (2014) descreve a área como um dos instrumentos de avaliação de padrões, cujo propósito é conseguir a excelência do movimento na relação entre gasto fisiológico e mecânico. Devido a isso, a análise da biomecânica da corrida vem sendo utilizada para diversos fins como identificar o padrão de aterrisagem, frequência de passada, postura do tronco, com o intuito de correlacionar às cargas de impacto, lesões e aspectos que possam incrementar a performance (HUANG et al., 2019).

Além disso, as avaliações funcionais se tornam preponderantes no ambiente clínico, já que a maioria não tem acesso a equipamentos padrão ouro como dinamômetros isocinéticos, plataformas de força e captura de movimento, tornando as avaliações funcionais como alternativa consistente para medição de capacidade funcional (ROSEN, NEEDLE & KO, 2019). Devido ao *Y Balance Test* ser considerado uma das melhores ferramentas para avaliar funcionalidade de membros inferiores, ressaltando seu custo-benefício para a prática e ainda entregar resultados de estabilidade que direciona a conduta profissional, foi determinado o uso do teste para avaliação, assim como utilizado em diversos estudos com este objetivo (ALKHATHAMI, 2023; HUANG et al., 2023; PHUAKLIKHIT et al., 2023). Principalmente na articulação do tornozelo, e não menos importante, é necessário determinar a influência de deficiência na ativação muscular ou processamento sensorial (NOZU et al., 2023).

Portanto, o presente estudo tem considerável relevância em verificar se estímulos agudos para musculatura intrínseca do pé afetam a funcionalidade e a biomecânica da corrida dos membros inferiores; pois a grande maioria das pesquisas relacionadas ao tema utilizam protocolos crônicos, de longo prazo, para o treinamento dessa musculatura.

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3. ARTIGO

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Acute effects of foot core exercises on running biomechanics and lower limb functionality in long-distance runners: A randomized clinical trial

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Acute effects of foot core exercises on running biomechanics and lower limb functionality in long-distance runners: A randomized clinical trial

Abstract

Purpose: This study aimed to investigate the acute effects of foot core exercises on running biomechanics and lower limb functionality in long-distance runners.

Methods: A randomized clinical trial was conducted involving long-distance runners of both sexes (35 ± 7 years). Participants were allocated into two groups: experimental group (EG: n=19) and control group (CG: n=17). All participants underwent an assessment of running biomechanics and a functional test (Y Balance Test). Afterwards, the EG performed a series of eight foot core activation exercises while the CG received no intervention. Following a post-assessment was conducted for both groups. A two-way mixed ANOVA was applied with a 5% significance level.

Results: No significant changes in running biomechanics were observed in the EG between pre and post intervention. However, the CG had an increased dorsiflexion peak and angle at initial contact. The Y Balance Test revealed significant improvements in the EG for the dominant limb following intervention, with increased composite score (p=0.014) and posterolateral reach (p=0.036).

Conclusion: The acute intervention on foot core muscles did not change hips and knees running kinematics but increased dorsiflexion, suggesting potential utility as a targeted intervention to enhance dorsiflexion when desired. Additionally, this activation protocol improved lower limb functionality through Y Balance Test. Therefore, activating intrinsic foot muscles prior to physical exercise is an alternative to assist lower limbs stability in long-distance runners.

Keywords: Biomechanical phenomena, running, athlete, proprioception, postural balance.

Introduction

The practice of running has evolved since ancient times, assuming diverse forms and contexts. It is widely recognized as a multifaceted sport, with physical and psychological well-being often serving as primary motivational factors. Furthermore, running can be practiced across various environments, offering accessibility and versatility (Hussein et al., 2023). A longitudinal survey conducted by Oliveira et al. (2021), involving over 15,000 Brazilian runners between 2006 and 2017, identified a clear increase in the number of street runners is over the years.

On the other hand, with this rise in popularity, health professionals are increasingly concerned about the rising number of incidents related to musculoskeletal injuries, which is causing absences or reducing the runners' performance (Ceyssens et al., 2019). Although rehabilitative programs targeting lower limbs injuries often incorporate foot muscle training, the role of the foot as a primary support structure in running is often underestimated during training sessions (Matias et al., 2022).

The foot is a complex biomechanical system with multiple degrees of movement, performing a crucial role in running dynamics. Intrinsic foot muscles act as primary stabilizers, involving eccentric contraction during the stance phase and a concentric contraction during the propulsion phase. This sequence is coordinated with the recoil of the plantar arch, which moves synergistically with the plantar fascia to facilitate efficient force transmission (Tourillon, Gojanovic and Fourchet, 2019).

Consequently, studies increasingly aim to enhance functionality and postural control by targeting intrinsic foot muscle activation in long-distance runners, with potential implications in injuries stabilization and management (Taddei et al., 2020). Commonly used foot core rehabilitative exercises are associated with increased activation in several plantar intrinsic foot muscles (Gooding et al., 2016) and immediate improvements in dynamic balance and reduced excessive foot arch pronation (Moon et al., 2014) suggesting relevant acute clinical benefits in prescribing these exercises.

Analyzing running kinematics provide useful information for understanding this complex joint system (Garofolini et al., 2024) allowing targeted treatment strategies, optimization of performance, and efficient management of pain and injury (Ceyssens et al., 2019). The Y Balance Test (YBT) is widely applied to assess ankle control and stability during dynamic tasks and has been used the YBT evaluate the acute effects of specific interventions (Wang et al., 2023). So, the present study aimed to evaluate the acute effects of foot core exercises on lower limb kinematics and functionality in long-distance runners.

