Manual Therapy, Posturology & Rehabilitation Journal
ISSN: 2236-5435

RESEARCH ARTICLE

Physiological complexity of body sway during dual-task gait in faller older adults

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Abstract

Background: The impact of simultaneous cognitive demand on gait's physiological complexity in community-dwelling older adults with and without self-reported falls is yet unknown. **Objective:** To analyze whether the physiological complexity of body sway during dual-task and single gait is worse in once-only fallers than in non-faller older adults. **Methods:** A total of 58 community-dwelling older adults aged 60 to 80 participated in this study, of whom 21 had self-reported a single fall in the previous 12 months (fallers) and 37 matched participants with no fall self-reported (non-fallers). An inertial sensor (Physilog® 5, Gait Up, Switzerland) was used to acquire the time series of the body center of mass (CoM) sway in the anteroposterior (AP), mediolateral (ML) and vertical (V) directions during single gait (ST) and the gait under dual task (DT). The composite refined multiscale fuzzy entropy method was used to calculate the physiological complexity index (CI) in a MATLAB environment. SPSS (IBM; v.25.0) was used to analyze the effects of group (Fallers vs. Non-fallers), condition (ST vs. DT), and interaction (group vs. condition), using generalized linear mixed models, with an alpha of 5%. **Results:** No interaction or group effect was observed for the CI. However, when comparing DT with ST, a main effect of the condition was observed for the AP direction (F = 62.394; p < .001) with a reduction of 0.53 (95% CI: -0.66 to -0.39), ML (F = 4.724; p = .034) with an increase of 0.22 (95% CI: 0.17 to 0.42), and V (F = 6.457; p = .014) with a decrease of 0.17. **Conclusion:** Just one fall in the previous 12 months does not deleteriously influence the body's physiological complexity during gait under concurrent cognitive demand (dual task). On the other hand, DT significantly affects the gait physiological complexity in community-dwelling older adults.

Keywords: Older adults; gait; dual task; entropy; physiological complexity.

BACKGROUND

Falls during walking in older adults[1,2] occur mainly when simultaneously performing dual tasks[3-5]. Walking while talking, carrying objects[6], or paying attention to traffic is very common in activities of daily living[3-5]. Motor and cognitive interaction during this type of activity is defined as a dual-task paradigm, in which the individual is required to successfully interact between postural control neural mechanisms and the competing cognitive or motor task[6].

Using linear analysis of gait kinematics has shown older people have reduced step length, increased double support phase, step width[7], and increased gait variability[8]. These motor behaviors can be seen as conservative and compensatory strategies to minimize the influence of changes in dynamic stability induced by the dual task[9]. The analysis of the variation in trunk accelerations—usually represented by maximum and

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Received: 03 Jun, 2024.
Accepted: 12 Aug, 2024.
Published: 09 Sept, 2024.

minimum values, the root means square, and the oscillation range, among others—has also been used to better understand older adults' gait[10].

Nevertheless, non-linear methods, such as entropy, go beyond the conventional linear approach, providing an in-depth view of the physiological complexity of biological signals[11], especially the gait[12]. Multiscale entropy can be seen as a complementary way to understand the association between cognitive and motor behavior during gait. However, to our knowledge, the impact of simultaneous cognitive demand on gait's physiological complexity in community-dwelling older adults with and without self-reported falls remains unknown. This information on postural control during gait can contribute to the development of future clinical trials to improve the performance of older adults during gait with and without cognitive demands, aiming at minimizing fall episodes.

This study analyzed the physiological complexity of body sway during single and dual-task gait in once-only faller and non-faller community-dwelling older adults. Our hypotheses are: (i) the physiological complexity of body sway is not worse in once-only faller compared to non-faller community-dwelling older adults; (ii) regardless of group, the physiological complexity of body sway will be worse (lower) during gait under dual task compared to single one.

