UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM FISIOTERAPIA

CONTROLE POSTURAL E FRAGILIDADE: EFEITOS DE DIFERENTES TAREFAS E DE UM TREINAMENTO MULTICOMPONENTE

VERENA DE VASSIMON BARROSO CARMELO

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Tese apresentada ao Programa de Pós-Graduação em Fisioterapia do Centro de Ciência Biológicas e da Saúde da Universidade Federal de São Carlos como parte dos requisitos para obtenção do título de Doutor em Fisioterapia. Área de concentração: Processos de Avaliação e Intervenção em Fisioterapia.

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Centro de Ciências Biológicas e da Saúde
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DEDICATÓRIA

Esse trabalho é inteiramente dedicado aos idosos
participantes do projeto e a todos que estudam
as mudanças decorrentes do processo
de envelhecimento.

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Vassimon-Barroso, V. Controle Postural e Fragilidade: Efeito de diferentes tarefas e de um treinamento multicomponente. [tese]. São Carlos: Programa de Pós-Graduação em Fisioterapia, Universidade Federal de São Carlos; 2019.

RESUMO

A Síndrome da Fragilidade ganha destaque, simultaneamente ao crescente processo de envelhecimento, uma vez que a mesma possui desfechos adversos como óbito, hospitalização, institucionalização, quedas e dependência funcional. Nesta síndrome ocorreria uma redução mais acentuada das reservas fisiológicas e dificuldade em manter a homeostase devido a uma redução da complexidade fisiológica. Uma vez que a queda é um desfecho importante nesta síndrome, seria interessante avaliar o controle postural por meio de medidas de complexidade e em condições perturbadoras e não somente em repouso. Assim, o **Estudo I**, intitulado *"Impact of different demands on the postural control complexity of prefrail older adults"* teve como objetivo comparar a complexidade do deslocamento do centro de pressão (CoP) de idosos pré-frágeis em resposta a diferentes estímulos: privação visual, demanda cognitiva e mudança postural. Os resultados mostraram que a complexidade do deslocamento do CoP permaneceu a mesma após a transição postural na direção anteroposterior (AP), assim como nas tarefas com olhos fechados e com demanda cognitiva na direção mediolateral (ML). Sugere-se que estas atividades sejam inseridas em programas de reabilitação para esta população. Como as transições entre os status de fragilidade são espontâneos, medidas que podem reduzir a progressão da fragilidade, como o exercício, devem ser levadas em consideração. Assim, o **Estudo II** intitulado *"Effect of multicomponent training in postural oscillation complexity in prefrail older adults"* teve como objetivo investigar o efeito de uma intervenção multicomponente (exercícios aeróbico, de equilíbrio, resistência e flexibilidade) na complexidade e nas medidas tradicionais do CoP nas direções AP e ML com os olhos abertos e fechados. Os dados mostraram que o treinamento multicomponente melhorou a integração dos sistemas que controlam o balance de pré-frágeis, especialmente em condições desafiadoras, como na tarefa olhos fechados.

Palavras-chave: Fragilidade, balance, entropia, exercício.

Vassimon-Barroso, V. Postural Control and Frailty: Effect of different tasks and multicomponent training. [thesis]. São Carlos: Programa de Pós-Graduação em Fisioterapia, Universidade Federal de São Carlos; 2019

ABSTRACT

The frailty syndrome is highlighted both the aging process, since it has adverse outcomes such as death, hospitalization, institutionalization, falls and functional dependence. In this syndrome there would be a greater reduction of the physiological reserves and difficulty in maintaining the homeostasis due to a reduction of the physiological complexity. Since fall is an important outcome in this syndrome, it would be interesting to evaluate the postural control through measures of complexity and in challenging conditions, not only at rest. Thus, the Study I, titled "Impact of different demands on the postural control of prefrail older adults", aimed to compare the complexity of center of pressure (CoP) displacements of prefrail older adults in response to different stimuli: visual deprivation, cognitive demand and postural change. The results showed that the complexity of CoP displacement remained the same after the postural transition in the anteroposterior (AP) direction, as well as in tasks with closed eyes and with cognitive demand in the mediolateral (ML) direction. It is suggested that these activities could be added into rehabilitation programs for this population. As transitions between frailty stages are spontaneous, measures that may reduce the progression of frailty, such as exercise, should be taken into account. Thus, the Study II entitled "Effect of multicomponent training in postural oscillation complexity in prefrail older adults" aimed to investigate the effect of a multicomponent intervention (aerobic, balance, resistance and flexibility exercises) on the complexity and traditional measures of CoP displacements in the AP and ML directions with the eyes open and closed. The data showed that multicomponent training improved the integration of systems that control the prefrail balance, especially in challenging conditions, such as with closed eyes.

Key words: Frailty, balance, entropy, exercise.

LISTA DE ILUSTRAÇÕES

ESTUDO 1

LISTA DE TABELAS

ESTUDO I:

ESTUDO II:

LISTA DE ABREVIATURAS E SIGLAS

RMS	Root mean Square
TMS	Total Mean Speed
CoP	Center of Pressure
CoM	Center of Mass
EO	Eyes Open
EC	Eyes Closed
STS	Sit-to-Stand
CD	Cognitive Demand
AP	Anteroposterior
ML	Mediolateral
MMSE	Mini Mental State Exam
SampEn	Sample Entropy
BMI	Body Mass Index
PF-MulTI	Treinamento Multicomponente para Pré-Frágeis
IG	Intervention Group
CG	Control Group
SPPB	Short Physical Performance Battery
TUG	Timed Up and Go
WS	Walking Speed
SS	Sit-to-Stand Test
ACSM	American College of Sports Medicine
HRR	Heart Rate Reserve
ES	Effect Size

SUMÁRIO

1. CONTEXTUALIZAÇÃO

O interesse em se estudar o processo de envelhecimento vem crescendo exponencialmente nas últimas décadas. Neste cenário, a síndrome da fragilidade tem ganhado destaque, uma vez que pode afetar cerca de 20% dos idosos (MARTÍNEZ-RAMÍREZ et al., 2011). No entanto, deve notar-se que o estado de pré-fragilidade pode ser uma medida sensível para detectar uma redução precoce na capacidade de reserva de idosos aparentemente saudáveis (FRIED et al. 2001). A pré-fragilidade é uma condição que precede a fragilidade, e deve ser levada em consideração assim como outras comorbidades mais comuns como diabetes e hipertensão arterial (SACHA et al. 2017). Assim, a detecção precoce de qualquer forma de declínio funcional em idosos parece relevante quando se pretende introduzir intervenções para preservar o status biológico, psicológico e social do idoso (SACHA et al. 2017).

Esta síndrome da fragilidade é descrita como um estado clínico de vulnerabilidade ao estresse, resultado do declínio da resiliência e de reservas fisiológicas associadas ao envelhecimento, com progressivo declínio na capacidade de manutenção da homeostase (CLEGG et al., 2013; FRIED et al., 2001; LIPSITZ, 2004). Com o processo de envelhecimento, uma redução gradual das reservas fisiológicas é esperada, entretanto, na fragilidade essa redução ocorre de forma mais acelerada e os mecanismos homeostáticos tornam-se ineficientes ao lidar com agentes estressores (CLEGG et al., 2013).

A manutenção da homeostase depende de uma rede complexa de interações entre os mecanismos de controle. Assim, um organismo saudável é dotado de múltiplas interações que permitem que o indivíduo se ajuste às exigências e mudanças imprevisíveis do cotidiano (LIPSITZ, 2002). Alguns autores vêm sugerindo que associado ao processo do envelhecimento, ocorre uma diminuição destas interações entre os sistemas fisiológicos, que limitaria as respostas aos mecanismos estressores e caracterizaria uma complexidade fisiológica reduzida (LIPSITZ, 2002; LIPSITZ; GOLDBERGER, 1992). Na fragilidade, sugere-se que essa perda de complexidade seja ainda mais acentuada, a qual acarretaria queda da capacidade funcional até níveis críticos, e tornaria o indivíduo menos resiliente e, portanto, mais vulnerável ao desenvolvimento de patologias, desfechos adversos e até mesmo ao óbito (LIPSITZ, 2004).

Dentre os desfechos adversos ligados a esta síndrome, destacam-se as quedas. Um estudo observou que 67% dos idosos que possuem histórico de quedas apresentam algum grau de fragilidade. As quedas são consequências do déficit do equilíbrio (THE AMERICAN GERIATRICS SOCIETY, 2011) e, portanto, a avaliação do controle postural de idosos pré-frágeis seria de extrema importância (FHON et al., 2013).

Ressalta-se que o controle postural é considerado uma habilidade motora complexa que exige a interação de múltiplos sistemas sensório-motores (HORAK, 2006). Os dois principais objetivos do controle postural são a orientação e o equilíbrio postural. O primeiro, diz respeito ao alinhamento ativo do corpo e o tônus em relação à gravidade, à base de suporte, ambiente visual e referencias internas. Já o segundo componente é baseado na intepretação sensorial de informação dos sistemas somatossensorial, vestibular e visual. Assim, o equilíbrio postural envolve a coordenação de estratégias sensoriomotoras para estabilizar o centro de massa do corpo (CoM) durante uma perturbação auto iniciada ou externamente gerada (HORAK, 2006).

No contexto de avaliação do controle postural, usualmente são reportados dados tradicionais (lineares) referentes ao deslocamento do centro de pressão (CoP), como amplitude, root mean square (RMS) e velocidade média de deslocamento do CoP (BIGGAN et al., 2014; SWANENBURG et al., 2009). Há alguns anos, medidas de complexidade passaram a oferecer novas possibilidades de analisar e interpretar as oscilações do CoP

(TALLON et al., 2013). As medidas obtidas por estes métodos não dependem da magnitude ou da variância dos dados, e sim caracterizam a organização dinâmica dos deslocamentos do CoP, sendo complementares às medidas tradicionalmente usadas (TALLON et al., 2013).

Uma vez que a síndrome da fragilidade pode ser caracterizada por uma quebra da complexidade fisiológica, avaliar o controle postural com medidas de complexidade poderia ser promissor. Alguns autores mostraram que na presença da síndrome, a complexidade da oscilação anteroposterior mostra-se ainda mais reduzida que no processo de senescência (KANG et al., 2009). Por sua vez, outro estudo indicou que idosos frágeis apresentam dificuldade em ajustar e reorganizar o controle postural, após a demanda da tarefa de levantar da cadeira, evidenciada pela não alteração das medidas de complexidade (VASSIMON-BARROSO et al., 2017).

Deste modo, além da avaliação do controle postural em situações de repouso é interessante avaliar as oscilações posturais em condições de perturbação como, privação visual, demandas cognitivas e após movimento auto iniciado, como na mudança postural (ALENCAR et al., 2007; CAVANAUGH; MERCER; STERGIOU, 2007; CHENG, P. LIAW, M. WONG, M. TANG, 1998; DONKER et al., 2007; HANKE; PAI; ROGERS, 1995; KANG et al., 2009; VASSIMON-BARROSO et al., 2017)

Diante do exposto, torna-se evidente que a síndrome da fragilidade é uma síndrome geriátrica distinta, com alta prevalência com o aumento da idade e associada com maior risco de desfechos adversos, estando associada a um substancial custo socioeconômico (SACHA et al., 2017). Com o envelhecimento populacional, estudos que busquem elucidar diferentes aspectos desta síndrome, constituem uma importante etapa. Dentro deste contexto, pesquisas que tenham como objetivo avaliar o controle postural em diferentes contextos nesta população, são de extrema importância. Adicionalmente, o estudo da complexidade de sinais biológicos vem surgindo como uma ferramenta importante na avaliação da dinâmica destes sinais (KANG et al., 2009; TALLON et al., 2013).

Nesse sentido, desenvolveu-se o Estudo 1 intitulado *"Impact of different demands on the postural control complexity of prefrail older adults"* que teve como objetivo comparar a complexidade do CoP de idosos pré-frágeis em resposta a diferentes estímulos: privação visual, demanda cognitiva e mudança postural.

É de suma importância destacar que a progressão da fragilidade, quando não são inseridas medidas de intervenção é espontânea. Um estudo observou que após 4,5 anos, dos 754 idosos participantes do estudo, 43,3% que foram classificados como não frágeis passaram para o estágio intermediário (pré-frágeis); 26,1% que eram pré-frágeis tornaram-se frágeis e 20,1% dos frágeis foram a óbito (GILL et al., 2006). No cenário nacional, outros autores demonstraram que os idosos pré-frágeis foram os que mais mudaram de status em um acompanhamento de 13 meses, sendo que 19,5% se tornaram frágeis (LANZIOTTI AZEVEDO DA SILVA et al., 2015).