Methods

This study was conducted as a randomized clinical trial, data was collected between January and April 2023. Participants were recruited from running coaching and training companies in Caxias do Sul, Rio Grande do Sul, Brazil, and surrounding areas. Sample size estimation was performed using G*Power software (Faul et al., 2007; Faul et al., 2009) version 3.1.9.2 (Universität Kiel, Germany), employing a F-test family, an effect size of 0.25, alpha error probability of 0.05, and statistical power of 0.8, selecting a mixed analysis of variance (ANOVA). The total sample size obtained was based on 34 individuals; considering possible sample losses, an additional 20% were included, resulting in a sample size of 40 individuals.

Initially, 40 long-distance runners of both sexes, aged 35 ± 7 years, participated in the study. Due to data acquisition errors that led to the missing data from four participants, a final sample of 36 volunteers was analyzed; with 19 participants in the experimental group (EG) and 17 in the control group (CG), assigned randomly.

The research was conducted at the Human Movement Biomechanics Analysis Laboratory at the Clinical Center of the University of Caxias do Sul (CECLIN-UCS) in adherence with the Declaration of Helsinki and Brazilian Resolution 466/2012, which governs ethical standards for human research. Approval was granted by the Ethics Committee of University of Caxias do Sul (approval number: 5.764.234; CAAE number 63190122.0.0000.534).

On the scheduled evaluation day, runners first provided signed informed consent (ICF) forms and completed a questionnaire regarding, general health status, sports history, previous injuries, and past injury treatments. Subsequently, lower limbs length, body mass, height, knee width, and ankle width, measurements were collected for biomechanical analysis (lower limb length was measured, from the anterior superior iliac spine to the distal portion of the lateral malleolus - Plisky et al., 2006). followed by the YBT.

Inclusion criteria were long-distance runners of both sexes, aged 18 to 45 years, who met the following conditions: a) engaged in street running at least three times a week, accumulating between 20 km to 100 km per week; b) practice the modality for at least one year; c) voluntarily agreed to participate by providing a signed ICF. Exclusion criteria included individuals who: a) had any cardiorespiratory, neuromuscular, or metabolic disease preventing participation; b) presented the following absolute contraindications: soft tissue healing; severe pain; severe joint effusion; acute injuries.

All participants went through a running biomechanics assessment using a motion capture system with seven integrated cameras (VICON MX systems, Oxford Metrics Group, UK) and completed a functional performance test (Y Balance Test). Randomization was conducted using a simple draw system, with participants selecting a number from two closed containers to determine group allocation. Those in the EG performed a series of eight foot core activation exercises, totaling approximately ten minutes, and were then re-assessed following the initial data collection protocol. The CG remained inactive during the intervention period and was subsequently re-evaluated.

For the YBT, three measuring tapes were placed on the ground, each separated by a 135° angle. The first tape was aligned in the anterior direction, and, using a goniometer, a 135° angle was measured to position the remaining tapes in the posterolateral (PL) and posteromedial (PM) directions, creating a 90° angle between the PL and PM tapes (Plisky et al., 2009) Plisky et al. (2006) was the protocol used for this testing. Each participant stood on one leg centrally over the three measuring tapes with hands on the waist. They were instructed to reach as far as possible in each direction, starting with the anterior reach, followed by the PM and PL directions, testing first the left limb and then the right limb. Participants performed three practice trials and three test trials in each direction per leg. The maximum distance reached in each direction was recorded analysis. Trials were considered invalid if the participant: touched the foot outside the target lines, transferred weight to the reaching foot, lose balance, or touch the suspended foot on the ground, requiring a retest. Dynamic balance was assessed by normalizing reach distance using the formula: Normalized Distance = (Distance Reached / Limb Length) × 100 (%). A composite score was calculated to evaluate overall test performance, using the formula: Composite Score = (Sum of Three Directions / 3 × Limb Length) × 100 (%). Asymmetry index was quantified using an asymmetry index, calculated from the average of the three measurements per direction and the composite score. The formula for asymmetry was: Asymmetry Index = (Average Distance of the Dominant Limb - Average Distance of Non-Dominant Limb) / (Average Distance of Dominant Limb + Average Distance of Non-Dominant Limb) × 100 (%) (Plisky et al., 2009; Schwiertz et al., 2019; Wiprich et al., 2022; Wiprich et al., 2024).

For the running biomechanics analysis, eighteen reflective markers were placed on subject's body following the Vicon Plug-in Gait model setup (Riley et al., 2007; Stief et al., 2013; Kainz et al., 2017). The warm-up was performed on an Imbramed Super ATL treadmill (Porto Alegre, BR), running at a comfortable speed for six minutes. After, the three-dimensional trajectory of the markers was captured using a motion capture system with seven integrated cameras (VICON MX systems, Oxford Metrics Group, UK). Ankle, knee, hip, pelvis initial kinematic data contact angles, and their peaks were collected at a sampling rate of 100Hz.

The intervention consisted of eight intrinsic foot muscle activation exercises as follows: a) standing, rise onto the forefoot and lower back down, performing 30 repetitions in a bilateral stance; b) seated with knees and ankles flexed at 90°, perform foot inversion and eversion for 10 repetitions, holding each position for one second; c) seated with knees and ankles flexed at 90°, adduct and abduct the toes, holding each position for two seconds across 10 repetitions; d) seated, lift the plantar arch while maintaining heel and toe contact with the ground, performing 10 repetitions per limb and holding each contraction for five seconds; e) seated, with the heel fixed and in contact with the ground, alternately lift the hallux and other toes for ten repetitions, maintaining toe pressure on the ground for one second; f) seated, pick up five marbles with the toes and place them in a container using both feet; g) seated, pull a towel with the toes until reaching the end; h) walk on the heels for 30 meters (Glasoe, 2016; Fourchet and Gojanovic, 2016; Gooding, 2016; Tourillon, Gojanovic and Fourchet, 2019).