METHODS

Study design and ethical considerations

This is an experimental cross-sectional study whose sample came from the main project called EQUIDOSO-I (Study on Falls in Older Adults), which was designed and developed in compliance with the National Health Council Resolution 466/2012, the Declaration of Helsinki and the World Health Organization's and the International Committee of Medical Journal Editors' recommendations. This study was approved by the Research Ethics Committee of the Integrated Center for Amaury de Medeiros Health (CISAM-UPE) (CAAE: 71192017.0.0000.5207, opinion number: 2.415.658).

Sample

A total of 58 community-dwelling older adults between 60 and 80 years old participated in the study. Twenty-one older adults who had suffered at most one fall in the past 12 months composed the fallers group (Fallrs). The non-fallers group (Non-fallers) was composed of 37 older adults who had no self-reports of falls in the same period.

In this study, a fall was defined as 'an unexpected event in which the participants come to rest on the ground, floor, or lower level'. The participants were asked if they had any fall episodes in the past 12 months, including a slip or trip in which they lost their balance and landed on the floor, ground, or lower level[13].

Eligibility Criterion

Participants who achieved ⩾ 52 points (up to a maximum of 56 points) on the Berg Balance Scale[14], ⩾ 24 points (up to a maximum of 30 points) on the Mini-Mental State Examination[15], and were able to walk uninterruptedly for a distance of 60 m at a self-selected speed of at least 1 m/s (without the aid of others or walking aids) were included in this study. Potential participants were excluded if they (i) had any postural balance or cognition impairment, (ii) had fallen two or more times in the past 12 months, (iii) were participating or had participated in any regular, structured exercise program for two or more times per week in the past six months, (iv) had any chronic health condition for which exercise is contraindicated, (v) had upper- or lower-limb fracture in the past six months, (vi) had evidence of any surgical procedure on the knees, ankles, or hips or muscle damage in the past six months, or (vii) had a diagnosis of uncontrolled diabetes.

Biomechanical analysis of gait

Participants' gait was analyzed during two conditions: (1) single task (ST) (gait task only), and (2) gait under a dual-task (DT). The data acquisition of both gait conditions occurred according to a random order for each participant. An inertial sensor (Physilog® 5, Gait Up, Lausanne, Switzerland) was used for gait data acquisition. The Physilog® 5 sensor is an inertial measurement unit (IMU) based on a stand-alone device (dimensions: 50 mm × 40 mm × 16 mm; weight: 36 g), including a tri-axial accelerometer (MMA7341LT, range ± 3 g, Freescale, Austin, TX, USA), a tri-axial gyroscope (ADXRS, range ± 600 °/s, Analog Devices, Norwood, MA, USA), a battery (3.7 V, 155 mAh), a memory unit and a microcontroller. This sensor was fixed between the participant's third and fifth lumbar vertebra with a hypoallergenic neoprene strip and a double-sided tape (3M). Before data acquisition, the participant had a habituation period to the biomechanics laboratory environment.

The participant was asked to walk a linear distance of 60 meters (round trip) in a straight, flat corridor 30 meters long and 4 meters wide at a self-selected walking speed. For the dual-task gait, the participant was asked to perform a three-digit countdown from 100 until the end of the 60-meter route. If the participant finished the countdown before the route, they would be required to start a new countdown from 100[16].

The tri-axial acceleration of the sensor was sampled on a 16-bit digital-analog converter at a sampling frequency of 128 Hz and saved on a micro SD card inside the IMU before being transferred to the analysis computer[17]. The first two and two last cycles of each 30-meter stretch (beginning of the march, before and after turning through the signaling cone, and at the end of the task) were excluded in the data analysis stage, as they respectively represent the positive and negative gait acceleration phases[18]. Approximately 40 gait cycles for each gait condition were used to calculate each participant's physiological complexity index (CI) in the MATLAB program using a refined composite generalized multiscale fuzzy entropy[11].

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Science (IBM SPSS version 22; IBM Corp., Armonk, NY), adopting a 5% significance level. Between- and within-group comparisons were performed using Generalized Linear Mixed Models (GLMM), considering the subjects as random factors and the conditions (ST and DT) as fixed factors. Q-Q graphs were plotted to verify each model's adequacy (normality).