No entanto, é possível a reversão da síndrome, podendo esta ser potencializada com intervenções, dentre as quais, o exercício tem ganhado destaque (SACHA et al., 2017). Apesar de estudos indicarem que intervenções baseadas em exercício físico, especialmente o treinamento multicomponente (exercícios resistido, aeróbio, balance, flexibilidade e agilidade) melhoram: a capacidade funcional, componentes físicos, mobilidade e reduzem o risco de quedas de idosos em processo de fragilização (DEDEYNE et al., 2017; LOZANO-MONTOYA et al., 2017), ainda não está claro se se este tipo de intervenção provocaria mudanças na complexidade do controle postural de idosos pré frágeis.

Nesse sentido, buscou-se responder ao segundo questionamento com a condução do Estudo 2, intitulado *"Effect of multicomponent training in postural oscillation complexity in* *prefrail older adults”*. Este estudo teve como objetivo investigar o efeito de uma intervenção baseada em exercícios multicomponentes na complexidade e nas medidas tradicionais do CoP, na condição olhos abertos e fechados de idosos pré frágeis.

1.1 REFERÊNCIAS BIBLIOGRÁFICAS

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ALENCAR, M. A. et al. Muscular function and functional mobility of faller and non-faller elderly women with osteoarthritis of the knee. **Brazilian Journal of Medical and Biological Research**, v. 40, n. 2, p. 277–283, fev. 2007.

BIGGAN, J. R. et al. Increased load computerized dynamic posturography in prefrail and nonfrail community-dwelling older adults. **Journal of Aging and Physical Activity**, v. 22, n. 1, p. 96–102, 2014.

CAVANAUGH, J. T.; MERCER, V. S.; STERGIOU, N. Approximate entropy detects the effect of a secondary cognitive task on postural control in healthy young adults: a methodological report. **Journal of neuroengineering and rehabilitation**, v. 4, p. 42, 2007.

CHENG, P. LIAW, M. WONG, M. TANG, F. No Titlehe Sit-to-Stand Movement in Stroke Patients. **Archives of Physical Medicine and Rehabilitation**, v. 79, p. 1043–1046, 1998.

CLEGG, A. et al. Frailty in elderly people. **The Lancet**, v. 381, n. 9868, p. 752–762, 2013.

DEDEYNE, L. et al. Effects of multi-domain interventions in (pre)frail elderly on frailty, functional, and cognitive status: A systematic review. **Clinical Interventions in Aging**, v. 12, p. 873–896, 2017.

DONKER, S. F. et al. Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. **Experimental Brain Research**, v. 181, n. 1, p. 1–11, 2007.

FHON, J. R. S. et al. Prevalencia de quedas de idosos em situacao de fragilidade. **Revista de Saúde Pública**, v. 47, n. 2, p. 266–273, 2013.

FRIED, L. P. et al. Frailty in older adults: evidence for a phenotype. **The journals of gerontology. Series A, Biological sciences and medical sciences**, v. 56, n. 3, p. M146–M156, 2001.

GILL, T. M. et al. Transitions Between Frailty States Among Community-Living Older Persons. **Archives of Internal Medicine**, v. 166, n. 4, p. 418, 2006.

HANKE, T. A.; PAI, Y. C.; ROGERS, M. W. Reliability of measurements of body center-of-mass momentum during sit-to-stand in healthy adults. **Physical therapy**, v. 75, n. 2, p. 105- 13; discussion 113–8, 1995.

KANG, H. G. et al. Frailty and the Degradation of Complex Balance Dynamics During a Dual-Task Protocol. **The Journals of Gerontology Series A: Biological Sciences and Medical Sciences**, v. 64A, n. 12, p. 1304–1311, 1 dez. 2009.

LANZIOTTI AZEVEDO DA SILVA, S. et al. Transition Patterns of Frailty Syndrome in Comunity-Dwelling Elderly Individuals: A Longitudinal Study. **The Journal of frailty & aging**, v. 4, n. 2, p. 50–5, 2015.

LIPSITZ, L. A. Dynamics of Stability: The Physiologic Basis of Functional Health and Frailty. **The Journals of Gerontology Series A: Biological Sciences and Medical Sciences**, v. 57, n. 3, p. B115–B125, 1 mar. 2002.

LIPSITZ, L. A. Physiological complexity, aging, and the path to frailty. **Science of aging knowledge environment : SAGE KE**, v. 2004, n. 16, p. 1–6, 2004.

LIPSITZ, L. A.; GOLDBERGER, M. Loss of “Complexity” and Aging. **Jama**, v. 267, n. 13, p. 1806, 1992.

LOZANO-MONTOYA, I. et al. Nonpharmacological interventions to treat physical frailty and sarcopenia in older patients: A systematic overview – the SENATOR project ONTOP series. **Clinical Interventions in Aging**, v. 12, p. 721–740, 2017.

MARTÍNEZ-RAMÍREZ, A. . et al. Frailty assessment based on wavelet analysis during quiet standing balance test. **Journal of Biomechanics**, v. 44, n. 12, p. 2213–2220, 2011.

SACHA, J. et al. Is it time to begin a public campaign concerning frailty and pre-frailty? A review article. **Frontiers in Physiology**, v. 8, n. JUL, p. 1–10, 2017.

SWANENBURG, J. et al. Compromising postural balance in the elderly. **Gerontology**, v. 55, n. 3, p. 353–360, 2009.

TALLON, G. et al. Dynamical and stabilometric measures are complementary for the characterization of postural fluctuations in older women. **Gait and Posture**, v. 38, n. 1, p. 92–96, 2013.

THE AMERICAN GERIATRICS SOCIETY. Summary of the updated american geriatrics society/british geriatrics society clinical practice guideline for prevention of falls in older persons. **Journal of the American Geriatrics Society**, v. 59, n. 1, p. 148–157, 2011.

VASSIMON-BARROSO, V. et al. Linear and nonlinear analysis of postural control in frailty syndrome. **Brazilian Journal of Physical Therapy**, v. 21, n. 3, p. 184–191, maio 2017.

2. ESTUDO 1

(Versão em inglês submetida à revista Journal of Motor Behavior)

IMPACT OF DIFFERENT DEMANDS ON THE POSTURAL CONTROL COMPLEXITY OF PREFRAIL OLDER ADULTS

POSTURAL CONTROL IN FRAILTY SYNDROME

Verena de Vassimon-Barroso, Marcele Stephanie De Souza Buto, Elie Fiogbè , Ana Claudia Silva Farche, Bianca Ferdin Carnavale, Paulo Giusti Rossi, Anielle Cristhine De Medeiros Takahashi

ABSTRACT

Aim: To compare the measures of center of pressure (CoP) displacement in prefrail older adults using nonlinear and linear measurements in different tasks (eyes open-EO; eyes closed – EC; sit-to-stand –STS, and cognitive demand – CD). *Material and Methods:* This was a transversal study. The CoP displacements of thirty-three prefrail older adults were evaluated by a force platform in different tasks in both anteroposterior (AP) and mediolateral (ML) directions. Assessments were performed using complexity (measured by sample entropy) and linear measurements (amplitude and total mean speed). *Results:* In the AP direction, there was an increase of CoP complexity in EC (0.32 ± 0.04) and CD (0.34 ± 0.05) compared to EO (0.30 ± 0.04) in the AP direction. In the ML direction, the CoP complexity of STS task (0.28 ± 0.06) was lower compared to EO (0.32 ± 0.07). The amplitude was higher in CD (ML: 10.11(7.16-15.67)) and in STS (AP: 20.70(17.89-24.14); ML: 11.83(8.45-15.85)) compared to EO (AP: 16.75(12.21-22.44); ML: 6.92(5.33-9.54)). Total mean speed was higher in all tasks (EC: 11.18 ± 4.46; CD: 10.98 ± 3.39; STS: 8.98 ± 2.86) compared to EO (7.64 ± 2.49). *Conclusions:* It is suggested that complexity of CoP displacements of prefrail older adults is altered depending on the stimulus offered as in the EC, STS and CD tasks.

Key words: balance, entropy, prefrail, falls.

2.1 INTRODUCTION

Frailty is a geriatric syndrome caused by a multisystem decrease in physiological reserve and is associated with a high risk of death, institutionalization, dependency, disability, functional decline, and falls (Fried et al., 2001; Morley et al., 2013).

Falls usually occur due to gait and balance disorders, often leading to injury, disability, loss of independence, and limitations in quality of life (Cuevas-Trisan, 2017). A recent systematic literature review and meta-analysis indicated that once older people enter the prefrail stage, they are likely to experience falls, since their risk for fall is 1.64 greater than that of nonfrail older people (Cheng & Chang, 2017). Another review showed that the prevalence of falls in prefrail older adults was between 10% and 52% (Fhon, Rodrigues, Neira, Huayta, & Robazzi, 2016). In this context, the systems that involve the maintenance of balance must be considered in evaluations aiming to prevent falls. These systems, such as the visual, vestibular, proprioceptive, and cognitive, are compromised during the aging process (Coelho, Fernandes, Santos, Paúl, & Fernandes, 2016).

One of the most common approaches of assessing balance is analyzing postural control through center of pressure (CoP) displacement during standing (Duarte & Freitas, 2010). Among the methods used are the linear (traditional) and nonlinear measures (Negahban, Sanjari, Karimi, & Parnianpour, 2016a; Zhou et al., 2013). While linear analysis quantifies the magnitude and/or variance of CoP displacements, nonlinear analysis considers their temporal organization (Tallon, Blain, Seigle, Bernard, & Ramdani, 2013). In this sense, complexity measures, such as entropy, enable additional information about the dynamic interactions in physiological systems organized in a nonlinear way. Since postural control involves visual, vestibular, somatosensory (Horak, 2006; Manor et al., 2010), numerous brain regions and musculo-skeletal systems that can be affected by pathology or subclinical constraints (Horak, 2006), such as the frailty process, it is important to assess postural control using both measurements.

The literature demonstrates that the complexity of CoP displacements is reduced in the presence of frailty syndrome during quiet standing (Kang et al., 2009). Knowing that other systems are involved in postural control, the evaluation of postural control is interesting not only in resting situations, but also in disturbance conditions such as visual occlusion, cognitive demands, and postural transitions (Duarte & Freitas, 2010; Horak, 2006; Kang et al., 2009; Negahban, Sanjari, Karimi, & Parnianpour, 2016b; Tallon et al., 2013; Zhou et al., 2013). A previous study demonstrates that the complexity of CoP displacements is reduced in prefrail older adults even after postural transition (Vassimon-Barroso, Catai, Buto, Porta, & Takahashi, 2017). However, to date, no studies involving the complexity of CoP displacements have been found evaluating the visual, cognitive, and functional demands.

The present study compares the measures of CoP displacement in prefrail older adults using nonlinear and linear measurements in different tasks (eyes-open – EO; eyes-closed – EC; sit-to-stand – STS; and cognitive demand – CD). The hypotheses of the study were (i) there is a reduction in the complexity of CoP displacement in EC, STS, and CD compared to EO task in the anteroposterior (AP) and mediolateral (ML) directions; (ii) there is an increased CoP displacement measured by linear measurements in EC, STS, and CD compared to EO task in both directions.

2.2 MATERIAL AND METHODS

2.2.1 Participants

The study sample included thirty-three older adults of both sexes, classified as prefrail and screened according to the frailty phenotype (Fried et al., 2001) that includes low strength measured by a handgrip, poor endurance and energy identified by the Center for Epidemiological Studies-Depression scale (CES-D) identified by two questions, slowed motor performance measured by the time to walk 4.6 meters, low physical activity calculated by Minnesota Leisure Time Activities Questionnaire, or unintentional weight loss equal or greater than 4.5 kilograms in prior year, or equal or greater than 5% of body weight in prior year. Sample size calculation was performed a priori using G*Power software (version 3.1.3, Kiel, Germany), which led to a sample containing 27 participants (power = 80%; effect size = 0.5; alpha = 0.05). Inclusion criteria were: age of 65 years or older; ability to understand the instructions; and agreement to participate in the study. Non-inclusion criteria were: (a) history of stroke with loss of strength and aphasia (Manor et al., 2010); (b) history of neurodegenerative disease; (c) peripheral neuropathy (Wayne et al., 2013), assessed by 5.07 (10 g) Semmes-Weinstein monofilaments (Souza et al., 2005); (d) history of uncorrected visual disorders; (e) history of vestibular problems; (f) cognitive impairment, with scores ≤18 in the Mini-Mental State Examination (MMSE) (Fried et al., 2001). The exclusion criterion was nonstationary signal. Sample recruitment was done through pamphlets, local radio, television, and churches. This study was approved by the local Research Ethics Committee (approval No. 1.800.231).