Initially, blinded evaluators unaware of group allocation organized the data in a spreadsheet using Microsoft Excel®. Kinematic outcome variables were collected in the NEXUS 1.8 software (Motion Capture Systems from Vicon OMG, Oxford, UK) as recommended by the plug-in gait model (McClelland et al., 2010; Dixon, Böhm and Döderlein, 2012; Nüesch et al., 2017). Pelvis, hip, knee, and ankle angles were collected at initial contact (the first frame where the foot contacts the treadmill) in the sagittal plane. Additionally, peak angles in the sagittal plane of the pelvis (maximum anterior and posterior tilt angles), hip (maximum flexion and extension angles), knee (maximum flexion and extension angles), and ankle (maximum plantarflexion and dorsiflexion angles) were extracted from POLYGON 4 software (Motion Capture Systems from Vicon OMG, Oxford, UK).

A two-way mixed analysis of variance (ANOVA) was conducted to identify effects between groups (EG vs. CG) and within groups (pre- and post-intervention). The significance level of 5% was established. Results are presented in tables, detailing mean and standard deviation, 95% confidence interval, F statistic, effect size, and statistical power (1-β). Effect size was assessed with eta squared (η^2), classified as negligible (N) when less than 0.20, small (S) when between 0.200 and 0.129, medium (M) when between 0.130 and 0.259, and large (L) when greater than 0.260 (Bakeman, 2005; Cohen, 1988). All analyses were conducted accordingly to Field (2013) using IBM Statistical Package for the Social Sciences, version 23.0 (SPSS Inc., Chicago, IL, USA).

Results

Thirty-six out of the initial 40 runners remained in the study after excluding four participants for inconsistencies in the biomechanical data analysis. The demographic and training characteristics of the remaining participants are detailed in Table 1. The sample exhibited a homogeneous composition regarding both physical attributes and training parameters.

Table 1. Sample characterization.

	Experimental Group	**Control Group**	
Characteristics	**M ± SD (95% CI)**	**M ± SD (95% CI)**	**Sig EG vs. CG (T)**
Age (years)	36.58 ± 6.02 (33.68 - 39.48)	36.71 ± 6.73 (33.25 - 40.16)	0.953 (0.06)
Height (m)	1.70 ± 0.11 (1.65 - 1.76)	1.68 ± 0.10 (1.63 - 1.73)	0.540 (0.619)
Weight (kg)	67.09 ± 11.71 (61.45 - 72.73)	64.98 ± 10.17 (59.75 - 70.21)	0.570 (0.573)
BMI (kg/cm²)	22.96 ± 2.20 (21.90 - 24.02)	22.84 ± 1.72 (21.96 - 23.73)	0.859 (0.179)
Sports practice duration (years)	6.68 ± 5.02 (4.26 - 9.11)	7.71 ± 6.03 (4.61 - 10.81)	0.583 (0.554)
Training semanal frequency (sessions)	4.95 ± 1.47 (4.24 - 5.66)	5.29 ± 1.57 (4.49 - 6.10)	0.499 (0.684)
Training time per session (hours)	1.26 ± 0.54 (1.00 - 1.52)	1.32 ± 0.79 (0.92 - 1.73)	0.788 (0.271)

Results are presented as mean ± standard deviation (M ± SD). EG: experimental group. CG: control group. T: T-test. m: meters. kg: kilograms. cm²: square centimeters.

No significant differences in running biomechanics ($p < 0.05$) were found between the pre-intervention and post-intervention phases in the EG, as shown in. In contrast, CG exhibited a higher ankle angle at initial contact, higher ankle dorsiflexion peak angle and a lower pelvic retroversion peak angle (Table 2). Furthermore, in the functional assessment utilizing the Y Balance Test a higher composite score and a higher posterolateral reach for the EG dominant limb were found (Table 3).

Table 2. Descriptive and inferential results of running kinematics.