The effect sizes between each pair of estimated marginal means (EMM) comparisons were presented by the values of the mean difference (MD; mean difference) when comparing the groups (Fallers and Non-fallers) and by the mean change values (MC; mean change) when comparing conditions within each group[19]. MD values were produced by calculating the arithmetic differences between both groups of independent observations. MD values were calculated as the arithmetic difference between the EMM of the conditions DT minus ST. The Bonferroni post-test was used for multiple comparisons

RESULTS

Both groups were not different regarding demographic and anthropometric characteristics, as shown in Table 1.

Table 1. Demographic and anthropometric characteristics of the fallers and non-fallers groups.

Variable	Fallers (*n* = 21)	Non-fallers (*n* = 37)	
Sex			
Female (n; %)	18 (85.7)	32 (86.5)	
Male (n; %)	3 (14.3)	5 (15.5)	
	Mean (standard deviation)		***p*-value**
Age (years)	65 (5)	67 (5)	0.126
Mass (kg)	69.34 (9.80)	69.23 (14.65)	0.976
Height (m)	1.53 (0.06)	1.56 (0.07)	0.107
BMI (kg/m²)	29.42 (4.01)	28.08 (5.10)	0.308

Note: BMI = Body mass index.

Fallers and non-fallers participants were not different regarding gait speed, as can be seen in Table 2. On the other hand, as shown in Table 2, the DT condition decreased gait speed in both the fallers (MC:- 0.11; 95%CI: -0.14 to -0.07) and the non-fallers (MC:-0.09; 95%CI: -0.12 to -0.06) groups when compared to ST, confirming a condition effect for gait speed (F = 67.837; p .001).

No interaction effect was observed in the center of mass sway complexity index (CI) during gait for the AP (F = .190; p = .664), ML (F = .074; p = .786), and V (F = .403; p = .528). Additionally, no group effect was seen for AP (F = .018; p = .893), ML (F = .021; p = .885) and V (F = 1.351; p = .250) directions.

When comparing CI between DT and ST, regardless of group, a main effect regarding the condition was observed for the AP direction (F = 62.394; p < .001), with a reduction of 0.53 (95%CI: -0.66 to -0.39), ML (F = 4.724; p = .034), with an increase of 0.22 (95%CI: 0.17 to 0.42), and V (F = 6.457; p = .014), with a decrease of 0.17 (95%CI: -0.30 to 0.04).

Table 2. Gait speed and complexity index of the fallers and non-fallers groups.

Variable	Fallers (*n* = 21)	Non-fallers (*n* = 37)	
	Mean (95%CI)		**MD (95%CI)**
Gait speed (m/s)			
ST	1.31 (1.25 to 1.36)	1.35 (1.29 to 1.40)	-0.04 (-0.12 to 0.04)
DT	1.20 (1.13 to 1.27)	1.25 (1.20 to 1.31)	-0.05 (-0.15 to 0.03)
MC (95%CI)	**-0.11** (-0.21 to -0.09)	**-0.09** (-0.17 to -0.02)	
Complexity index			
AP direction			
ST	4.05 (3.96 to 4.13)	4.05 (3.94 to 4.16)	-0.00 (-0.16 to 0.16)
DT	3.97 (3.89 to 4.05)	3.87 (3.71 to 4.04)	-0.09 (-0.13 to 0.33)
MC (95%CI)	0.07 (-0.18 to 0.04)	-0.17 (-0.26 to -0.08)	
ML Direction			
ST	3.51 (3.28 to 3.75)	3.50 (3.31 to 3.71)	0.01 (-0.32 to 0.34)
DT	3.50 (3.30 to 3.71)	3.46 (3.29 to 3.63)	0.04 (-0.24 to 0.33)
MC (95%CI)	-0.01 (-0.15 to 0.12)	-0.04 (-0.15 to 0.06)	
Vert Direction			
TS	2.90 (2.71 to 3.10)	3.11 (2.92 to 3.31)	0.21 (-0.51 to 0.09)
DT	2.98 (2.80 to 3.18)	3.16 (2.95 to 3.39)	-0.18 (-0.51 to 0.15)
MC (95%CI)	0.08 (-0.06 to 0.23)	0.05 (-0.06 to 0.16)	

Note: ST: Single task; DT: Dual task; MD: Mean difference; MC: Mean change; 95%CI: 95% confidence interval; MD and MC highlighted in bold indicate significant differences at 5%.

