Sensory assessment of balance regulation of physically active women, 60-79 years old

Avaliação sensorial da regulação do equilíbrio de mulheres fisicamente ativas, 60-79 anos

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ABSTRACT

OBJECTIVE: To evaluate the performance of sensory regulation of static and dynamic balance in older women, and to verify the sensitivity and specificity levels of the Body Balance Test (*Teste de Equilíbrio Corporal*, TEC) in relation to its reference standard, determining the best cutoff point for identifying risk of falling. **METHODS:** 74 women (age 67.59 ± 5.26 years) participated in the study, divided into fallers ($n = 18$) and non-fallers ($n = 56$). **RESULTS:** Comparatively, non-fallers had higher performance scores on static balance exteroceptive regulation (SBER), dynamic balance exteroceptive regulation (DBER), and dynamic balance interoceptive regulation (DBIR). Statistically significant differences were found in DBER ($p = \leq 0.001$) and DBIR ($p = 0.031$). The area under the ROC curve was 0.73 (95%CI 0.58 – 0.88; $p = 0.003$), with a sensitivity level of 42.30% and specificity of 84.80%. **CONCLUSIONS:** The greatest chance of falling was found for dynamic balance in situations of exteroceptive and interoceptive regulation for older women with and without a history of falls. Deficits in sensory regulation of body balance are common in older women, both fallers and non-fallers. **KEYWORDS:** aged; aging; body balance.

RESUMO

OBJETIVO: Avaliar o desempenho da regulação sensorial do equilíbrio estático e dinâmico de mulheres idosas e verificar os níveis de sensibilidade e especificidade do Teste de Equilíbrio Corporal (TEC) em relação ao seu padrão de referência, determinando o melhor ponto de corte para a identificação do risco de queda. **METODOLOGIA:** participaram do estudo 74 mulheres ($67,59 \pm 5,26$ anos), divididas em caídas ($n = 18$) e não-caídas ($n = 56$). **RESULTADOS:** Comparativamente, não-caídas indicaram escores de desempenho mais elevados para equilíbrio estático regulação exteroceptiva (EERE), equilíbrio dinâmico regulação exteroceptiva (EDRE) e equilíbrio dinâmico regulação interoceptiva (EDRI). Diferenças estatisticamente significativas foram encontradas na regulação EDRE ($p = \leq 0,001$) e EDRI ($p = 0,031$). A área verificada sob a curva ROC foi de 0,73 (IC95% 0,58 – 0,88; $p = 0,003$) e nível de sensibilidade de 42,30% e especificidade de 84,80%. **CONCLUSÕES:** A maior chance de queda foi encontrada para o equilíbrio dinâmico em situação de regulação exteroceptivo e interoceptivo para mulheres idosas com e sem histórico de queda. Déficits na regulação sensorial do equilíbrio corporal são comuns em mulheres idosas caídas e não-caídas. **PALAVRAS-CHAVE:** idoso; envelhecimento; equilíbrio corporal.

INTRODUCTION

With advancing age, the human body undergoes a set of biological, psychological and functional changes that make it difficult for the person to adapt to the environment.¹ Among these changes, some are physiological, such

as neuromuscular disorders, determining strength deficits and decreased gait speed, and sensory system disorders (vision, hearing, somatosensory), which impair regulation of static and dynamic balance.^{2,3} For this reason, older adults with sensory function deficits exhibit a higher risk of falling.^{4,5}

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The fact highlights the importance of examining these systems, because falls in this age group are a leading cause of injuries, fractures, hospitalization, and even death.⁶

Approximately 28 to 35% of people aged 65 and over fall every year.⁷ Falls are multifactorial events; a review focusing specifically on older adults pointed out the main risk factors as deficits in balance and gait, polypharmacy, history of previous falls, visual impairment, cognitive decline (attention and executive dysfunction), environmental factors, advancing age, and female sex.^{6,8} The risk of falling increases by 32–42% from the age of 70, and women are more likely to fall than men.^{9,10} Any explanation for the difference in the rate of falls between men and women interacts with the loss of bone mineral density in the latter, causing an increase in the incidence of fractures in perimenopause.¹¹ A recent study conducted in Brazil evaluated the rate of falls among older adults living in urban areas.¹² A total of 4,174 participants with a mean age of 70.20 years (56.6% women) were included. The prevalence of falls was 25.1%, with 1.8% resulting in hip or femur fractures and 31.8% requiring surgical treatment and arthroplasty. According to the Department of Informatics of the Brazilian Unified Health System,¹³ between 2018 and 2019, 115,905 hospitalizations were recorded due to falls among older adults (60 to 79 years), costing approximately US\$ 700,000 in inpatient services. Among the hospitalizations recorded, 56.8% were of women.