	Experimental Group			Control Group			EG vs. CG
Variable (degrees)	**Pre M ± SD (95% CI)**	**Post M ± SD (95% CI)**	**Sig ES (F; η²; 1-ß)**	**Pre M ± SD (95% CI)**	**Post M ± SD (95% CI)**	**Sig ES (F; η²; 1-ß)**	**Sig ES (T; d; 1-ß)**
Ankle initial contact	0.90 ± 6.17 (2.08 - 3.87)	1.90 ± 7.62 (1.77 - 5.58)	0.420 S (0.681; 0.036; 0.122)	2.61 ± 5.84 (.39 - 5.61)	3.75 ± 6.20 (0.56 - 6.94)	**0.012* L (8.057; 0.335; 0.760)**	0.401 S (0.724; 0.021; 0.131)
Peak dorsiflexion	22.04 ± 7.56 (18.39 - 25.68)	23.91 ± 6.23 (20.90 - 26.91)	0.200 S (1.774; 0.090; 0.243)	23.84 ± 3.02 (22.28 - 25.39)	24.83 ± 3.44 (23.06 - 26.60)	**0.040* M (5.011; 0.239; 0.557)**	0.365 S (0.842; 0.024; 0.145)
Peak plantarflexion	-20.74 ± 7.91 (24.55 - 16.93)	-21.28 ± 7.98 (25.12 - 17.44)	0.780 N (0.080; 0.004; 0.058)	-20.43 ± 7.17 (24.11 - 16.74)	-19.91 ± 7.47 (23.75 - 16.07)	0.391 S (0.778; 0.046; 0.132)	0.903 N (0.015; 0.000; 0.052)
Knee initial contact	37.81 ± 19.00 (28.66 - 46.97)	40.42 ± 17.85 (31.82 - 49.03)	0.239 S (1.483; 0.076; 0.211)	43.23 ± 9.67 (38.26 - 48.21)	42.90 ± 9.55 (37.99 - 47.81)	0.624 N (0.250; 0.015; 0.076)	0.297 S (1.121; 0.032; 0.177)
Peak flexion	104.58 ± 21.01 (94.45 - 114.70)	109.15 ± 14.99 (101.92 - 116.38)	0.284 S (1.220; 0.063; 0.182)	109.08 ± 15.23 (101.24 - 116.91)	108.02 ± 15.42 (100.09 - 115.95)	0.291 S (1.190; 0.069; 0.177)	0.472 N (0.530; 0.015; 0.109)
Peak extension	7.78 ± 6.30 (4.74 - 10.81)	9.02 ± 5.23 (6.50 - 11.54)	0.103 M (2.943; 0.141; 0.369)	7.04 ± 4.81 (4.57 - 9.52)	7.53 ± 5.24 (4.84 - 10.23)	0.151 S (2.273; 0.124; 0.294)	0.699 N (0.152; 0.004; 0.067)
Hip initial contact	26.94 ± 13.61 (20.38 - 33.49)	27.32 ± 12.88 (21.11 - 33.53)	0.645 N (0.219; 0.012; 0.073)	26.84 ± 9.04 (22.19 - 31.48)	26.13 ± 10.49 (20.74 - 31.53)	0.302 S (1.140; 0.066; 0.171)	0.980 N (0.001; 0.000; 0.050)
Peak flexion	52.22 ± 7.70 (48.51 - 55.93)	54.68 ± 11.14 (49.31 - 60.05)	0.315 S (1.070; 0.056; 0.165)	53.78 ± 5.36 (51.03 - 56.53)	52.21 ± 7.05 (48.58 - 55.84)	0.060 M (4.097; 0.204; 0.477)	0.491 N (0.486; 0.014; 0.104)
Peak extension	-11.21 ± 5.50 (13.86 - 8.55)	-11.56 ± 5.54 (14.23 - 8.89)	0.585 N (0.310; 0.017; 0.082)	-9.49 ± 7.11 (13.15 - 5.83)	-9.78 ± 7.55 (13.66 - 5.91)	0.417 S (0.695; 0.042; 0.123)	0.421 N (0.664; 0.019; 0.124)
Pelvis initial contact	18.30 ± 5.87 (15.47 - 21.13)	19.53 ± 10.29 (14.58 - 24.49)	0.502 S (0.470; 0.025; 0.100)	19.95 ± 4.72 (17.53 - 22.38)	19.47 ± 5.16 (16.82 - 22.13)	0.114 M (2.791; 0.149; 0.349)	0.363 S (0.850; 0.024; 0.146)
Peak anteversion	22.14 ± 4.83 (19.81 - 24.47)	26.66 ± 23.20 (15.48 - 37.84)	0.372 S (0.838; 0.044; 0.140)	23.93 ± 4.96 (21.38 - 26.48)	23.55 ± 5.41 (20.77 - 26.33)	0.199 S (1.796; 0.101; 0.243)	0.280 S (1.203; 0.034; 0.187)
Peak retroversion	13.78 ± 5.75 (11.00 - 16.55)	12.66 ± 5.61 (9.96 - 15.36)	0.087 M (3.281; 0.154; 0.403)	16.09 ± 4.99 (13.53 - 18.66)	15.47 ± 5.40 (12.69 - 18.24)	**0.035* M (5.292; 0.249; 0.580)**	0.208 S (1.648; 0.046; 0.239)

Results are presented as mean ± standard deviation (M ± SD). EG: Experimental Group. CG: Control Group. 95% CI: 95% Confidence Interval. Sig: P-value found in the test. ES: Effect size classification where N: negligible η^2, S: small η^2 (0.020 – 0.129), M: medium η^2 (0.130 – 0.259), L: large η^2 (above 0.26). F: F-ratio of two-factor ANOVA. η^2: eta squared effect size. 1-β: observed statistical power. Significant comparisons are highlighted with * and in bold. Results of post-hoc analysis with Bonferroni correction are presented under significant comparisons.

Table 3: Y Balance Test variable results for the experimental and control groups.

	Experimental Group			Control Group			EG vs. CG
Variable	**Pre M ± SD (95% CI)**	**Post M ± SD (95% CI)**	**Sig ES (F; η²; 1-ß)**	**Pre M ± SD (95% CI)**	**Post M ± SD (95% CI)**	**Sig ES (F; η²; 1-ß)**	**Sig ES (T; d; 1-ß)**
Dominant composite score (%)	0.92 ± 0.08 (0.89 - 0.96)	0.95 ± 0.08 (0.91 - 0.99)	**0.014* L (7.336; 0.279; 0.729)**	0.92 ± 0.07 (0.89 - 0.95)	0.91 ± 0.07 (0.88 - 0.94)	0.281 S (1.230; 0.061; 0.184)	0.864 S (0.172; .086; 0.044)
Composite asymmetry (%)	99.72 ± 4.51 (97.61-101.83)	99.86 ± 3.77 (98.10 - 101.62)	0.886 N (0.021; 0.001; 0.052)	98.54 ± 3.53 (96.89 - 100.19)	98.98 ± 3.48 (97.35 - 100.61)	0.700 N (0.153; 0.008; 0.066)	0.363 N (0.921; .412; 0.237)
Dominant anterior score (cm)	0.61 ± 0.05 (0.59 - 0.64)	0.63 ± 0.07 (0.60 - 0.66)	0.060 M (4.016; 0.174; 0.477)	0.62 ± 0.07 (0.59 - 0.65)	0.62 ± 0.07 (0.58 - 0.65)	0.918 N (0.011; 0.001; 0.051)	0.814 S (0.237; 0.106; 0.050)
Anterior asymmetry (%)	99.30 ± 7.59 (95.75 - 102.85)	98.38 ± 5.43 (95.84 - 100.92)	0.613 N (0.265; 0.014; 0.078)	100.43 ± 5.16 (98.02 - 102.85)	100.05 ± 5.67 (97.39 - 102.70)	0.777 N (0.083; 0.004; 0.059)	0.585 N (0.551; 0.247; 0.110)
Dominant posteromedial score (cm)	0.93 ± 0.11 (0.88 - 0.98)	0.96 ± 0.11 (0.91 - 1.01)	0.134 S (2.456; 0.114; 0.319)	0.92 ± 0.11 (0.87 - 0.98)	0.92 ± 0.12 (0.86 - 0.97)	0.426 S (0.662; 0.034; 0.121)	0.832 S (0.214; .096; 0.047)
Posteromedial asymmetry (%)	99.23 ± 6.41 (96.23 - 102.24)	99.99 ± 3.52 (98.34 - 101.64)	0.656 N (0.205; 0.011; 0.071)	99.16 ± 4.01 (97.29 - 101.04)	98.96 ± 6.34 (95.99 - 101.93)	0.892 N (0.019; 0.001; 0.052)	0.967 N (0.042; .019; 0.028)
Dominant posterolateral score (cm)	0.87 ± 0.09 (0.83 - 0.91)	0.90 ± 0.12 (0.85 - 0.95)	**0.036* M (5.089; 0.211; 0.572)**	0.87 ± 0.11 (0.82 - 0.92)	0.86 ± 0.10 (0.81 - 0.91)	0.310 S (1.088; 0.054; 0.168)	0.950 S (0.063; 0.028; 0.030)
Posterolateral asymmetry (%)	100.35 ± 5.57 (97.75 - 102.96)	100.52 ± 5.08 (98.14 - 102.89)	0.912 N (0.012; 0.001; 0.051)	97.26 ± 5.89 (94.51 - 100.02)	99.13 ± 5.59 (96.52 - 101.74)	0.302 S (1.126; 0.056; 0.172)	0.096 N (1.705; .763; 0.650)