DISCUSSION

This study analyzed the physiological complexity of body sway during gait under variable- and fixed-priority dual-tasking in faller and non-faller community-dwelling older adults. The first hypothesis of this study was faller community-dwelling older adults would present less (worse) physiological complexity of body sway during gait than non-faller ones. However, no significant between-group difference was observed regarding gait conditions and physiological complexity.

Older people who have self-reported at least one fall in the previous six months[20] or one year[21-23] are usually defined as fallers[21,23,24]. Nevertheless, some studies have found that older people who fell only once showed no significant changes in gait kinematics[20] and physiological measures such as visual contrast sensitivity, response time, body sway, quadriceps strength, and vibration perception[25]. On the other hand, a faller person has also been defined as someone who has had two or more falls in a given period[21]. This fact may explain the lack of significant difference between both groups in this study regarding the physiological complexity index during the execution of both gait conditions since once-only fallers and non-faller older adults were considered in this study.

Furthermore, participants' recall bias may have been an important factor in the results due to the limited accuracy of self-reported fall recall by older people[26]. Recalling some events in the previous three and six months has proven less accurate[13]. In a prospective study of 304 outpatients, 13 to 32% denied falling, depending on how long after the event they were questioned. Although longer intervals were associated with lower falls recall[26], some participants from the non-faller group could not neglect some fall events in the previous 12 months.

The second hypothesis that both groups would present a lower physiological complexity of postural oscillation during gait under DT was partially confirmed since this measure was lower only in the AP (MC = 0,53) and vertical (MC = 0,17) directions. Conversely, the physiological complexity increased in the ML direction (MC = 0,22). A possible explanation for these results may be based on the oscillation characteristic observed in the gait cycle. Human gait is generally conceived as the cyclical rotation of the lower limbs, whose goal is the forward translation of the body system (represented mechanically by its center of mass). The lower limbs support an inverted pendulum toward minimizing muscle work from childhood to old age[27]. Once the toes are removed from the ground (known as toe-off), there is a gradual acceleration during the swing phase as the body is propelled forward[28]. The findings of this study suggest that the demand for a cognitive activity while walking caused older individuals to reduce complexity in two axes of movement (AP and ML), which was then compensated for by increasing the body's ML oscillation complexity.

The "complexity theory of aging" states that age-related changes in the quantity and quality of these components and their structural and functional connectivity reduce the system's functionality and impair an organism's ability to adapt to environmental stress[29]. According to this theory, the reduced complexity of postural sway has been linked to a decrease in the quantity and quality of sensory input to the postural control system[30]. Regulation of permanent postural sway requires the integration of numerous sensory, spinal, and supraspinal inputs, a range of cognitive functions, and the peripheral neuromuscular system[29]. There is a greater possibility of observing changes in the complexity index of postural oscillation compared to dual-task and single gait due to a greater need for interactions, sensory inputs, and integrating more systems in a situation that generates more significant stress or bodily demands. This can also be observed in the results regarding gait speed in DT since there was a reduction in this speed when older adults perform cognitive demands associated with walking. Thus, a compensatory mechanism may have occurred to compensate for the decrease in complexity during DT.

It is worth highlighting that the main strength of this study was that we used an analysis tool that considers the structural richness of signals throughout a time series instead of restricting ourselves only to linear analyses, commonly reported by a large portion of literature. This allowed us to analyze in more detail the dynamic postural control during dual and single-task gait of older adults with and without self-reported falls in a previous period of 12 months. It is also important to highlight that the present study has some limitations. These results cannot be generalized to older adults reporting recurrent falls and to those individuals who live in long-term institutions or have some functional impairments. Furthermore, all participants in this study did not show cognitive impairment. It may be that older people with some cognitive impairment have their physiological complexity during walking under DT and ST more affected than older adults without cognitive impairment.