Regulation of body balance

Falls are multifactorial events arising from extrinsic and intrinsic causes.² The extrinsic group concerns lighting, paving, and scattered obstacles on the way. The intrinsic causes are associated with physiological changes, such as musculoskeletal system performance, attention, and cognition levels, and the sensory condition itself.^{3,14} The regulation of body balance is handled by the sensory system, composed of the visual, vestibular, and somatosensory apparatuses. Its function is the apprehension of information regarding body movement in relation to the environment.¹⁵ Once captured, postural stimuli are sent to the central nervous system (CNS), which analyzes the information and then decides the type of motor adjustment most compatible and effective for the situation.^{16,17}

Postural data are constantly processed according to a value scale, which considers the type of movement and environment. Thus, in unbalanced situations, the CNS immediately creates a particular strategy for adjusting the center of gravity on the body's support base.^{18–20} Disturbances in the functioning of sensory receptors thus hinder transmission of postural information to the CNS. As a result, there is a delay

or inability to send corrective commands to the extremities to compensate for imbalances and prevent the fall.^{21,22}

Each sensory system has a definite function. The visual system acts on the perception of space, regulating posture based on the relationship established between body movement and objects placed in the environment.^{23,24} Data processing occurs in the retina, where stimuli are captured and sent by the extraocular muscles to the CNS. Deficits in this sensory system may be related to refractive errors (myopia, astigmatism, and hyperopia),²⁵ which are common in older adults. Thus, early identification of disorders and factors associated with the risk of falling is a strategy to prevent falls.^{24,25}

The vestibular system is responsible for sending information to the CNS about the positions assumed by the head in space, as well as its relationship with the forces of gravity and inertia.²⁶ Analysis of these stimuli occurs through linear acceleration measurements, which are created by the affinity of the head position with the gravitational angular axis.²⁷ This system has sensory and motor characteristics because it is involved in the control of eye movements. The somatosensory system has the role of sending to the CNS information on the position and speed of movement of body segments in space.¹⁵ Information is captured by receptors located on joints, tendons, and muscles.^{3,21} Sensory receptors are also located in the plantar region, where they continuously capture postural information through the pressure exerted by the body on shoes.^{28,29}

Methods for the evaluation of human body balance

Tests for evaluation of balance differ in the complexity of their methods, technological components, purpose, application time, and cost. These tests can be divided into two categories: clinical and field tests or laboratory tests.³⁰ Clinical tests are further classified into subjective, observational, functional, timed, and static.³¹

Clinical tests have the advantage of not requiring sophisticated materials and being easily administered, in a short time, at a low cost. However, they allow evaluation of only one body segment. Conversely, laboratory tests such as force platforms, electromyography, and photo film systems have the advantage of examining different variables simultaneously, offering greater accuracy. This is because these are composed of inertial sensors, which allow measurement of the center of pressure (COP).³⁰ Considering that studies on the risk of falls in older adults seek to explain a specific problem, the methods and parameters offered by laboratory tests allow a broader analysis of the data and, consequently, better interpretation and explanation of the person's behavioral balance model. However, these tests require advanced training and

adequate equipment space. This makes laboratory testing more expensive than clinical testing.

Among the most widely used clinical tests to assess body balance in older adults are the Berg Balance Scale (BSE),³² the Performance Oriented Mobility Assessment (POMA) Tinetti Balance Test,³³ the Dynamic Gait Index (DGI),³⁴ Sensory Interaction and Balance (CTSIB),³⁵ and Timed Up and Go (TUG),³⁶ applied in the gait pattern evaluation (auxiliary data to estimate the risk of falling). Each test is able to evaluate distinct facets of body balance, which implies that joint application of two or more tests is necessary. For this reason, they are considered complementary.³⁷ The specialized literature highlights some problems inherent to these clinical tests in examining the body balance of older adults who practice regular physical exercise.³⁰ Among them is the low sensitivity of these tests, which may not be sufficient to detect changes in populations other than those of the country where the test was validated. Thus, the use of established cut-off points means that older adults who are physically trained will more easily reach maximum performance scores, generating a ceiling effect.³⁷⁻³⁹