2.2.2 Procedures

Participants were asked about their anthropometric data and medical history by a physiotherapist. The history of falls in the last six months comprised any nonaccidental and involuntary event in which the participant lost his/her balance and fell to the floor or onto a hard surface (“World Health Organization,” 2017).

Center of pressure displacements in the AP and ML directions were collected using a force platform (BERTEC Corporation - USA, model 4060-08) at a sampling rate of 1000 Hz. As the EO and STS tasks were performed in the same data collection, the order of execution was randomized between 3 tasks (EO – STS, EC, and CD). Three valid trials were performed for each task, with an approximate one-minute rest interval.

Participants performed the tests barefoot, standing with their feet side-by-side and parallel at pelvis width. For the EO, CD, and STS trials, the older adults were instructed to keep their eyes fixed to a 1-meter target fixed ahead, with a height approximately equal to the participant's eyes (Duarte & Freitas, 2010).

For both CD and EC tasks, the older adults were instructed to maintain the orthostatic posture for 40 seconds. During CD, subjects had to count backwards while standing on the force plate. The starting number was selected at random from a series of numbers ranging from 80 to 199. If backward counting in steps of seven proved to be too difficult to the subject, steps of three or one were used instead (Swanenburg, De Bruin, Uebelhart, & Mulder, 2009).

EO and STS tasks were performed for 100 seconds. The test began with the participant in the standing posture for 45 s (EO task). After this period, a standardized verbal command was given: ‘‘Attention. Sit.’’ The participant would sit on the chair and, as soon as his/her trunk touched the backrest, the following command was given: ‘‘Attention. Rise.’’ The participant would then rise with the help of the upper limbs, and remain in the standing position until the end of the collection (STS task). The chair had armrests, and its height was adjusted individually to keep knees and hips flexed to 90° (Vassimon-Barroso et al., 2017).

2.2.3 Data analysis

The segments of data collection used for the CoP analysis were the 30 s before (EO task) and the 30 s after the end of the activity of sitting and rising from the chair (STS task). Regarding the other tasks, 30 seconds of collection were used for analysis. To obtain these segments and to calculate the variables, MATLAB software (version 7.6.0.324, MathWorks Inc., Natick, MA, USA) was used. After obtaining the segments, the CoP displacement signals were filtered with a fourth-order Butterworth filter with a cutoff frequency of 10 Hz [13]. The signal was resampled from 1000 to 20 Hz for nonlinear analysis, resulting in 600-point sections, aiming to reduce redundancy while preserving the essential information of the signal (Vassimon-Barroso et al., 2017). The choice among the three attempts was based on the stationarity of the signal, which is a premise for the calculation of entropy (Ferdjallah, Harris, & Wertsch, 1999).

2.2.4 Linear and Nonlinear analysis

Regarding linear analysis, the amplitude and total mean velocity of CoP displacement were calculated (Duarte & Freitas, 2010). Nonlinear measurements, such as complexity, were performed by calculating the entropy, which reflects temporal information of the organization, sequencing, and regularity of CoP displacements (Borg & Laxåback, 2010). In this study, normalized Sample Entropy (SampEn) was used for nonlinear analysis (Vassimon-Barroso et al., 2017). The parameters were computed with $m = 2$, $r = 0.2$ times the standard deviation of the signal, and $N = 600$ (Vassimon-Barroso et al., 2017).

2.2.5 Statistical Analysis

The Shapiro-Wilk test was used to verify the normality of data distribution. Paired T-test or Wilcoxon Test were performed to compare all tasks related to the EO condition, depending on the normality of distribution. Bonferroni correction was used. Then, the p-value considered was 0.016, and statistical analysis was performed by SigmaPlot version 11.0.

2.3 RESULTS

Clinical and anthropometric data are shown in Table 1.

Table 1: Sociodemographic data

Variables	**Values**
Gender (number)	W:24
Age (years)	75.12 ± 6.00
Body mass(kg)	72.81 ± 14.37
Stature (cm)	1.55 ± 0.06
BMI (kg/cm²)	30.17 ± 6.06
MSSE (total score)	25.46 ± 2.85
History of falls (%)	24.24

W: women; BMI: body mass index; MSSE: Mini-Mental State Examination

In the AP direction, the complexity of CoP displacement, measured by SampEn, was significantly greater in CD (p=0.002) and EC (p=0.007) compared to EO task (Table 2). Regarding linear analysis, the CoP amplitude was significant greater only in STS (p=0.001) compared to EO task. Moreover, there was an increased in STS (p<0.001) compared to EO task. The TMS of CoP displacement, shown in both Tables (2 and 3), was lower in EO compared to the other tasks (p<0.001)

Table 2: Nonlinear and linear data in the anteroposterior direction**.**

Variables	**Postural tasks**			
Nonlinear analysis	EO	EC	CD	STS
SampEn	0.30 ± 0.04	0.32 ± 0.04[*]	0.34 ± 0.05[*]	0.28 ± 0.04
Linear analysis				
Amplitude (mm)	16.75(12.21-22.44)	20.40(17.02-28.26)	21.17(15.21-23.90)	20.70(17.89-24.14) [*]
TMS (mm/s)	7.64 ± 2.49	11.18 ± 4.46 [*]	10.98 ± 3.39[*]	8.98 ± 2.86 [*]

SampEn: sample entropy; TMS: total mean speed. The values are expressed as means ± standard deviation and as medians and interquartile distance (first and third quartiles); [*]Comparison were made between EO and other tasks.

In the ML direction, statistical tests revealed a significant decrease in the complexity of CoP displacement, measured by SampEn, in STS compared to EO task ($p=0.003$) (Table 3). Furthermore, regarding linear analysis, the amplitude of CoP was greater in CD (both $p<0.001$) and STS (both $p<0.001$) compared to EO task.

Table 3: Nonlinear and linear data in the mediolateral direction.

Variables	**Postural tasks**			
Nonlinear analysis	EO	EC	CD	STS
SampEn	0.32 ± 0.07	0.33 ± 0.06	0.33 ± 0.08	0.28 ± 0.06*
Linear analysis				
Amplitude (mm)	6.92(5.33-9.54)	7.32(5.46-10.27)	10.11(7.16-15.67) *	11.83(8.45-15.85) *
TMS (mm/s)	7.64 ± 2.49	11.18 ± 4.46 *	10.98 ± 3.39*	8.98 ± 2.86*

SampEn: sample entropy; TMS: total mean speed. The values are expressed as means ± standard deviation and as medians and interquartile distance (first and third quartiles); * Comparisons made between EO and other tasks.

2.4 DISCUSSION

The main findings of this study were the increase of CoP displacement complexity in the AP direction in EC and CD compared to EO task, while in the ML direction there was a decrease only in STS compared to EO task. Related to linear measures in the AP direction, there was an increased CoP amplitude in STS task. Therefore, in the ML direction, the CoP amplitude was greater in CD and STS compared to EO task. The total mean velocity of CoP displacement was higher in all tasks compared to EO.

Over time, various theories have sought to understand how the motor system is organized in a coordinated and controlled manner on the various possible responses (Kelso, Southard, & Goodman, 1979), such as against a postural control disturbance. A coordinated response of a system considers its degrees of freedom, that is, the movement possibilities of that system, as well as the response variability that is conditioned to the context in which the task is performed (Kelso et al., 1979). Therefore, it is suggested that when the system shows a change in complexity, it reacts to a disturbance, and then cannot be considered a rigid system without a significant repertoire of responses.

It is well established that postural orientation and postural equilibrium contribute to the efficiency of postural control (Horak, 2006). Since the visual environment and visual systems are involved, respectively, with postural and spatial orientation (Horak, 2006), visual occlusion would influence postural control in a negative manner. Although the results of the present study are contrary to the hypothesis regarding measures of complexity, they agree with the findings of Borg & Laxåback (2010). The authors compared the sample entropy between older adults and young in both AP and ML directions and within-between groups and eyes closed, eyes open, foam, self-perturbation and nudge conditions. They found that older adults showed increased amplitude measures with eyes closed as well as data results related sample entropy. Regarding the complexity of CoP displacement, some authors have demonstrated a reduction in the complexity of older adults with eyes closed (Zhou et al., 2013), disagreeing with the present results. However in the present study we used the sample entropy that quantifies the characteristic of regularity of the signal, while the authors mentioned before used the detrended fluctuation analysis that brings information about auto similarity at different time scales, that is another type of signal characteristic (Vaillancourt & Newell, 2002).

Our findings suppose that other mechanisms could be involved in the maintenance of postural control, enhancing the complexity of CoP displacements in this task compared to the EO condition. This is supported by the fact that other means may contribute to adjust postural changes, since a sensory system alone would not meet this demand (Chagdes et al., 2009). In addition, a previous study comparing the same tasks showed a greater dependence on closed-loop (postural muscles plus sensory feedback) mechanisms in frail compared to healthy older adults (Toosizadeh, Mohler, Wendel, & Najafi, 2014). The authors aimed to use to use open-loop and closed-loop mechanisms to explore differences in postural balance mechanisms between nonfrail, prefrail and frail individuals. Although we cannot state this, probably a greater activation of lower limb muscles could contribute to postural stabilization in the absence of vision, increasing CoP displacement complexity. Moreover, the authors mentioned above found that, in contrast to traditional balance parameters, the metric used to analyze CoP dynamics (stabilogram diffusion analysis) was efficient in distinguishing balance behaviors between nonfrail, prefrail, and frail older adults only in the AP direction (Toosizadeh et al., 2014). The authors also explain that the AP direction was more associated with frailty, which corroborates our findings, once the alterations between EO and EC tasks were seen only in this direction.

Regarding the postural performance associated with the cognitive task, it is believed that since the resources involved in information processing are limited, there is a competition between the two tasks that can negatively affect one or both of them (Potvin-Desrochers, Richer, & Lajoie, 2017). We hypothesized that there was a reduction in the complexity CoP displacement, such as there was an increase in the linear measures in both directions compared to the EO task. The results disagree with the hypothesis, only in the AP direction, since there was an increased complexity, and was in accordance related to the linear metrics, once amplitude and RMS increased only in the ML direction. There was also an increase in the total mean velocity. There is a divergence in the literature about cognitive dual tasks and the change (increase or decrease) of CoP displacement complexity (Kang et al., 2009; Negahban et al., 2016b; Potvin-Desrochers et al., 2017). Kang et al. (2009) compared CoP complexity using multiscale entropy and found that it was reduced in prefrail older adults while performing a subtraction task. However, it has been shown that a greater CoP displacement complexity means a shift of attention towards the cognitive task. This allows the automatic processes regulating posture to work unconstrained (Potvin-desrochers, Richer, & Lajoie, 2017), especially in continuous cognitive tasks (Lajoie, Richer, Jehu, & Tran, 2016), such as those used in the present study. These tasks seem to give less opportunities for the control of posture, facilitating automatic control (Lajoie et al., 2016; Polskaia, Richer, Dionne, & Lajoie, 2015). This finding is supported by the absence of difference between CD and EO in terms of linear measures in the AP direction. The CD task was different from EO in the AP, probably because of the limited conscious interference to the postural control, allowing it to function in a self-organizing manner (Polskaia et al., 2015). Concerning linear measurements, they are more promising in determining the risk of falls in the ML direction (Sample et al., 2016), especially under cognitive dual-task demands. Once falls result from poor postural control, this is in accordance with our results, since there was a greater CoP displacement in the ML direction when comparing the CD and EO tasks.