CONCLUSION

Just one fall in the previous 12 months does not deleteriously influence the body's physiological complexity during gait under concurrent cognitive demand (dual task). On the other hand, DT significantly affects the body sway complexity during gait in community-dwelling older adults.

Conflict of interest: The authors declare no conflict of interest.

Financial support: The National Council for Scientific and Technological Development (CNPq) funded Trombini-Souza's research (Grant number: MCT/CNPq 423805/2016–9) and Alencar's scientific initiation scholarship (PIBIC 143092/2020-0). The Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) funded Alencar (Finance Code: 001) and Lima (Finance Code: 001). The University of Pernambuco's Academic Improvement Program funded Leal (Grant number: PPGRDF 2022.1-01) and Silva (Grant number: PPGRDF 2022.1-02).

Author contributions: Conception and design of the study: J.G.A, I.S.L., F.T.-S.; Data acquisition: J.G.A, I.S.L., L.A.S.L.; Data analysis and interpretation: J.G.A, I.S.L., C.F.S., L.R.A.S., L.A.S.L., F.T.-S; Preparation of the manuscript: J.G.A, I.S.L., C.F.S., L.R.A.S., L.A.S.L., F.T.-S.; Intellectual review of the manuscript: J.G.A, I.S.L., C.F.S., L.R.A.S., L.A.S.L., F.T.-S., T.F.A.S.; Final approval of the manuscript: J.G.A, I.S.L., C.F.S., L.R.A.S., L.A.S.L., F.T.-S., T.F.A.S.

Acknowledgements: The authors are grateful to the National Council for Scientific and Technological Development (CNPq) for financing the Trombini-Souza's research (Grant number: MCT/CNPq 423805/2016–9) and Alencar's scientific initiation scholarship (PIBIC 143092/2020-0). The authors are also thankful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) for funding Lima (Finance Code: 001) and to the University of Pernambuco's Academic Improvement Program by funding Leal (Grant number: PPGRDF 2022.1-01) and Silva (Grant number: PPGRDF 2022.1-02). The authors are also grateful to Prof. Javier Escudero from the School of Engineering at the University of Edinburgh for his assistance with part of the entropy analysis code.

REFERENCES

1. Geerse DJ, Roerdink M, Marinus J, van Hilten JJ. Walking adaptability for targeted fall-risk assessments. Gait & posture. 2019;70:203-10.

2. Svoboda Z, Bizovska L, Janura M, Kubonova E, Janurova K, Vuillerme N. Variability of spatial temporal gait parameters and center of pressure displacements during gait in elderly fallers and nonfallers: A 6-month prospective study. PLoS One. 2017;12(2):e0171997.

3. Bloem BR, Valkenburg VV, Slabbekoorn M, Willemsen MD. The Multiple Tasks Test: development and normal strategies. Gait Posture. 2001;14(3):191-202.

4. Li W, Keegan TH, Sternfeld B, Sidney S, Quesenberry CP, Jr., Kelsey JL. Outdoor falls among middle-aged and older adults: a neglected public health problem. Am J Public Health. 2006;96(7):1192-200.

5. Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. Age and ageing. 1997;26(4):261-8.

6. Kelly VE, Janke AA, Shumway-Cook A. Effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults. Exp Brain Res. 2010;207(1-2):65-73.

7. Herssens N, Verbecque E, Hallemans A, Vereeck L, Van Rompaey V, Saeys W. Do spatiotemporal parameters and gait variability differ across the lifespan of healthy adults? A systematic review. Gait & posture. 2018.

8. Dingwell JB, Salinas MM, Cusumano JP. Increased gait variability may not imply impaired stride-to-stride control of walking in healthy older adults: Winner: 2013 Gait and Clinical Movement Analysis Society Best Paper Award. Gait & posture. 2017;55:131-7.

9. Howcroft J, Lemaire ED, Kofman J, McIlroy WE. Dual-Task Elderly Gait of Prospective Fallers and Non-Fallers: A Wearable-Sensor Based Analysis. Sensors (Basel). 2018;18(4).