A functional test that allows the general examination of static and dynamic balance and that is also able to specifically analyze the performance of its three regulation systems is the GGT (*Gleichgewichtstest*). This test is comprised of success rules for each gender, according to age groups ranging from 30 to 79 years. The test was designed by Wydra,⁴⁰ and validated in Germany with 306 subjects of both genders (20–79 years), with a test-retest reliability of 0.78, Cronbach's alpha consistency of 0.92, and correlation of $r = 0.60$ ($p < 0.001$) with postural radiographs. The GGT was later introduced to the Portuguese-speaking community by Nascimento et al.,⁴¹ named as *Teste de Equilíbrio Corporal* (TEC), which means 'body balance test'.

The present study aimed to evaluate the performance of sensory regulation (visual, vestibular, and somatosensory) of the static and dynamic balance of a group of older adults, all regular exercise practitioners, with and without a history of falls, and measure the sensitivity and specificity of the Body Balance Test (TEC) in relation to its reference standard, determining the best cutoff point for identifying a risk of falls.

METHODS

This is an observational exploratory study with a cross-sectional design. The procedures were approved by the Human Research Ethics Committee of Universidade Federal do Vale do São Francisco (CAAE: 87094218.0.0000.5196).

Participants

The study included women who practiced 60 minutes of Pilates twice a week. The activities were offered by the University Federal do Vale do São Francisco, located in the city of Petrolina, Pernambuco, Brasil. The sample size calculation was performed considering 105 subjects, with a margin of error of 5%, outcome prevalence of 20%, and confidence level of 95%. The study included 74 participants (age 67.59 ± 5.26 years), subsequently divided into two groups: fallers ($n = 18$) and non-fallers ($n = 56$). The inclusion criteria were: age 60–79 years, a minimum time of 6 months of Pilates practice with 75% of attendance, no muscle, joint, or bone injury during the evaluation period, and no neurological conditions such as Parkinson's disease or stroke. Participants who did not complete all stages of the study were excluded from the investigation, as were those who did not provide written informed consent.

Procedures

Data were collected by two trained researchers between May and July 2019. The study was conducted in three phases:

- Phase I: Collection of data on sociodemographic parameters, comorbidities, and history of falls for the past twelve months;
- Phase II: Anthropometric data were collected by assessing body mass and height with a mechanical scale (Welmy, Brazil, capacity 300 kg), and an anthropometric ruler (capacity 2 meters). Body mass index (BMI) was calculated with the formula $\text{mass (kg)}/\text{height (m)}^2$;
- Phase III: Body balance was assessed using the TEC.^{40,41}

The TEC consists of 14 tasks and provides some advantages over other clinical tests, including more possibilities for assessment, interpretation and subsequent intervention in postural deficit in the older adult population:

- Its validation included independent and healthy individuals;
- The 14 test tasks are distributed in increasing order of difficulty, allowing more accurate and easy identification of the patient's type of postural problem. For safety reasons, Wydra⁴⁰ advises discontinuation of the test if the subject is unable to complete two tasks in a row;
- The scoring system is dichotomous, assigning zero (0) for missed tasks and one (1) for correctly performed tasks. This avoids errors in scoring results and makes assessment of postural control more accurate;

- Interpretation of the results is based on norms, which allow categorizing performance by gender and age group (Table 1).

Among the advantages of the TEC test is its evaluation of static and dynamic balance, with an emphasis on exteroceptive (visual system) and interoceptive (vestibular and somatosensory) sensory regulation. Another particularity of the test is the interpretation of the results in two ways:

- General assessment: here, the examination of body balance is determined on a scale of 1-14 points;
- Specific assessment: here, body balance is established according to the performance of sensory functions.

Figure 1 illustrates the model used in this study to assess the sensory regulation of postural control. It is possible to observe that the 14 TEC tasks are divided into four sensory dimensions:

Table 1. TEC: Test performance norms.

Classification	Sex	30-39 years	40-49 years	50-59 years	60-69 years	70-79 years
Very Good	Men	> 11	> 10	> 8	> 7	> 6
	Women	> 10	> 10	> 8	> 6	> 5
Good	Men	10-11	9-10	8	7	6
	Women	9-10	9-10	7-8	5-6	4-5
Fair	Men	8-9	7-8	6-7	5-6	4-5
	Women	7-8	7-8	5-6	3-4	2-3
Poor	Men	6-7	5-6	4-5	3-4	2-3
	Women	5-6	5-6	3-4	< 3	< 2
Very Poor	Men	< 6	< 5	< 4	< 3	< 2
	Women	< 5	< 5	< 3	< 2	< 1

Source: adapted from Nascimento et al.³⁷

Figure 1 – Conceptual model for balance regulation evaluation, Balance Test (TEC).