Results are presented as mean ± standard deviation (M ± SD). EG: Experimental Group. CG: Control Group. 95% CI: 95% Confidence Interval. Sig: P-value found in the test. ES: Effect size classification where N: negligible η², S: small η² (0.020 – 0.129), M: medium η² (0.130 – 0.259), L: large η² (above 0.26). F: F-ratio of two-factor ANOVA. η²: eta squared effect size. 1-β: observed statistical power. Significant comparisons are highlighted with * and in bold. Results of post-hoc analysis with Bonferroni correction are presented under significant comparisons.

Discussion

The foot is characterized by a highly intricate anatomical framework comprising bones, ligaments, and musculature, which operate synergistically to preserve structural integrity and facilitate dynamic motion (Gooding et al., 2016). This study evaluated the immediate effects of an acute protocol of exercises to activate intrinsic foot muscles (foot core) on running kinematics and lower limb functional performance. Our findings indicate that the EG did not exhibit significant alterations in any lower limb kinematic parameters during running after the acute intervention protocol. However, the YBT analysis revealed an enhancement in the composite score and the posterolateral reach. Thus, these results suggest that the acute protocol altered some functional parameters but did not elicit measurable changes in the running kinematics of the EG.

Dynamic balance is a critical skill for optimal performance in many sports, related to the ability to run and change direction, affecting daily activities and overall athletic performance (Huang et al., 2023). The YBT has been recognized as a valid and reliable tool for identifying stability deficits (Phuaklikhit et al., 2023). It provides an individual's muscle coordination, stability, and symmetry performance across three movement directions: anterior, posterolateral, and posteromedial (Huang et al., 2023). Despite the limited number of studies examining the acute effects of exercise interventions targeting the intrinsic foot muscles. Investigations by James et al. (2013) and Kelly et al. (2014) presented results of electrical stimulation on these muscles, supporting the findings of the present research by demonstrating immediate adaptations after performing these interventions. James et al. (2013) evaluated the immediate effects of electrical stimulation on intrinsic foot muscles and observed immediate adaptation in forefoot-rearfoot behavior during gait. These adaptations suggests that acute intervention can promote postural control adaptations during functional tasks as gait and our YBT results. Additionally, Kelly et al. (2014) demonstrated that acute electrical stimulation increased stiffness of the foot's longitudinal arch, a biomechanical adjustment that may influence the transmission of forces during locomotor and postural tasks.

These results suggest that activating the intrinsic foot muscles influences the stiffness of the foot-ankle complex and corroborates the fact that only the EG maintained consistent running kinematics. Furthermore, Moon et al. (2014) investigated the acute effects of a protocol of passive, active-assisted, and active foot exercises on individuals exhibiting excessive pronation. Their results demonstrated immediate changes in dynamic balance, leading to an improved ankle and foot stability.

The vast majority of studies evaluated the chronic effects of intrinsic foot muscle stimulation. Suda et al. (2022) proposed an eight-week intervention protocol to evaluate the influence of foot core exercises on predictive injury risk factors. They found that the intervention had a protective effect against running-related injuries over a one-year period. Despite age and weekly training volume negatively impacting these risk factors. Studies by Taddei et al. (2020) and Matias et al. (2022) evaluated an eight-week foot core exercises protocol. Their results revealed cumulative impact forces, enhanced load absorption capacity, improved movement control, and better foot-ankle alignment compared to a control group. It is noteworthy that even with a single intervention session, the present results observed some improvements in the YBT results. These highlights the potential of training regimens aimed at optimizing foot and ankle stability, which neglected by coaches.

Hashimoto and Sakuraba (2014) investigated the effects of an eight-week intervention targeting the intrinsic flexor muscles of the foot, assessing changes in muscle strength, plantar arch structure, and functional dynamics. Their findings demonstrated an increase in muscle strength and a notable enhancement in the longitudinal plantar arch, suggesting that targeted training of this region positively influences functional foot performance in athletes. Furthermore, in a recent systematic review, systematic review, de Souza et al. (2023) evaluated the effects of intrinsic foot muscle strengthening on longitudinal arch mobility and function, reporting that eight weeks of training significantly altered arch mobility, while as few as four weeks improved dynamic balance in healthy individuals. These findings highlight the need for a systematic review focusing on the acute effects of foot core interventions.