Regarding STS, since there is a deterioration of musculoskeletal, neuromuscular, and sensory system with age, the ability to rise from a seated position becomes more difficult (Akram & McIlroy, 2011). Among the challenges involved in the transition from sitting to standing, modifying a relatively large and stable base of support to a smaller base (Akram & McIlroy, 2011) can negatively impact postural balance. A decrease in the complexity of CoP displacements was expected in STS compared to EO task, proving that as the postural challenge increases, there is a reduction in the complexity of the control system (Negahban et al., 2016b; Zhou et al., 2013). However, complexity decreased only in the ML direction, whereas there was an increase of sway in linear measurements in both directions regarding EO task. It has been described that the major difficulty in controlling stability occurs in the terminal phases of the movement from STS, which leads to the increase of CoP in both directions (Akram & McIlroy, 2011), corroborating our outcomes about linear measurements. The reduction in postural transitions observed in the daily routine of prefrail and frail older adults may be related to an impairment in performance during STS (Parvaneh, Mohler, Toosizadeh, Grewal, & Najafi, 2017), enhancing instability on this task. In addition, prefrail older adults use strategies to successfully perform postural transition, moving further away from the natural motion (Ganea, Paraschiv-Ionescu, Büla, Rochat, & Aminian, 2011). Thus, probably the upward movement is no longer automatic, and therefore CoP displacement complexity decreases. The literature is scarce in demonstrating alterations in the complexity of CoP displacements in the STS task, especially in prefrail older adults. Our previous results also demonstrated a reduction in CoP complexity in prefrail subjects (Vassimon-Barroso et al., 2017). We could suggest that major attention was given to postural control in ML, once this direction is associated with fall risk (Sample et al., 2016) and the orthostatic posture is controlled primarily in the sagittal plane (Roerdink et al., 2006).

Although we did not compare the directions of CoP displacements, from the results, it was possible to notice that there were changes on the complexity of CoP displacements in the different tasks at least in one direction (AP or ML). Thus, we believe that even though the subjects of the present study are in the frailty process, the subsystems involved in postural control manage the postural impacts of each task relatively well, increasing or decreasing the complexity. On the other hand, we assumed that the lack of changes in complexity demonstrates a rigid system that could not adapt to stress conditions. This could be important to highlight the impact of each task on the complexity of postural control, and to suggest under what postural demands intervention plans could be drawn for prefrail older adults.

The limitation of the present study was that once we not assessed the activity of lower limb muscles or the movements kinematics, it was not possible to note if the older adults used ankle or hip strategies to compensate the balance perturbations.

2.5 CONCLUSIONS

CoP displacement complexity did not change in STS task in the AP direction, nor in EC and CD tasks in the ML direction, in comparison to EO task.

The occurrence of a complexity increases in EC and CD tasks in the AP direction, and decreases in STS in the ML direction, when compared to EO task, shows that depending on the task and direction, the subsystems of postural control in prefrail older adults still demonstrate a significant interaction.

Regarding clinical practice, it is suggested that interventions involving eyes closed, cognitive demand as well as the sit-to-stand task are indicated to compose a rehabilitation program of prefrail older adults.

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2.7 REFERENCES

Akram, S. B., & McIlroy, W. E. (2011). Challenging horizontal movement of the body during sit-to-stand: Impact on stability in the young and elderly. *Journal of Motor Behavior*, *43*(2), 147–153. https://doi.org/10.1080/00222895.2011.552077

Borg, F. G., & Laxåback, G. (2010). Entropy of balance--some recent results. *Journal of Neuroengineering and Rehabilitation*, *7*, 38. https://doi.org/10.1186/1743-0003-7-38

Chagdes, J. R., Rietdyk, S., Haddad, J. M., Zelaznik, H. N., Raman, A., Rhea, C. K., & Silver, T. A. (2009). Multiple timescales in postural dynamics associated with vision and a secondary task are revealed by wavelet analysis. *Experimental Brain Research*, *197*(3), 297–310. https://doi.org/10.1007/s00221-009-1915-1

Cheng, M. H., & Chang, S. F. (2017). Frailty as a Risk Factor for Falls Among Community Dwelling People: Evidence From a Meta-Analysis. *Journal of Nursing Scholarship*, *49*(5), 529–536. https://doi.org/10.1111/jnu.12322

Coelho, T., Fernandes, Â., Santos, R., Paúl, C., & Fernandes, L. (2016). Quality of standing balance in community-dwelling elderly: Age-related differences in single and dual task conditions. *Archives of Gerontology and Geriatrics*, *67*, 34–39. https://doi.org/10.1016/j.archger.2016.06.010

Cuevas-Trisan, R. (2017). Balance Problems and Fall Risks in the Elderly. *Physical Medicine and Rehabilitation Clinics of North America*, *28*(4), 727–737. https://doi.org/10.1016/j.pmr.2017.06.006

Duarte, M., & Freitas, S. M. S. F. (2010). Revisão sobre posturografia baseada em plataforma de força para avaliação do equilíbrio. *Revista Brasileira de Fisioterapia*, *14*(3), 183–192. https://doi.org/10.1590/S1413-35552010000300003

Ferdjallah, M., Harris, G. F., & Wertsch, J. J. (1999). Instantaneous postural stability characterization using time-frequency analysis. *Gait and Posture*, *10*, 129–134.

Fhon, J. R. S., Rodrigues, R. A. P., Neira, W. F., Huayta, V. M. R., & Robazzi, M. L. do C. C. (2016). Fall and its association with the frailty syndrome in the elderly: systematic review with meta-analysis. *Revista Da Escola de Enfermagem Da USP*, *50*(6), 1005–1013. https://doi.org/10.1590/s0080-623420160000700018

Fried, L. P., Tangen, C. M., Walston, J., Newman, a B., Hirsch, C., Gottdiener, J., … McBurnie, M. a. (2001). Frailty in older adults: evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146–M156.

https://doi.org/10.1093/gerona/56.3.M146

Ganea, R., Paraschiv-Ionescu, A., Büla, C., Rochat, S., & Aminian, K. (2011). Multi-parametric evaluation of sit-to-stand and stand-to-sit transitions in elderly people. *Medical Engineering and Physics*, *33*(9), 1086–1093. https://doi.org/10.1016/j.medengphy.2011.04.015

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35*(SUPPL.2), 7–11. https://doi.org/10.1093/ageing/afl077

Kang, H. G., Costa, M. D., Priplata, A. a., Starobinets, O. V., Goldberger, A. L., Peng, C.-K., … Lipsitz, L. a. (2009). Frailty and the Degradation of Complex Balance Dynamics During a Dual-Task Protocol. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *64A*(12), 1304–1311. https://doi.org/10.1093/gerona/glp113

Kelso, J. A. S., Southard, D. L., & Goodman, D. (1979). On the nature of human interlimb coordination. *Science*, *203*(4384), 1029–1031. https://doi.org/10.1126/science.424729

Lajoie, Y., Richer, N., Jehu, D. A., & Tran, Y. (2016). Continuous Cognitive Tasks Improve Postural Control Compared to Discrete Cognitive Tasks. *Journal of Motor Behavior*, *48*(3), 264–269. https://doi.org/10.1080/00222895.2015.1089833

Manor, B., Costa, M. D., Hu, K., Newton, E., Starobinets, O., Kang, H. G., … Lipsitz, L. A. (2010). Physiological complexity and system adaptability: evidence from postural control dynamics of older adults. *Journal of Applied Physiology*, *109*(6), 1786–1791. https://doi.org/10.1152/japplphysiol.00390.2010

Morley, J. E., Vellas, B., Abellan van Kan, G., Anker, S. D., Bauer, J. M., Bernabei, R., … Walston, J. (2013). Frailty Consensus: A Call to Action. *Journal of the American Medical Directors Association*, *14*(6), 392–397. https://doi.org/10.1016/j.jamda.2013.03.022

Negahban, H., Sanjari, M. A., Karimi, M., & Parnianpour, M. (2016a). Complexity and variability of the center of pressure time series during quiet standing in patients with knee osteoarthritis. *Clinical Biomechanics*, *32*, 280–285. https://doi.org/10.1016/j.clinbiomech.2015.10.011

Negahban, H., Sanjari, M. A., Karimi, M., & Parnianpour, M. (2016b). Complexity and variability of the center of pressure time series during quiet standing in patients with knee osteoarthritis. *Clinical Biomechanics*, *32*, 280–285. https://doi.org/10.1016/j.clinbiomech.2015.10.011

Parvaneh, S., Mohler, J., Toosizadeh, N., Grewal, G. S., & Najafi, B. (2017). Postural Transitions during Activities of Daily Living Could Identify Frailty Status: Application of Wearable Technology to Identify Frailty during Unsupervised Condition. *Gerontology*, *63*(5), 479–487. https://doi.org/10.1159/000460292

Polskaia, N., Richer, N., Dionne, E., & Lajoie, Y. (2015). Continues cognitive task promotes greater postural stability than in internal or external focus of attention. *Gait & Posture*, *41*(2), 454–458. https://doi.org/10.1016/J.GAITPOST.2014.11.009

Potvin-desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait & Posture*. https://doi.org/10.1016/j.gaitpost.2017.05.019

Potvin-Desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait and Posture*, *57*, 40–45. https://doi.org/10.1016/j.gaitpost.2017.05.019

Roerdink, M., De Haart, M., Daffertshofer, A., Donker, S. F., Geurts, A. C. H., & Beek, P. J. (2006). Dynamical structure of center-of-pressure trajectories in patients recovering from stroke. *Experimental Brain Research*, *174*(2), 256–269. https://doi.org/10.1007/s00221-006-0441-7

Sample, R. B., Jackson, K., Kinney, A. L., Diestelkamp, W. S., Reinert, S. S., & Bigelow, K. E. (2016). Manual and cognitive dual tasks contribute to fall-risk differentiation in posturography measures. *Journal of Applied Biomechanics*, *32*(6), 541–547. https://doi.org/10.1123/jab.2016-0038

Souza, A., Augusto, C., Nery, D. S., Helena, L., Camargo, S., & José, A. (2005). Avaliação da neuropatia periférica : correlação entre a sensibilidade cutânea dos pés , achados clínicos e eletroneuromiográficos. *Acta Fisiatr*, *12*(3), 87–93.

Swanenburg, J., De Bruin, E. D., Uebelhart, D., & Mulder, T. (2009). Compromising postural balance in the elderly. *Gerontology*, *55*(3), 353–360. https://doi.org/10.1159/000212757

Tallon, G., Blain, H., Seigle, B., Bernard, P. L., & Ramdani, S. (2013). Dynamical and stabilometric measures are complementary for the characterization of postural fluctuations in older women. *Gait and Posture*, *38*(1), 92–96. https://doi.org/10.1016/j.gaitpost.2012.10.021

Toosizadeh, N., Mohler, J., Wendel, C., & Najafi, B. (2014). Influences of frailty syndrome on open-loop and closed-loop postural control strategy. *Gerontology*, *61*(1), 51–60. https://doi.org/10.1159/000362549

Vaillancourt, D. E., & Newell, K. M. (2002). Changing complexity in human behavior and physiology through aging and disease. *Neurobiol.Aging*, *23*(0197–4580 (Print)), 1–11.

Vassimon-Barroso, V., Catai, A. M., Buto, M. S. D. S., Porta, A., & Takahashi, A. C. D. M. (2017). Linear and nonlinear analysis of postural control in frailty syndrome. *Brazilian Journal of Physical Therapy*, *21*(3), 184–191. https://doi.org/10.1016/j.bjpt.2017.03.015

Wayne, P. M., Manor, B., Novak, V., Costa, M. D., Hausdorff, J. M., Goldberger, A. L., … Lipsitz, L. A. (2013). A systems biology approach to studying Tai Chi, physiological complexity and healthy aging: design and rationale of a pragmatic randomized controlled trial. *Contemporary Clinical Trials*, *34*(1), 21–34. https://doi.org/10.1016/j.cct.2012.09.006

World Health Organization. (2017). Retrieved from http://www.who.int/mediacentre/factsheets/fs344/en/

Zhou, J., Manor, B., Liu, D., Hu, K., Zhang, J., & Fang, J. (2013). The Complexity of Standing Postural Control in Older Adults: A Modified Detrended Fluctuation Analysis Based upon the Empirical Mode Decomposition Algorithm. *PLoS ONE*, *8*(5). https://doi.org/10.1371/journal.pone.0062585

3. ESTUDO II

(Versão em inglês submetida à revista Journal of Aging and Physical Activity)

EFFECT OF MULTICOMPONENT TRAINING IN POSTURAL OSCILLATION COMPLEXITY IN PREFRAIL OLDER ADULTS

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ABSTRACT

The purpose of this study was to investigate the effects of a multicomponent training on prefrail (PF-MulTI) postural oscillation complexity. Twenty-five prefrail older adults were randomly assigned to an intervention group (IG; n=16) and a control group (CG; n=9). The IG performed PF-MulTI over 16 weeks. Postural control was assessed with eyes open (EO) and eyes closed (EC) conditions. Sample entropy and traditional measures of center of pressure displacements (CoP) (amplitude, root-mean-square and total mean speed) were calculated to anteroposterior (AP) and mediolateral (ML) direction. Clinical data such as Short-Physical Performance Battery (SPPB), Timed Up and Go test (TUG), Walking Speed (WS) and 5 times Sit-to-Stand Test (SS) were also evaluated. Only IG presents an improvement in WS and sample entropy in EC condition to AP direction.