10. Craig JJ, Bruetsch AP, Huisinga JM. Coordination of trunk and foot acceleration during gait is affected by walking velocity and fall history in elderly adults. Aging Clin Exp Res. 2019;31(7):943-50.

11. Azami H, Escudero J. Refined composite multivariate generalized multiscale fuzzy entropy: A tool for complexity analysis of multichannel signals. . Phys A Stat Mech its Appl 2017;465:261-76.

12. Mirelman A, Shema S, Maidan I, Hausdorff JM. Gait. Handbook of clinical neurology. 2018;159:119-34.

13. Lamb SE, Jorstad-Stein EC, Hauer K, Becker C, Prevention of Falls Network E, Outcomes Consensus G. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. Journal of the American Geriatrics Society. 2005;53(9):1618-22.

14. Silsupadol P, Lugade V, Shumway-Cook A, van Donkelaar P, Chou LS, Mayr U, et al. Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial. Gait Posture. 2009;29(4):634-9.

15. Azadian E, Torbati HR, Kakhki AR, Farahpour N. The effect of dual task and executive training on pattern of gait in older adults with balance impairment: A Randomized controlled trial. Arch Gerontol Geriatr. 2016;62:83-9.

16. Malatesta D, Canepa M, Menendez Fernandez A. The effect of treadmill and overground walking on preferred walking speed and gait kinematics in healthy, physically active older adults. European journal of applied physiology. 2017;117(9):1833-43.

17. Sucerquia A, Lopez JD, Vargas-Bonilla JF. SisFall: A Fall and Movement Dataset. Sensors. 2017;17(1).

18. Malatesta D, Canepa M, Menendez Fernandez AJEJoAP. The effect of treadmill and overground walking on preferred walking speed and gait kinematics in healthy, physically active older adults. 2017;117:1833 - 43.

19. Kamper SJ. Interpreting Outcomes 1-Change and Difference: Linking Evidence to Practice. J Orthop Sports Phys Ther. 2019;49(5):357-8.

20. Freire Junior RC, Porto JM, Marques NR, Magnani PE, Abreu DC. The effects of a simultaneous cognitive or motor task on the kinematics of walking in older fallers and non-fallers. Human movement science. 2017;51:146-52.

21. Masud T, Morris RO. Epidemiology of falls. Age and ageing. 2001;30 Suppl 4:3-7.

22. Newstead AH, Walden JG, Gitter AJ. Gait variables differentiating fallers from nonfallers. Journal of geriatric physical therapy. 2007;30(3):93-101.

23. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med. 1988;319(26):1701-7.

24. Le Mouel C, Tisserand R, Robert T, Brette R. Postural adjustments in anticipation of predictable perturbations allow elderly fallers to achieve a balance recovery performance equivalent to elderly non-fallers. Gait & posture. 2019;71:131-7.

25. Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. Journal of the American Geriatrics Society. 1994;42(10):1110-7.

26. Cummings SR, Nevitt MC, Kidd S. Forgetting falls. The limited accuracy of recall of falls in the elderly. Journal of the American Geriatrics Society. 1988;36(7):613-6.

27. Tesio L, Rota V. The Motion of Body Center of Mass During Walking: A Review Oriented to Clinical Applications. Frontiers in neurology. 2019;10:999.

28. Menz HB, Lord SR, Fitzpatrick RC. Acceleration patterns of the head and pelvis when walking on level and irregular surfaces. Gait Posture. 2003;18(1):35-46.

29. Zhou J, Habtemariam D, Iloputaife I, Lipsitz LA, Manor B. The Complexity of Standing Postural Sway Associates with Future Falls in Community-Dwelling Older Adults: The MOBILIZE Boston Study. Sci Rep. 2017;7(1):2924.

30. Manor B, Costa MD, Hu K, Newton E, Starobinets O, Kang HG, et al. Physiological complexity and system adaptability: evidence from postural control dynamics of older adults. J Appl Physiol (1985). 2010;109(6):1786-91.