Additional studies by Lai et al. (2023), Fourchet and Gojanovic (2016), and Tourillon, Gojanovic and Fourchet (2019) observed the complementary role of intrinsic foot muscles in stabilizing posture. For optimal force transfer during propulsion and force absorption, the foot's core system must act as a rigid lever to effectively transfer forces from the lower limbs through the ankle. This outcome supports the present findings, where the acute intervention in the EG, enhanced ankle stability and control, as evidenced by improvements in the YBT, while preserving running kinematic patterns. In contrast, the CG showed an increased ankle dorsiflexion in the second evaluation. suggesting a potential time-dependent effect on ankle kinematics, as previously reported in other studies (Willer et al., 2021; Urbaczka et al., 2022), when as no interventions were applied.

Two prevalent running-related injuries - medial tibial stress syndrome and Achilles tendinopathy - are often associated with insufficient stiffness of the medial foot arch and inadequate dynamic control (Tourillon, Gojanovic and Fourchet, 2019). This finding again emphasizes the importance of this body region in maintaining posture during running. McKeon et al. (2015) explain that foot core training can increase the capacity and control of the central foot system; comparing its functional subsystems to those of the lumbopelvic core. This analogy suggests that intentional activation of intrinsic foot muscles prior to athletic activities may support consistent movement pattern (Fayh et al., 2018).

Both long-term interventions (Mulligan and Cook, 2013), acute interventions (James et al., 2013; Moon et al., 2014; Kelly et al., 2014; Fayh et al., 2018) demonstrate effectiveness in postural control. Notably, among these studies, only Moon et al., (2014), specifically investigated runners, highlighting the relevance of this research for this population. Many plantar alterations, if inadequately managed, can lead to both local and distal injuries, often attributed to insufficient foot conditioning among runners (Glasoe, 2016). Providing targeted guidance for runners on preparing to withstand training loads is essential, as it promotes resilience and overall health when fundamental exercises are integrated into their routines. Additionally, incorporating foot muscle activation exercises into training programs presents a practical approach to help runners tolerate the substantial reaction forces encountered during running.

Even so, it is important to consider that this study has some limitations. Firstly, these results are limited to healthy runners with no recent injury history or discomfort during running. Additionally, participants' previous training volumes and intensities were not standardized. The kinematic analysis was restricted to the sagittal plane, which may not capture the full complexity of running mechanics. Nonetheless, it is worth noting that the data collection protocols used in this study can be easily replicated by other professionals in the field. Consistent methodologies, including comparable techniques, software, and statistical analyses, are essential for reliable comparisons across studies.

In summary, future research should consider evaluating runners with recent histories of injuries or discomfort during running. Further investigations are warranted with varied evaluation protocols, longitudinal training interventions, and frontal and transverse planes evaluations. Studies examining the effects of fatigue on ankle control are also recommended, as changes in ankle kinematics were observed in the CG.

Conclusions

The acute intervention targeting foot core muscles did not cause changes in running kinematics. However, the YBT results demonstrated functional improvements in lower limbs stability following the exercise protocol in the EG. Thus, activating intrinsic foot muscles prior to physical exercise presents a viable approach to enhancing lower limbs stability in long-distance runners.

Statements & Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Hélen Spadari, Laura Buzin Zapparoli, Guilherme Auler Brodt and Leandro Viçosa Bonetti contributed to the study conception and design. Material preparation, data collection and analysis were performed by all the authors. The first draft of the manuscript was written by Hélen Spadari and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki and Brazilian Resolution 466/2012, which approves the guidelines and regulation standards for research involving human beings. Approval was granted by the Ethics Committee of University of Caxias do Sul (approval number: 5.764.234) and which is registered under CAAE number 63190122.0.0000.5341.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

The study does not contain any individual person's data in any form (including any individual details, images or videos).

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4. CONSIDERAÇÕES FINAIS E PERSPECTIVAS

A pergunta de pesquisa surgiu devido à alta complexidade da estrutura plantar e sua importância para a população de corredores para gerenciamento de lesões e performance. Todavia, o fortalecimento e o condicionamento dessa musculatura intrínseca do pé são negligenciados pelos profissionais e pelos próprios atletas.

Os resultados dessa dissertação demonstraram que os ângulos da cinemática da corrida não terem demonstrado alterações no grupo experimental na comparação pré x pós protocolo de exercícios de fortalecimento da musculatura intrínseca do pé realizados de maneira aguda, os resultados do *Y Balance Test* demonstraram uma melhora funcional dos membros inferiores após o protocolo de exercícios. Portanto, a ativação da musculatura intrínseca do pé prévia ao exercício físico pode ser uma alternativa para auxiliar na estabilidade de membros inferiores de corredores de longa distância e potencialmente, diminuir a incidência de lesões musculoesqueléticas de membros inferiores. Além disso, por ter sido eficaz funcionalmente na forma aguda, pode-se pensar nessa estratégia a longo prazo.

Vale ressaltar que a configuração do protocolo utilizado pode ser facilmente reproduzida por outros profissionais. Porém, é importante avaliar se esses resultados se reproduzem com outros sistemas, com outras intervenções ou com intervenção a longo prazo. A partir do exposto, futuras pesquisas podem avaliar corredores com histórico recente de lesões ou desconforto durante a corrida, já que este estudo recrutou participantes saudáveis. Ainda, os próximos estudos podem verificar se esses resultados também acontecem em indivíduos que passaram por um evento lesivo recente e se esse tipo de sessão pode favorecê-los; assim como utilizar diferentes protocolos de avaliação.

APÊNDICE A

UCS

UNIVERSIDADE DE CAXIAS DO SUL

ÁREA DO CONHECIMENTO DE CIÊNCIAS DA SAÚDE

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Título do Projeto: a influência de exercícios *footcore* nas variáveis biomecânicas da corrida, na estabilidade e funcionalidade de membros inferiores em fundistas.