KEYWORDS: Frailty; postural control; entropy; exercise.

3.1 INTRODUCTION

Frailty syndrome has been associated with high risk for adverse health care outcomes, such as worsening chronic illnesses, mortality, falls, functional decline and disability (Fried et al., 2001; Walston, 2016). It is known that older adults can transit to a worse status of frailty when preventive measures are not implemented (Gill et al., 2006). Thus, detecting prefrail older adults may present an opportunity to introduce effective management to improve outcomes. (Sacha et al., 2017)

Among the intervention options to improve gait, balance, functional mobility, fear of falling, falls, and frailty in prefrail older adults, different modalities of exercises have been studied (Arantes et al., 2015; Ng et al., 2015; Tsang & Hui-Chan, 2003). Some systematic reviews point out the multicomponent exercises as being the most appropriate for prefrail, with positive results on frailty status, cognition, muscle mass, strength and power, functional and social outcomes (Dedeyne et al., 2017; Jadczak, Makwana, Luscombe-Marsh, Visvanathan, & Schultz, 2018). In addition, it has been reported that this exercise modality improves balance and consequently the rate of falls (Cadore & Rodrı, 2013; Daniels, van Rossum, de Witte, Kempen, & van den Heuvel, 2008). Once falls are considered one of the adverse outcomes of frailty syndrome (Fried et al., 2001), it becomes important to evaluate the postural control of prefrail older adults under this type of training.

The studies integrating balance and prefrail older adults generally reports the assessment of CoP displacements through the traditional measurements (Biggan et al., 2014; Toosizadeh et al., 2014). Nevertheless, recent works have described the importance of other tools, such as the nonlinear measures, to quantify the complexity and to complement the traditional assessment of balance (Tallon et al., 2013). It is worth noting that this type of analysis would be interesting in the approach to the frailty syndrome, since it would be characterized by a loss of physiological complexity. This change in complexity would be responsible for adaptive responses not appropriate for stressors, resulting in reduced functional independence and adverse outcomes (L. A. Lipsitz, 2002). However, to our knowledge, the literature is scarce in showing the effects of an intervention focusing the complexity of CoP displacements in older adults (Brad Manor, Lipsitz, Wayne, Peng, & Li, 2013).

The aim of the present study was to investigate the effect of a multicomponent intervention for prefrail older adults (PF-MulTI) on complexity and traditional measures of CoP displacements in anteroposterior (AP) and mediolateral (ML) direction, with eyes open (EO) and eyes closed (EC) task, the latter being chosen as a challenging task, since the visual information is taken from the Postural Control System. In addition, this study investigated whether the improved CoP displacement measured by complexity and by traditional measures, was accompanied by improvement in clinical tests. The hypotheses of the study were: (i) PF-MulTI would improve the complexity of CoP displacement in the intervention group (IG) compared to the control group (CG) under the conditions of EO and EC; (ii) PF-MulTI enhanced the traditional variables from the IG under both conditions; (iii) the clinical measurements such as Short Physical-Performance Battery (SPPB), Timed Up and Go test (TUG), Walking speed (WS) and 5-times Seat-to-Stand Test (SS) of IG would be improved by PF-MulTI.

3.2 METHODS

3.2.1 Study Design

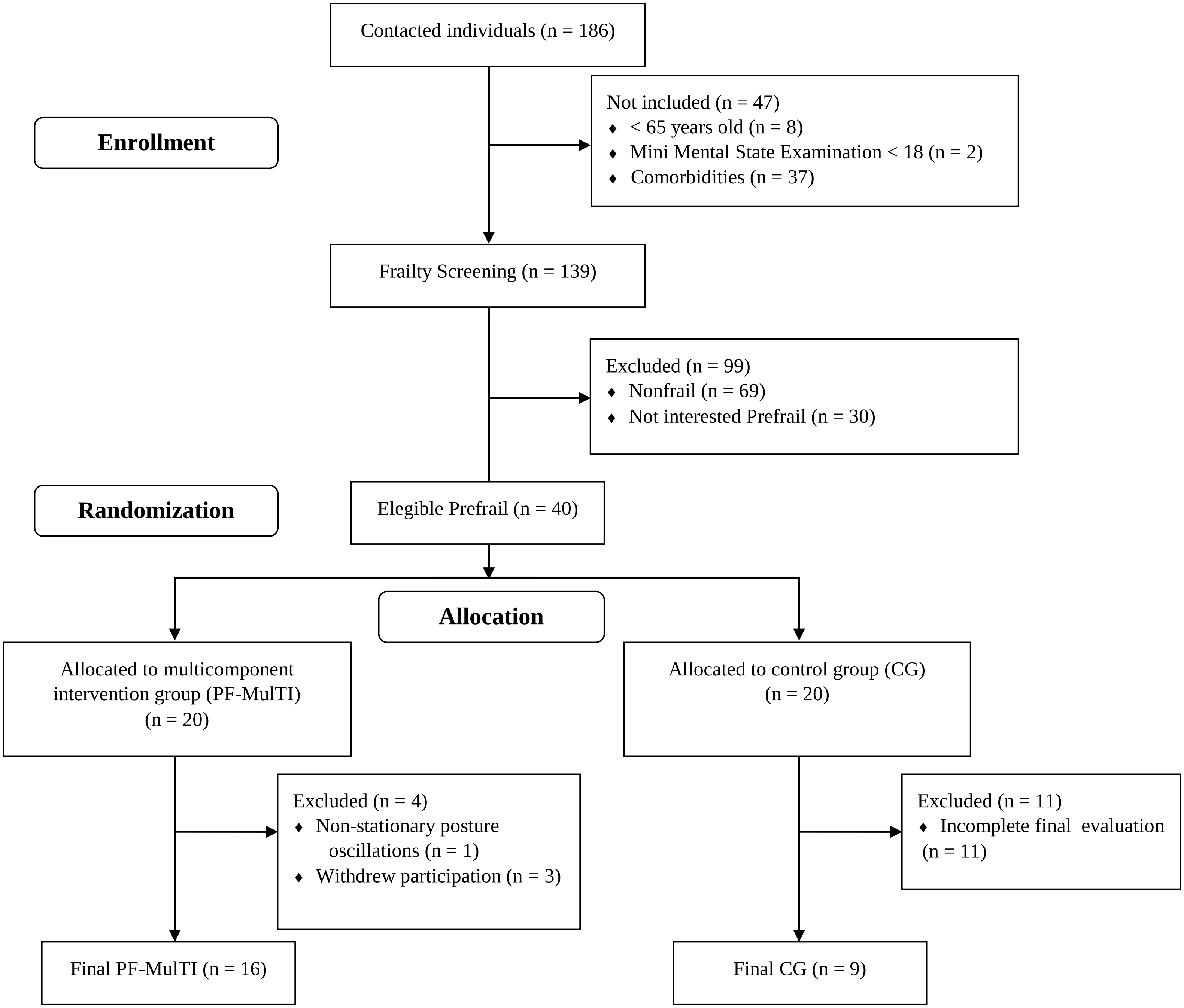
This was a blinded randomized controlled trial properly registered (Clinical Trial Registration ID: xxxxxxxxxxx), approved by the Research Ethics Committee of the institution (x.xxx.xxx). The assessment of CoP displacements was performed in pre and post-intervention. After the initial assessments, the older adults were randomly distributed into blocks of eight subjects by a separate researcher using the Random Allocation software. According to the sequence generated by block randomization, each participant corresponded to a sealed and opaque envelope, and was allocated to the IG or CG. The researchers were blinded about the allocation of the participants. The IG started training one week after the end of the initial assessments while the CG was instructed not to interrupt any type of exercise they may already practice (Bleijenberg et al., 2012). If the intervention program would be effective for the IG, the CG would also be invited to participate. The training protocol was conducted by two appropriately trained physiotherapists, and the assessment of postural control was conducted by another researcher.

3.2.2 Participants

The initial sample included forty older adults of both sexes classified previously as prefrail screened according to the frailty phenotype (Fried et al., 2001). The inclusion criteria were age 65 years or older, ability to understand the instructions, medical release for exercise and agreement to participate in the study by signing the informed consent form. The non-inclusion criteria were (a) had a history of stroke with loss of strength and aphasia (B. Manor et al., 2010); (b) had a severe motor impairment; (c) had Parkinson's disease; (d) presence of peripheral neuropathy (Wayne et al., 2013) assessed by Semmes-Weinstein monofilaments 5.07 (10 g) (Souza et al., 2005); (e) had visual disorders; (f) had vestibular problems; (g) presence of cognitive impairment with scores ≤18 in the Mini-Mental State Examination (MMSE) (Fried et al., 2001).

The exclusion criteria were: (i) withdrawal from the program; (ii) not complete the final evaluations; (iii) non-stationary signal. Figure 1 shows the flowchart containing the steps included in the process from the initial recruitment of the participants (n = 186) to the final study sample (n = 25).

Figure 1: Flowchart of the final sample



3.2.3 Exercise Program

The PF-MulTI was designed following the recommendations of the American College of Sports Medicine (ACSM) (Chodzko-Zajko et al., 2009), combining aerobic, balance exercises, muscular strengthening, cool down; flexibility. A 16-week training protocol was performed, carried out on three alternate days, with 60-minute sessions of duration.

In the week before the beginning of training, three sessions were performed with a 48-hour interval between each session, in order to familiarize the participants with the exercises and determine the muscular strengthening load. For each exercise, the participants performed a set of eight repetitions without additional weight and reported his/her level of effort according to the Borg CR-10 scale (Borg, 1998). Then, participants were asked about the effort rate of the muscles involved in the exercise; if this value was between 5 and 8 on the Borg CR-10 scale, the repetitions and load would be maintained in the first two weeks of the muscle strengthening exercises. If it was below 5, the number of repetitions was progressively increased to 12 (Giné-Garriga M, Roqué-Fíguls M, Coll-Planas L, Sitjà-Rabert M, 2014). This procedure was performed for the following muscular strengthening exercises: sit to stand from the chair, strengthening exercises for the upper limbs, calf exercises, lunges, step up and step down. Halters and a special waistcoat (vest) with large pockets (where ankle weights could be inserted) were used to facilitate the exercise execution and load increase. The duration of this component was 15 minutes.

For aerobic component (20 minutes), the intensity of the exercises corresponded to a training heart rate (THR) calculated from the resting HR with an increase of 45-80% of the heart rate reserve (HRR). The training started at 45% HRR in the first two weeks and increased by 5% every two weeks until reaching 80% HRR (Pollock et al., 2011). Participants used a cardiac frequency monitor (Polar Polar® S810i) during walking on the ground or on the treadmill.

The balance component (10 minutes) had the progression concerning the support base, in the following order: bipodal, semi-tandem, and tandem associated with visual disturbance (visual conflict glasses, closed eyes), different surfaces (rigid and foam), changes in the direction and speed, and overload of muscular groups involved in the posture (walking on tiptoe, heel) (Chodzko-Zajko et al., 2009).

Finally, related to flexibility (5 minutes), the exercises were applied separately for global muscles groups during 30s to 60s.

3.2.4 Clinical Data

To assess clinical data, Short Physical Performance Battery (SPPB) (Guralnik et al., 1994), Timed Up and Go test (TUG) (Podsiadlo & Richardson, 1991), Walking speed (WS) (Fritz & Lusardi, 2009) and 5 times Sit-to-stand test (SS) (Csuka & McCarty, 1985) were used. SPPB is composed of the static balance, gait speed, and muscular strength of the lower limbs. The score for each test corresponds to a scale between zero (worst performance) and four (best performance) and total score is 12.

To assess mobility, the time taken to complete TUG test was measured. Older adults had to rise from a standard armchair, walk 3 meters at a normal and safe pace, turn around, walk back to the chair, and sit down again.

To evaluate WS, the mean of three trials was on usual speed required to walk through 4.6 meters was registered.

3.2.5 Postural Control Assessment

The CoP displacements in AP and ML directions were collected with a sampling rate of 1000 Hz on a force platform (BERTEC Corporation - USA, model 4060-08). The order of execution was randomized between EO and EC tasks. Three valid trials were performed for each task with approximately one-minute rest interval.