Você está sendo convidado a participar de uma pesquisa que tem como objetivo verificar a influência de exercícios *footcore* nas variáveis biomecânicas da corrida, na estabilidade e funcionalidade de membros inferiores em fundistas. A pesquisa em si não contém benefícios diretos aos participantes, no entanto, os resultados contribuirão para a compreensão do fenômeno estudado e para a produção de conhecimento científico. Ainda será possível analisar os protocolos e seus efeitos com os participantes.

Os pesquisadores tratarão a sua identidade com padrões profissionais, atendendo as legislações brasileiras (Resoluções Nº 510/16 e Nº 466/12 do Conselho Nacional de Saúde), utilizando as informações somente para os fins acadêmicos e científicos. Sua participação no estudo será feita através de um questionário e os seguintes testes:

1- Análise biomecânica da corrida: Trata-se de uma avaliação em três dimensões, na qual serão capturados de forma integral oito passos sobre a plataforma de força.

2- *Y Balance Test*: teste funcional de membros inferiores

3- apoio unipodal na plataforma de força.

Esta pesquisa faz parte do Programa de Pós-Graduação em Ciências da Saúde que tem como professor responsável Leandro Viçosa Bonetti. As coletas serão feitas no Laboratório de Marcha, que se encontra no Centro Clínico localizado no Bloco 70 da Universidade de Caxias do Sul (UCS), em horário pré-agendado com os pesquisadores, vestindo roupas que permitam correr de forma confortável. Sua participação poderá ser em duas etapas, já que o projeto inclui sorteio da metade da amostra para intervenção, sendo esta composta por cinco exercícios de ativação dos músculos do pé. O tempo previsto será em torno de 60-120 minutos, dependendo se o voluntário for sorteado e será aplicado pela pesquisadora Hélen Spadari. Todo protocolo será realizado no mesmo dia.

A pesquisa apresenta baixo risco aos participantes. No entanto, pequenos acidentes podem acontecer como: entorses de joelho e tornozelo e vertigem, ainda você poderá ficar com um pouco de dor muscular após a avaliação e a intervenção. Se algum dos sintomas citados ocorrerem a coleta de dados será interrompida imediatamente. Ocorrendo algum acidente não previsto ou você sentir algum desconforto demasiado e de longa duração, tontura ou dor após a realização da avaliação, o pesquisador responsável o acompanhará até o Ambulatório mais próximo, localizado no hospital geral da Universidade de Caxias do Sul, Rua Prof. Antônio Vignoli, 255 - Bairro Petrópolis, e arcará com o prejuízo financeiro, ressarcindo todos os gastos, caso exista algum. Haverá garantia de confidencialidade e sigilo dos pesquisadores quanto aos dados coletados.

O pesquisador responsável compromete-se a conduzir a pesquisa de acordo com as exigências da Resolução CNS 466/12, que regulamenta as pesquisas envolvendo seres humanos. Este termo de consentimento encontra-se impresso em duas vias originais, sendo que uma será arquivada pelo pesquisador responsável e a outra será fornecida a você. Os resultados serão informados ao Comitê de Ética e Pesquisa da Universidade de Caxias do Sul e aos participantes da pesquisa. A sua participação na pesquisa é voluntária, não gerando nenhum tipo de pagamento. Qualquer dúvida que surgir você poderá entrar em contato com o Comitê de Ética em Pesquisa da Universidade de Caxias do Sul – CEP UCS - Francisco Getúlio Vargas, número 926 Bloco M – sala 306 – Cidade Universitária - Bairro Petrópolis. Caxias do Sul – RS, CEP: 95070-560. Fone: (54) 3218-2829. E-mail: cep@ucs.br ou com pesquisadores responsáveis através dos contatos abaixo.

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Hélen Spadari

Linha Amadeu, Pinto Bandeira/RS

helenspadari28@hotmail.com (54) 996970078

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Leandro Viçosa Bonetti

Rua Francisco Getúlio Vargas, 1130-Bloco 70 / Caxias do Sul

lvbonetti@ucs.br (51) 991278034

DECLARAÇÃO DE CONSENTIMENTO DO PARTICIPANTE

Mediante ao disposto no Artigo 9º da Resolução 510/16 e 466/12 CNS no que diz: “São direitos dos participantes”: “V – decidir se sua identidade será divulgada e quais são, dentre as informações que forneceu as que podem ser tratadas de forma pública;”. Declaro que entendi os objetivos, procedimentos, riscos e benefícios da pesquisa e concordo em participar da pesquisa, que me foi dada a oportunidade de ler e esclarecer as minhas dúvidas e que minha identidade e os meus dados pessoais serão mantidos sob sigilo, porém as informações que dizem respeito ao estudo poderão ser divulgadas.

Assinatura ____

Caxias do Sul,___/____/____

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APÊNDICE B

UNIVERSIDADE DE CAXIAS DO SUL
ÁREA DO CONHECIMENTO DE CIÊNCIAS DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

QUESTIONÁRIO

Nome: ____

Idade:____________ Data Nasc.: ____________________

Sexo:________________ Peso: _____Kg / Altura: ______cm / IMC:_______

Histórico do atleta:

1) Compete em qual modalidade de longa distância? __________________________

2) Tempo dessa prática esportiva: ____

3) Frequência semanal atual (horas):______________________________________

4) Antes da prática esportiva, você costuma realizar algum tipo de aquecimento?

( ) Alongamento ( )Mobilidade ( ) ativação muscular ( ) educativos de corrida

( ) Corrida leve ( ) Outro, qual? _______________________________

5) Você pratica algum outro exercício físico? ( ) SIM ( ) NÃO

Qual? ____

Com que frequência: ____

6) Treina em que tipo de solo? _________________________

7) Já faz fortalecimento para o pé – *footcore?*_____________________

Histórico de lesões neuromusculoesqueléticas:

1) Já realizou alguma cirurgia em membros inferiores.