Participants performed the tests barefoot and with their feet side-by-side and parallel at pelvis width. In the EO condition older adults were instructed to keep their eyes fixed to a 1-meter target ahead and with height approximately equal to the participant's eyes (Duarte & Freitas, 2010). Older adults were to maintain the orthostatic posture for 40 seconds in both EO and EC tasks.

3.2.6 Data analysis

The time series of the data used for the CoP analysis were 30s both for EO and EC tasks. To obtain these segments and to calculate variables, MATLAB (version 7.6.0.324, MathWorks Inc., Natick, MA, USA) was used. After obtaining segments, CoP displacements signal were filtered with a fourth-order Butterworth filter with cutoff frequency of 10 Hz (Vassimon-Barroso et al., 2017). The signal was resampled from 1000 to 20 Hz for complexity analysis, resulting in 600-point sections, in order to reduce redundancy while preserving the essential information of the signal. The choice among three attempts was based on the stationarity of the signal, which is a premise for the calculation of entropy (Ferdjallah et al., 1999).

3.2.7 Traditional and Complexity analysis

Regarding to the traditional analysis, amplitude, root mean square (RMS), and total mean velocity (TMS) of CoP displacements were calculated (Swanenburg, de Bruin, Uebelhart, & Mulder, 2010). Complexity measurements such as entropy reflect temporal information of the organization, sequencing and regularity of CoP displacements (Borg & Laxåback, 2010). Larger entropy corresponds to less regularity and therefore, greater complexity. In this study, Sample Entropy (SampEn) was used to the complexity analysis (Richman & Moorman, 2000). The parameters were computed with $m = 2$, $r = 0.2$ times the standard deviation of the signal, and $N = 600$ (Vassimon-Barroso et al., 2017).

3.2.8 Statistical Analysis

The Shapiro-Wilk test was used to verify the normality of data distribution. The independent t-test or Mann-Whitney test were used to compare the characteristics of participants (age, sex, body mass, stature, BMI) in pre-intervention. The two-way mixed within-between subject's analysis of variance was used to test the differences within (baseline vs. post 16-week) and between (PF-MulTI vs control) groups for complexity and traditional CoP measurements and for clinical data (SPPB, TUG, WS, SS). Where appropriate, multiple comparisons were performed using the Holm-Sidak test. The magnitude of the effect of PF-MulTI on investigated variables was assessed through the effect size (ES). The partial eta-squared (η^2_p) was used to estimate the effect size. The η^2_p of 0.01, 0.06, and 0.14 and over represented small, medium, and large effect sizes, respectively (Lakens, 2013). The significance level for tests was 5% and the statistical analysis was performed in SigmaPlot 11.0 (Systat Software, San Jose, CA, USA).

3.3 RESULTS

The anthropometrics data are shown in Table 1. There were no significant differences between IG and CG.

Table 1: Anthropometrics data for the IG and CG.

Variables	IG	CG	P Value
Age	76.43±6.48	72.55±5.07	0.13
Body mass (Kg)	76.17±11.35	67.51±13.39	0.09
Stature(m)	1.55±0.06	1.54±0.07	0.59
BMI(kg/m²)	31.57±4.94	28.63±6.56	0.21

BMI: body mass index

The condition of EO showed no main effects of groups and moments and neither an interaction between them for complexity and traditional analysis. (Table 2).

Table 2: Complexity and Traditional analysis of CoP displacements between IG and CG for EO.

Variables	IG		CG		p Value			Effect Size
	Pre	Post	Pre	Post	Groups	Moments	Interaction	
Complexity								
SampEn_AP	0.67±0.12	0.66±0.09	0.65±0.12	0.65±0.08	0.63	0.80	0.80	0.00
SampEN_ML	0.72±0.16	0.74±0.17	0.70±0.22	0.79±0.16	0.82	0.17	0.34	0.03
Traditional								
RMS_AP(mm)	3.30±1.23	3.48±1.56	3.35±0.81	3.77±1.12	0.73	0.13	0.55	0.01
RMS_ML(mm)	1.54±1.05	1.63±0.82	1.42±0.57	1.44±0.5	0.57	0.80	0.86	0.00
Ampl_AP(mm)	17.55±9.46	17.69±7.06	16.59±5.27	17.59±5.24	0.85	0.68	0.75	0.00
Ampl_ML(mm)	7.86±4.23	8.35±4.94	7.80±4.69	6.84±2.6	0.57	0.84	0.54	0.02
TMS (mm/s)	7.64±2.57	7.90±2.97	7.50±1.55	7.97±2.25	0.97	0.32	0.78	0.00

SampEn_AP: sample entropy in the anteroposterior direction; SampEn_ML: sample entropy in the mediolateral direction; RMS_AP: root mean square in the anteroposterior direction; RMS_ML root mean square in the mediolateral direction; Ampl_AP: amplitude in the anteroposterior direction; Ampl_ML: amplitude in the mediolateral direction; TMS: total mean speed.

Regarding the EC task, there was an interaction in sample entropy in AP direction, demonstrating a greater value in post compared to pre-intervention for the IG ($p<0.001$). There was a positive and large effect of PF-MulTI for this variable ($\eta^2_p = 0.26$). There was also a positive and large effect for amplitude in the AP direction ($\eta^2_p = 0.13$).The sample entropy in ML direction was greater in post intervention regardless of groups ($p=0.03$). Traditional variables showed no change after the intervention. (Table 3).

Table 3: Complexity and Traditional analysis of CoP displacements between IG and CG for EC

Variables	**IG**		**CG**		**p Value**			**Effect**
	Pre	**Post**	**Pre**	**Post**	**Groups**	**Moments**	**Interaction**	**Size**
Complexity								
SampEn_AP	0.71 ±0.11	0.81±0.12*	0.77 ±0.14	0.73±0.08	0.81	0.13	**0.00**	0.26
SampEn_ML	0.73 ±0.11	0.82 ±0.19	0.77 ±0.15	0.83 ±0.12	0.61	**0.04**	0.59	0.02
Traditional								
RMS_AP(mm)	4.31 ±1.31	3.98 ±1.40	3.73 ±1.20	3.79±1.12	0.44	0.52	0.36	0.04
RMS_ML(mm)	1.59 ±1.00	1.17 ±0.44	1.30 ±0.76	1.19±0.77	0.63	0.08	0.32	0.04
Ampl_AP(mm)	23.59 ±8.15	19.94 ±8.10	18.76 ±5.59	20.09±5.90	0.41	0.39	0.07	0.13
Ampl_ML(mm)	7.97 ±4.18	6.42 ±2.38	6.89 ±3.64	6.09 ±3.77	0.60	0.08	0.57	0.01
TMS(mm/s)	11.73 ±4.80	12.12 ±5.13	10.46 ±3.49	10.59 ±3.42	0.42	0.73	0.86	0.00

SampEn_AP: sample entropy in the anteroposterior direction; SampEn_ML: sample entropy in the mediolateral direction; RMS_AP: root mean square in the anteroposterior direction; RMS_ML root mean square in the mediolateral direction; Ampl_AP: amplitude in the anteroposterior direction; Ampl_ML: amplitude in the mediolateral direction; TMS: total mean speed; * p<0.001: Pre vs Post in IG.

Table 4 shows clinical data in both IG and CG and in pre and post intervention. An interaction only for WS was observed ($p=0.02$). There was an increase in post compared to pre intervention in IG ($p<0.001$). In addition, there was a positive and large effect of PF-MulTI for WS ($\eta^2_p = 0.19$).

Table 4: Clinical data for IG and CG

Variables	**IG**		**CG**		**p Value**			**Effect Size**
	Pre	**Post**	**Pre**	**Post**	**Groups**	**Moments**	**Interaction**	
SPPB	8.19±1.68	8.56±1.9	8.44±1.81	9.11±1.83	0.57	0.07	0.60	0.01
TUG (s)	14.92±5.15	14.12±4.25	12.9±2.22	12.28±2.33	0.24	0.14	0.84	0.00
WS (m/s)	0.82±0.25	0.97±0.19[*]	0.91±0.21	0.91±0.21	0.86	**0.03**	**0.02**	0.19
SS (s)	18.67±6.13	16.78±3.70	16.77±2.51	17.17±3.42	0.66	0.36	0.16	0.08

IG: Intervention Group; CG: Control Group; SPPB: Short Physical Performance Battery; TUG: Timed Up and Go; GS: Gait Speed; SS: Sit-to-Stand; [*] p<0.001: Pre vs Post in IG.

Moreover, PF-MulTI was effective when related to the frailty status. All the participants of IG became nonfrail after intervention, whereas only around 22% of CG prefrail older adults became nonfrail, around 67% remained prefrail and 11% became frail.

3.4 DISCUSSION

The main finds of this study were that PF-MulTI improved complexity of CoP displacements of IG in AP direction in EC task. Besides that, in ML direction the complexity of CoP was greater in post-intervention regardless of groups. There was also an enhance in the WS only in IG after treatment.

In the EO condition, the traditional and complexity measurements of CoP displacements remained the same as in pre-intervention moment. It was expected that multicomponent training would improve balance data. Balance control is assumed to consist of a set of reflexes that triggered equilibrium responses based on visual, vestibular or somatosensory systems (Horak, 2006) and numerous brain regions and the musculo-skeletal system (B. Manor et al., 2010). Biological aging and diseases, such as frailty, are believed to contribute to reduced feedback from these systems, which would lead to loss of physiological complexity (L. A. Lipsitz, 2002; Lewis A. Lipsitz, 2004; Lewis A. Lipsitz & Goldberger, 1992). Thus, the organism would be unable to mount a focused adaptive response in order to perform a specific task (Lewis A. Lipsitz, 2004).

As described in the literature, it was hypothesized that interventions could restore healthy dynamics in biological systems including the multisystem interventions that have effect on multiple systems (L. A. Lipsitz, 2002). It is suggested that the absence of a significant change in the EO condition may be due to the fact that prefrail older adults already exhibit adequate responses under conditions that are not challenging. Thus, the older adults would not have a deficit to be improved, and therefore the complexity did not change. Regarding linear measurements in EO condition our results are in accordance with a study that reported no changes in balance of older adults measured by traditional variables after a Tai-Chi intervention (Tsang & Hui-Chan, 2003).

The exact physiological pathways through which sensory deficits are associated with postural control are unknown (B. Manor et al., 2010). However, it is suggested that the complexity of CoP displacement can be altered by three different ways: by reducing the interaction between subsystems of posture control; by removing one of the subsystems (as in the case of visual input); by adding a new factor (as vibration platform) (Vaillancourt & Newell, 2002). Data from a previous study showed that the complexity of the postural control of the older adults was reduced when there was a visual impairment (B. Manor et al., 2010).

Still, there are few studies that investigated the meaning of a training on postural control under conditions of alteration of the sensory system (Brad Manor et al., 2013). The authors found a greater complexity of postural control in older adults with peripheral neuropathy after training with Tai-Chi (Brad Manor et al., 2013), corroborating our data, which SampEn was improved after training in EC condition. This occurrence could indicate that even in the absence of an important visual information, the training possibly leads to a greater interaction between the remaining systems in the challenging condition. This fact caused to a greater entropy value in the trained group, making it possibly more adapted in a stressful situation (as in the absence of information of a system).

Still, a previous work described that some analyses revealed that complexity measures were more sensitive to differences between groups, especially those that are more homogeneous (exercise vs control group, fallers and nonfallers) while the traditional measures were only able to discriminate heterogeneous groups (older adults vs young) (Montesinos, Castaldo, & Pecchia, 2018). Also, another study described no changes in traditional measures with eyes closed after a Tai-Chi intervention in older adults with periphery neuropathy (Brad Manor et al., 2013). Similar results were observed in this study, only sample entropy was modified after intervention. Considering the absence of training impact in traditional measures, it is suggested that a qualitative reorganization of postural control subsystems occurs prior to changes in the traditional variables. Furthermore, it seems that tools derived from complex systems biology that capture the characteristics of integrated, multi-scale control (i.e., physiologic complexity) may be better suited to study human behavior in health and disease, and to evaluate the physiological impact of interventions (Brad Manor et al., 2013)

Therefore, with eyes closed, the magnitude effects of PF-MulTI in the CoP complexity and amplitude in AP direction, had a positive and large effect in the present results. Manor et al. 2013 presented no changes related to traditional metrics corroborating our data. However, the authors reported no effect size, because their study was a non-controlled trial (Brad Manor et al., 2013).

Besides, still related to EC task, complexity of CoP presented an increase in post intervention assessment regardless of the groups in ML direction. It is possible that the treatment had a positive impact in IG, as well as in CG, since this group possibly had their complexity enhanced even without receiving any type of intervention. We could justify these findings basing that spontaneous transitions occur between different frailty status. Although the most common are to the most frail stages, transitions between prefrail and nonfrail status occur around 35% (Gill et al., 2006). In this sense, the amount of 22% of CG older adults that became nonfrail, may have strongly influenced the complexity improvement of this group in post intervention.

It is also important to analyze the effect of training on functional measures, since adding its evaluation may be a proactive strategy in enhancing the effectiveness of regular older adults health examination and health promotion (Li et al., 2017). Although a previous study reported an improvement in TUG, WS, SPPB and strength after a multicomponent intervention (Li et al., 2017), these improvements were seen with frail older adults. In the present data, involving only prefrail, there was an improvement in WS. Some authors have described the feasibility of WS test and consider that even when assessed in shorter distances it could ponder the "six vital sign" given the relevant functional perspective to the health status provided by the system-level vital signs (Fritz & Lusardi, 2009). Furthermore, there was a positive and large effect only WS in favor of IG, demonstrating the relevant clinical effectiveness of PF-Multi to prefrail older adults, and corroborating previous results only related to WS (Arantes et al., 2015). The difference between our results and the authors could be the modality training focused on balance. The authors trained two times per week, for one hour and for twelve weeks, but only applying balance exercises (Arantes et al., 2015). In the balance training probably there were different mechanisms underlying multicomponent training that lead to the improvements in clinical measures.

Regarding the direction of changes in complexity, we expected that changes would occur in both AP and ML directions. However, it was demonstrated that PF-MulTI had an effect only in AP direction. The changes in ML direction occurred regardless of the groups. Our previous results showed that prefrail older adults changed their complexity after a functional transition of rising from a chair, only in AP direction (Vassimon-Barroso et al., 2017), corroborating the present findings and suggesting that PF-MulTI was more effective in this direction. The improvement of CoP complexity in ML direction regardless of training may be due to the greater activation of lower limbs muscles that contributed to the postural stabilization in the absence of vision, especially in the CG (Toosizadeh et al., 2014).

The present study showed some limitations. First, there was a considered sample loss. The participants dropped out of the program because of the difficulty in moving to the intervention site. Other older adults did not complete the final evaluations, especially those of CG. Perhaps if the design of the study provided some kind of accompaniment of the CG older adults, there would not be so many withdrawals. Finally, larger scale controlled trials would be necessary to validate the results presented in this study.

3.5 CONCLUSIONS

The results of present study allow us to conclude that multicomponent training improves integration of systems that control balance of prefrail older adults, especially in more challenging conditions, such as with eyes closed.

Thus, it is recommended that measures of CoP displacements complexity may be relevant in assessing balance, showing more sensitivity than measures traditionally used.

In addition, multicomponent training improved walking speed suggesting that the evaluation of this measure in clinical practice should be explored as a means of assessing treatments efficacy in prefrail older adults.

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Conflict of Interest: The authors declared no conflict of interest.

Author contributions: Vassimon-Barroso, V.: study concept and design; acquisition of participants; analysis and interpretation of data; preparation of manuscript. Giusti, P.R..: study concept and design; preparation of manuscript. Buto, M. S. S.: acquisition of participants; preparation of manuscript. Fiogbè, E..: study concept and design; data analysis; preparation of manuscript. Carnavale, B. F.: study concept and design; data analysis; preparation of manuscript. Farche, A.C.S.: study concept and design; data analysis; preparation of manuscript. Takahashi, A.C.M.: study concept and design; analysis and interpretation of data; preparation of manuscript. I thank the scholarship provided to me by CAPES.

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3.7 REFERENCES

Akram, S. B., & McIlroy, W. E. (2011). Challenging horizontal movement of the body during sit-to-stand: Impact on stability in the young and elderly. *Journal of Motor Behavior*, *43*(2), 147–153. https://doi.org/10.1080/00222895.2011.552077

Alencar, M. A., Arantes, P. M. M., Dias, J. M. D., Kirkwood, R. N., Pereira, L. S. M., & Dias, R. C. (2007). Muscular function and functional mobility of faller and non-faller elderly women with osteoarthritis of the knee. *Brazilian Journal of Medical and Biological Research*, *40*(2), 277–283. https://doi.org/10.1590/S0100-879X2007000200016

Arantes, P. M. M., Dias, J. M. D., Fonseca, F. F., Oliveira, A. M. B., Oliveira, M. C., Pereira, L. S. M., & Dias, R. C. (2015). Effect of a Program Based on Balance Exercises on Gait, Functional Mobility, Fear of Falling, and Falls in Prefrail Older Women: A Randomized Clinical Trial. *Topics in Geriatric Rehabilitation*, *31*(2), 113–120. https://doi.org/10.1097/TGR.0000000000000056

Biggan, J. R., Melton, F., Horvat, M. A., Ricard, M., Keller, D., & Ray, C. T. (2014). Increased load computerized dynamic posturography in prefrail and nonfrail community-dwelling older adults. *Journal of Aging and Physical Activity*, *22*(1), 96–102. https://doi.org/10.1123/JAPA.2012-0209

Bleijenberg, N., Drubbel, I., ten Dam, V. H., Numans, M. E., Schuurmans, M. J., & de Wit, N. J. (2012). Proactive and integrated primary care for frail older people: Design and methodological challenges of the Utrecht Primary care PROactive Frailty Intervention Trial (U-PROFIT). *BMC Geriatrics*, *12*(1), 16. https://doi.org/10.1186/1471-2318-12-16

Borg. (1998). Perceived Exertion and Pain Scales, (August).

Borg, F. G., & Laxåback, G. (2010). Entropy of balance--some recent results. *Journal of Neuroengineering and Rehabilitation*, *7*, 38. https://doi.org/10.1186/1743-0003-7-38

Cadore, E. L., & Rodrı, L. (2013). Effects of Different Exercise Interventions on Risk of Falls , Gait Ability , and Balance in Physically Frail Older Adults : A Systematic Review, *16*(2). https://doi.org/10.1089/rej.2012.1397

Cavanaugh, J. T., Mercer, V. S., & Stergiou, N. (2007). Approximate entropy detects the effect of a secondary cognitive task on postural control in healthy young adults: a methodological report. *Journal of Neuroengineering and Rehabilitation*, *4*, 42. https://doi.org/10.1186/1743-0003-4-42

Chagdes, J. R., Rietdyk, S., Haddad, J. M., Zelaznik, H. N., Raman, A., Rhea, C. K., & Silver, T. A. (2009). Multiple timescales in postural dynamics associated with vision and a secondary task are revealed by wavelet analysis. *Experimental Brain Research*, *197*(3), 297–310. https://doi.org/10.1007/s00221-009-1915-1

Cheng, P. Liaw, M. Wong, M. Tang, F. (1998). No Titlehe Sit-to-Stand Movement in Stroke Patients. *Archives of Physical Medicine and Rehabilitation*, *79*, 1043–1046.

Cheng, M. H., & Chang, S. F. (2017). Frailty as a Risk Factor for Falls Among Community Dwelling People: Evidence From a Meta-Analysis. *Journal of Nursing Scholarship*, *49*(5), 529–536. https://doi.org/10.1111/jnu.12322

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, *41*(7), 1510–1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *The Lancet*, *381*(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Coelho, T., Fernandes, Â., Santos, R., Paúl, C., & Fernandes, L. (2016). Quality of standing balance in community-dwelling elderly: Age-related differences in single and dual task conditions. *Archives of Gerontology and Geriatrics*, *67*, 34–39. https://doi.org/10.1016/j.archger.2016.06.010

Csuka, M., & McCarty, D. J. (1985). Simple method for measurement of lower extremity muscle strength. *The American Journal of Medicine*, *78*(1), 77–81. https://doi.org/10.1016/0002-9343(85)90465-6

Cuevas-Trisan, R. (2017). Balance Problems and Fall Risks in the Elderly. *Physical Medicine and Rehabilitation Clinics of North America*, *28*(4), 727–737. https://doi.org/10.1016/j.pmr.2017.06.006

Daniels, R., van Rossum, E., de Witte, L., Kempen, G. I. J. M., & van den Heuvel, W. (2008). Interventions to prevent disability in frail community-dwelling elderly: a systematic review. *BMC Health Services Research*, *8*, 278. https://doi.org/10.1186/1472-6963-8-278

Dedeyne, L., Deschodt, M., Verschueren, S., Tournoy, J., & Gielen, E. (2017). Effects of multi-domain interventions in (pre)frail elderly on frailty, functional, and cognitive status: A systematic review. *Clinical Interventions in Aging*, *12*, 873–896. https://doi.org/10.2147/CIA.S130794

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research*, *181*(1), 1–11. https://doi.org/10.1007/s00221-007-0905-4

Duarte, M., & Freitas, S. M. S. F. (2010). Revisão sobre posturografia baseada em plataforma de força para avaliação do equilíbrio. *Revista Brasileira de Fisioterapia*, *14*(3), 183–192. https://doi.org/10.1590/S1413-35552010000300003

Ferdjallah, M., Harris, G. F., & Wertsch, J. J. (1999). Instantaneous postural stability characterization using time-frequency analysis. *Gait and Posture*, *10*, 129–134.

Fhon, J. R. S., Rodrigues, R. A. P., Neira, W. F., Huayta, V. M. R., & Robazzi, M. L. do C. C.

(2016). Fall and its association with the frailty syndrome in the elderly: systematic review with meta-analysis. *Revista Da Escola de Enfermagem Da USP*, *50*(6), 1005–1013. https://doi.org/10.1590/s0080-623420160000700018

Fhon, J. R. S., Rosset, I., Freitas, C. P., Silva, A. O., Santos, J. L. F., & Rodrigues, R. A. P. (2013). Prevalencia de quedas de idosos em situacao de fragilidade. *Revista de Saúde Pública*, *47*(2), 266–273. https://doi.org/10.1590/S0034-8910.2013047003468

Fried, L. P., Tangen, C. M., Walston, J., Newman, a B., Hirsch, C., Gottdiener, J., … McBurnie, M. a. (2001). Frailty in older adults: evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146–M156. https://doi.org/10.1093/gerona/56.3.M146

Fritz, S., & Lusardi, M. (2009). White Paper: “Walking Speed: the Sixth Vital Sign.” *Journal of Geriatric Physical Therapy*, *32*(2), 2–5. https://doi.org/10.1519/00139143-200932020-00002

Ganea, R., Paraschiv-Ionescu, A., Büla, C., Rochat, S., & Aminian, K. (2011). Multi-parametric evaluation of sit-to-stand and stand-to-sit transitions in elderly people. *Medical Engineering and Physics*, *33*(9), 1086–1093. https://doi.org/10.1016/j.medengphy.2011.04.015

Gill, T. M., Gahbauer, E. A., Allore, H. G., & Han, L. (2006). Transitions Between Frailty States Among Community-Living Older Persons. *Archives of Internal Medicine*, *166*(4), 418. https://doi.org/10.1001/archinte.166.4.418

Giné-Garriga M, Roqué-Fíguls M, Coll-Planas L, Sitjà-Rabert M, S. A. (2014). Physical Exercise Interventions for Improving Performance-Based Measures of Physical Function in Community-Dwelling , Frail Older Adults : A Systematic Review and Meta-Analysis. https://doi.org/10.1016/j.apmr.2013.11.007

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., …

Wallace, R. B. (1994). A Short Physical Performance Battery Assessing Lower Extremity Function: Association With Self-Reported Disability and Prediction of Mortality and Nursing Home Admission. *Journal of Gerontology*, *49*(2), M85–M94. https://doi.org/10.1093/geronj/49.2.M85

Hanke, T. A., Pai, Y. C., & Rogers, M. W. (1995). Reliability of measurements of body center-of-mass momentum during sit-to-stand in healthy adults. *Physical Therapy*, *75*(2), 105-13; discussion 113–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7846131

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, *35*(SUPPL.2), 7–11. https://doi.org/10.1093/ageing/afl077

Jadczak, A. D., Makwana, N., Luscombe-Marsh, N., Visvanathan, R., & Schultz, T. J. (2018). Effectiveness of exercise interventions on physical function in community-dwelling frail older people. *JBI Database of Systematic Reviews and Implementation Reports*, *16*(3), 752–775. https://doi.org/10.11124/JBISRIR-2017-003551