( ) SIM ( ) NÃO

Qual?:____

2) Nos últimos meses sofreu alguma lesão.

( ) SIM ( ) NÃO

Qual lesão e qual região anatômica: ____

3) Qual foi o mecanismo de lesão? _________________________________

4) Em uma escala de 0 a 10 qual a intensidade da dor após o momento da lesão?

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7 ( ) 8 ( ) 9 ( ) 10

5) Foi necessário afastamento das atividades esportivas por conta de alguma dessas lesões?

( ) SIM ( ) NÃO.

Por quanto tempo? ____

6) Realizou tratamento fisioterapêutico para essa(s) lesão(ões)?

( ) SIM ( ) NÃO Por quanto tempo?:

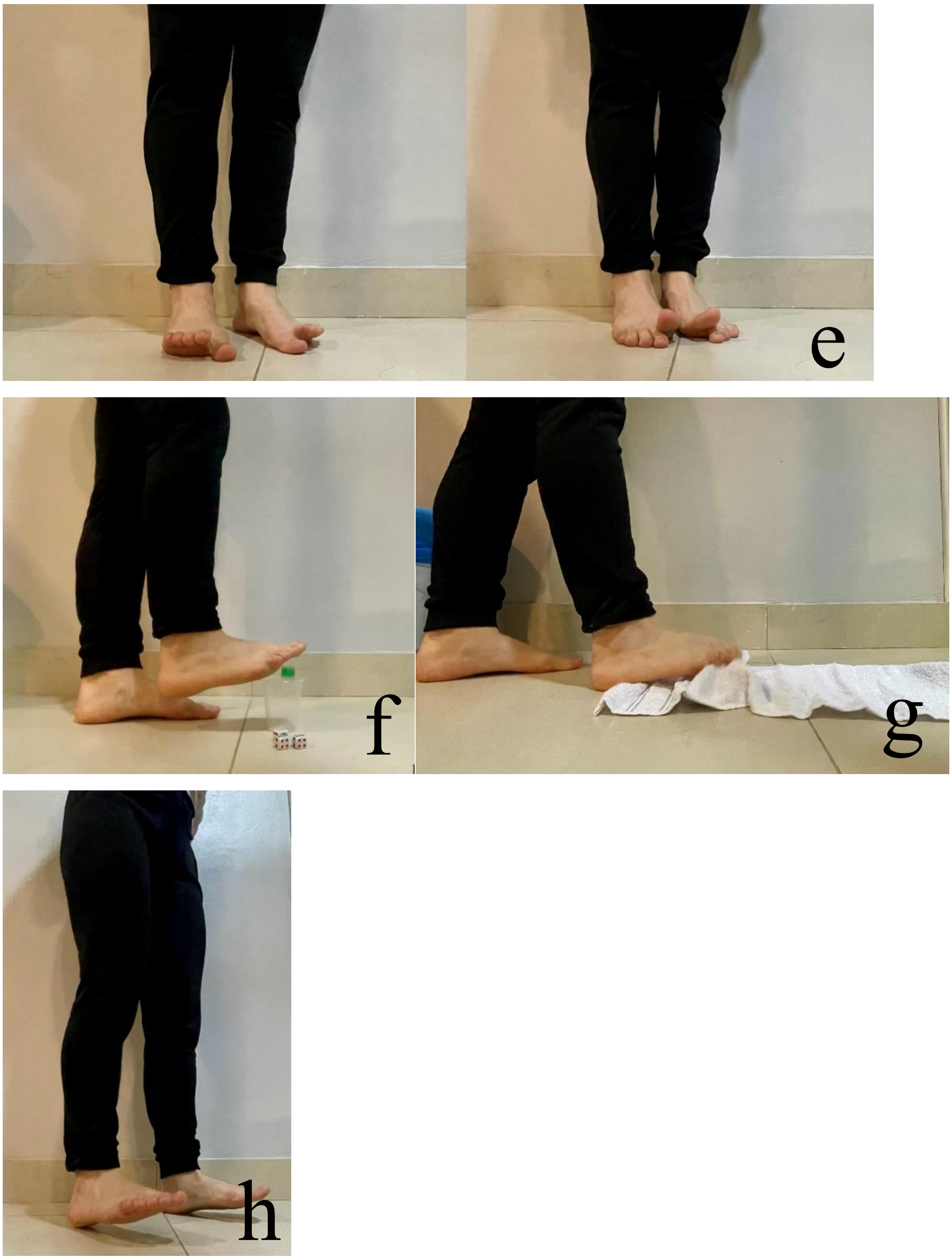
APÊNDICE C

UNIVERSIDADE DE CAXIAS DO SUL

ÁREA DO CONHECIMENTO DE CIÊNCIAS DA VIDA

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

EXERCÍCIOS DA INTERVENÇÃO



a) em pé, subir e descer no antepé por 30 repetições. Iniciando em pé, usando os dois pés; b) sentado, com 90º graus de flexão do joelho e tornozelo, realizam inversão do pé e eversão por dez repetições mantendo por um segundo cada posição; c) sentado, com 90º de flexão do joelho e tornozelo, aduzir e abduzir os dedos mantendo cada posição por dois segundos fazendo dez repetições; d) sentado, levantar o arco plantar, mantendo o calcanhar e as pontas dos dedos no chão, repetir dez vezes cada membro mantendo cinco segundos por contração; e) sentado, com o calcanhar fixo e entrando em contato com o chão, alternar a elevação do hálux com os outros dedos, por dez repetições mantendo a pressão dos dedos no chão por um segundo; f) sentado, pegar as cinco bolinhas de gude com os dedos do pé e colocar dentro do recipiente, com os dois pés; g) sentado, puxar a toalha com os dedos até chegar ao final dela; h) caminhar com os calcanhares por 30 metros.