Kang, H. G., Costa, M. D., Priplata, A. a., Starobinets, O. V., Goldberger, A. L., Peng, C.-K., … Lipsitz, L. a. (2009). Frailty and the Degradation of Complex Balance Dynamics During a Dual-Task Protocol. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *64A*(12), 1304–1311. https://doi.org/10.1093/gerona/glp113

Kelso, J. A. S., Southard, D. L., & Goodman, D. (1979). On the nature of human interlimb coordination. *Science*, *203*(4384), 1029–1031. https://doi.org/10.1126/science.424729

Lajoie, Y., Richer, N., Jehu, D. A., & Tran, Y. (2016). Continuous Cognitive Tasks Improve Postural Control Compared to Discrete Cognitive Tasks. *Journal of Motor Behavior*, *48*(3), 264–269. https://doi.org/10.1080/00222895.2015.1089833

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*(NOV), 1–12. https://doi.org/10.3389/fpsyg.2013.00863

Lanziotti Azevedo da Silva, S., Campos Cavalcanti Maciel, Á., de Sousa Máximo Pereira, L., Domingues Dias, J. M., Guimarães de Assis, M., & Corrêa Dias, R. (2015). Transition Patterns of Frailty Syndrome in Comunity-Dwelling Elderly Individuals: A Longitudinal Study. *The Journal of Frailty & Aging, 4*(2), 50–5. https://doi.org/10.14283/jfa.2015.43

Li, C. M., Chang, C. I., Yu, W. R., Yang, W., Hsu, C. C., & Chen, C. Y. (2017). Enhancing elderly health examination effectiveness by adding physical function evaluations and interventions. *Archives of Gerontology and Geriatrics, 70*, 38–43. https://doi.org/10.1016/j.archger.2016.12.009

Lipsitz, L. A. (2002). Dynamics of Stability: The Physiologic Basis of Functional Health and Frailty. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 57*(3), B115–B125. https://doi.org/10.1093/gerona/57.3.B115

Lipsitz, L. A. (2004). Physiological complexity, aging, and the path to frailty. *Science of Aging Knowledge Environment : SAGE KE, 2004*(16), 1–6. https://doi.org/10.1126/sageke.2004.16.pe16

Lipsitz, L. A., & Goldberger, M. (1992). Loss of “Complexity” and Aging. *Jama, 267*(13), 1806. https://doi.org/10.1001/jama.1992.03480130122036

Lozano-Montoya, I., Correa-Pérez, A., Abraha, I., Soiza, R. L., Cherubini, A., O’Mahony, D., & Cruz-Jentoft, A. J. (2017). Nonpharmacological interventions to treat physical frailty and sarcopenia in older patients: A systematic overview – the SENATOR project ONTOP series. *Clinical Interventions in Aging, 12*, 721–740. https://doi.org/10.2147/CIA.S132496

Manor, B., Costa, M. D., Hu, K., Newton, E., Starobinets, O., Kang, H. G., … Lipsitz, L. A. (2010). Physiological complexity and system adaptability: evidence from postural control dynamics of older adults. *Journal of Applied Physiology*, *109*(6), 1786–1791. https://doi.org/10.1152/japplphysiol.00390.2010

Manor, B., Lipsitz, L. A., Wayne, P. M., Peng, C. K., & Li, L. (2013). Complexity-based measures inform tai chi's impact on standing postural control in older adults with peripheral neuropathy. *BMC Complementary and Alternative Medicine, 13*. https://doi.org/10.1186/1472-6882-13-87

Martínez-Ramírez, A. ., Lecumberri, P. ., Gómez, M. ., Rodriguez-Manãs, L., García, F. J., & Izquierdo, M. (2011). Frailty assessment based on wavelet analysis during quiet standing balance test. *Journal of Biomechanics*, *44*(12), 2213–2220. https://doi.org/10.1016/j.jbiomech.2011.06.007

Montesinos, L., Castaldo, R., & Pecchia, L. (2018). On the use of approximate entropy and sample entropy with centre of pressure time-series. *Journal of NeuroEngineering and Rehabilitation*, *15*(1), 116. https://doi.org/10.1186/s12984-018-0465-9

Morley, J. E., Vellas, B., Abellan van Kan, G., Anker, S. D., Bauer, J. M., Bernabei, R., … Walston, J. (2013). Frailty Consensus: A Call to Action. *Journal of the American Medical Directors Association*, *14*(6), 392–397. https://doi.org/10.1016/j.jamda.2013.03.022

Negahban, H., Sanjari, M. A., Karimi, M., & Parnianpour, M. (2016a). Complexity and variability of the center of pressure time series during quiet standing in patients with knee osteoarthritis. *Clinical Biomechanics*, *32*, 280–285. https://doi.org/10.1016/j.clinbiomech.2015.10.011

Negahban, H., Sanjari, M. A., Karimi, M., & Parnianpour, M. (2016b). Complexity and variability of the center of pressure time series during quiet standing in patients with knee osteoarthritis. *Clinical Biomechanics*, *32*, 280–285. https://doi.org/10.1016/j.clinbiomech.2015.10.011

Ng, T. P., Feng, L., Nyunt, M. S. Z., Feng, L., Niti, M., Tan, B. Y., … Yap, K. B. (2015). Nutritional, Physical, Cognitive, and Combination Interventions and Frailty Reversal among Older Adults: A Randomized Controlled Trial. *American Journal of Medicine*, *128*(11), 1225–1236. https://doi.org/10.1016/j.amjmed.2015.06.017

Parvaneh, S., Mohler, J., Toosizadeh, N., Grewal, G. S., & Najafi, B. (2017). Postural Transitions during Activities of Daily Living Could Identify Frailty Status: Application of Wearable Technology to Identify Frailty during Unsupervised Condition. *Gerontology*, *63*(5), 479–487. https://doi.org/10.1159/000460292

Podsiadlo, D., & Richardson, S. (1991). The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, *39*(2), 142–8. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x

Pollock, L, M., A, G., Butcher, Janus D, M. D., Pierre, … Ewing. (2011). ACSM Position Stand : The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness , and Flexibility in Healthy Adults. *Medicine & Science in Sport & Exercise*, *30*(6), 975–991. https://doi.org/10.1249/01.MSS.0000115224.88514.3A

Polskaia, N., Richer, N., Dionne, E., & Lajoie, Y. (2015). Continues cognitive task promotes greater postural stability than in internal or external focus of attention. *Gait & Posture*, *41*(2), 454–458. https://doi.org/10.1016/J.GAITPOST.2014.11.009

Potvin-desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait & Posture*. https://doi.org/10.1016/j.gaitpost.2017.05.019

Potvin-Desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait and Posture*, *57*, 40–45.

https://doi.org/10.1016/j.gaitpost.2017.05.019

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology-Heart and Circulatory Physiology*, *278*(6), H2039–H2049. https://doi.org/10.1111/j.1468-0084.1985.mp47002006.x

Roerdink, M., De Haart, M., Daffertshofer, A., Donker, S. F., Geurts, A. C. H., & Beek, P. J. (2006). Dynamical structure of center-of-pressure trajectories in patients recovering from stroke. *Experimental Brain Research*, *174*(2), 256–269. https://doi.org/10.1007/s00221-006-0441-7

Sacha, J., Sacha, M., Sobon, J., Borysiuk, Z., & Feusette, P. (2017). Is it time to begin a public campaign concerning frailty and pre-frailty? A review article. *Frontiers in Physiology*, *8*(JUL), 1–10. https://doi.org/10.3389/fphys.2017.00484

Sample, R. B., Jackson, K., Kinney, A. L., Diestelkamp, W. S., Reinert, S. S., & Bigelow, K. E. (2016). Manual and cognitive dual tasks contribute to fall-risk differentiation in posturography measures. *Journal of Applied Biomechanics*, *32*(6), 541–547. https://doi.org/10.1123/jab.2016-0038

Souza, A., Augusto, C., Nery, D. S., Helena, L., Camargo, S., & José, A. (2005). Avaliação da neuropatia periférica : correlação entre a sensibilidade cutânea dos pés , achados clínicos e eletroneuromiográficos. *Acta Fisiatr*, *12*(3), 87–93.

Swanenburg, J., de Bruin, E. D., Uebelhart, D., & Mulder, T. (2010). Falls prediction in elderly people: A 1-year prospective study. *Gait and Posture*, *31*(3), 317–321. https://doi.org/10.1016/j.gaitpost.2009.11.013

Swanenburg, J., De Bruin, E. D., Uebelhart, D., & Mulder, T. (2009). Compromising postural balance in the elderly. *Gerontology*, *55*(3), 353–360. https://doi.org/10.1159/000212757

Tallon, G., Blain, H., Seigle, B., Bernard, P. L., & Ramdani, S. (2013). Dynamical and stabilometric measures are complementary for the characterization of postural fluctuations in older women. *Gait and Posture*, *38*(1), 92–96. https://doi.org/10.1016/j.gaitpost.2012.10.021

The American Geriatrics Society. (2011). Summary of the updated american geriatrics society/british geriatrics society clinical practice guideline for prevention of falls in older persons. *Journal of the American Geriatrics Society*, *59*(1), 148–157. https://doi.org/10.1111/j.1532-5415.2010.03234.x

Toosizadeh, N., Mohler, J., Wendel, C., & Najafi, B. (2014). Influences of frailty syndrome on open-loop and closed-loop postural control strategy. *Gerontology*, *61*(1), 51–60. https://doi.org/10.1159/000362549

Tsang, W. W. N., & Hui-Chan, C. W. Y. (2003). Effects of Tai Chi on Joint Proprioception and Stability Limits in Elderly Subjects. *Medicine and Science in Sports and Exercise*, *35*(12), 1962–1971. https://doi.org/10.1249/01.MSS.0000099110.17311.A2

Vaillancourt, D. E., & Newell, K. M. (2002). Changing complexity in human behavior and physiology through aging and disease. *Neurobiol.Aging*, *23*(0197–4580 (Print)), 1–11.

Vassimon-Barroso, V., Catai, A. M., Buto, M. S. D. S., Porta, A., & Takahashi, A. C. D. M. (2017). Linear and nonlinear analysis of postural control in frailty syndrome. *Brazilian Journal of Physical Therapy*, *21*(3), 184–191. https://doi.org/10.1016/j.bjpt.2017.03.015

Walston, J. D. (2016). Connecting Age-Related Biological Decline to Frailty and Late- Nestle Nutr Inst W orkshop Ser Life Vulnerability. *Nutr Inst Workshop Ser*, *83*(1), 1–10. https://doi.org/10.1159/000382052.Connecting

Wayne, P. M., Manor, B., Novak, V., Costa, M. D., Hausdorff, J. M., Goldberger, A. L., … Lipsitz, L. A. (2013). A systems biology approach to studying Tai Chi, physiological complexity and healthy aging: design and rationale of a pragmatic randomized controlled trial. *Contemporary Clinical Trials*, *34*(1), 21–34. https://doi.org/10.1016/j.cct.2012.09.006

World Health Organization. (2017). Retrieved from http://www.who.int/mediacentre/factsheets/fs344/en/

Zhou, J., Manor, B., Liu, D., Hu, K., Zhang, J., & Fang, J. (2013). The Complexity of Standing Postural Control in Older Adults: A Modified Detrended Fluctuation Analysis Based upon the Empirical Mode Decomposition Algorithm. *PLoS ONE*, *8*(5). https://doi.org/10.1371/journal.pone.0062585

4. CONSIDERAÇÕES FINAIS E DESDOBRAMENTOS FUTUROS

Os estudos realizados contribuíram com informações importantes a respeito de aspectos ainda incipientes no estudo do controle postural e síndrome da fragilidade. No que diz respeito ao controle postural, dependendo do estímulo estressante utilizado, os idosos pré-frágeis apresentaram ausência de alteração na complexidade do deslocamento do CoP. Sendo assim, sugere-se que em estudos futuros, intervenções incluindo tarefas desafiadoras (privação visual, demanda cognitiva e mudança postural) devam ser testadas para se verificar se este tipo de intervenção contribuiria para a melhor resposta funcional e de complexidade das oscilações do controle postural.

Adicionalmente, destaca-se que o treinamento multicomponente melhorou a integração dos sistemas que controlam o balance de pré-frágeis, especialmente em condições mais desafiadoras, como com os olhos fechados. Estudos futuros de intervenção devem considerar o uso de medidas de complexidade, que parecem detectar alterações que as medidas tradicionais não contemplam. Ainda, espera-se que um maior número de intervenções seja direcionado à condição de fragilidade, a fim de garantir maiores ganhos a população idosa.