- static balance, exteroceptive regulation (SBER);
- static balance, interoceptive regulation (SBIR);
- dynamic balance, exteroceptive regulation (DBER);
- dynamic balance, interoceptive regulation (DBIR):

Description of TEC tasks

Static balance exteroceptive regulation

- Task 1: The person is asked to lean on one lower limb of their free choice. *Pass criterion:* Stay in position for at least 15 seconds;
- Task 2: The person is required to lean on one lower limb (free choice) and must swing the other leg back and forth without moving the support foot. *Pass criterion:* Stay in position for at least 15 seconds;
- Task 3: The person is asked to perform a 360° turn and then lean on one lower limb of their free choice. *Pass criterion:* Stay in position for at least 15 seconds.

Static balance interoceptive regulation

- Task 9: The person is asked to walk on a wooden beam (4 meters long, 10 cm wide, 3 cm high). *Pass criterion:* Walk and maintain balance until the end of the course;
- Task 10: The person is asked to walk on the wooden beam up to the 2-meter mark, rotate 180°, and return to the beginning of the beam. *Pass criterion:* Walk and maintain balance until the end of the course;
- Task 13: The person is asked to walk on the wooden beam and simultaneously bounce a volleyball on the floor beside them. *Pass criterion:* Walk and maintain balance until the end of the course.

If imbalance occurs and one foot touches the ground while walking over the beam, a score of zero (0) is assigned.

Dynamic balance exteroceptive regulation

- Task 4: The person is asked to lean on a lower limb of their own choice and move the other foot/leg in the air around two plastic bottles, drawing a figure-8. The task is performed twice consecutively: first with eyes open, then with eyes closed. The objects should be positioned laterally to the body, spaced apart to the same extent as their heights. *Pass criterion:* During execution of the task, the foot cannot touch the ground or the objects;
- Task 6: The person is asked to close their eyes and lean on a lower limb of their free choice. *Pass criterion:* Stay in position for at least 15 seconds;

- Task 7: The person is asked to make a 360° rotation, close their eyes, and rest on a lower limb of their own choice. *Pass criterion:* Stay in position for at least 15 seconds without moving the support foot;
- Task 8: The person is asked to close their eyes, rest on a lower limb of their own choice, and swing the other leg (forwards and backwards) without moving the support foot. *Pass criterion:* Stay in position for at least 15 seconds.

Dynamic balance interoceptive regulation

- Task 5: The person is asked to close their eyes and perform 5 jumping jacks on a marked line on the ground, moving their arms and legs simultaneously. At the end of each run, one foot should always be in contact with the line. *Pass criterion:* One foot must remain in contact with the line during execution. Otherwise, the score will be zero (0);
- Task 11: The person is asked to walk for 2 meters over the wooden beam, rotate 180°, and keep walking forward for another 2 meters until the end of the beam. *Pass criterion:* Maintain balance until the end of the course without touching the ground;
- Task 12: The person is asked to walk for 2 meters over the wooden beam, rotate 360° and continue walking for another 2 meters, returning to the original position. *Pass criterion:* Maintain balance until the end of the course without touching the ground;
- Task 14: The person is asked to walk the wooden beam from end to end (4 meters) with eyes closed. *Pass criterion:* Maintain balance until the end of the course without touching the ground.

Statistical analysis

Normality of data distribution was confirmed by the Shapiro–Wilk test. Descriptive statistics (mean, frequency, and standard deviation) were used to present the results. Nominal variables were compared by the chi-squared test. In the presence of values lower than five, Fisher's exact test was applied. Statistically significant differences between fallers and non-fallers were determined by the Mann–Whitney *U* test. The receiver operating characteristic (ROC) curve was used to examine the sensitivity and specificity levels of the TEC test and to determine the cutoff point for fall risk. The area below the curve was considered as a reference for quantification of the predictor factor, which allowed discrimination between individuals with and without postural control disorder.⁴² Data were processed in SPSS, Version 24. The confidence level adopted was 5%.

RESULTS

Table 2 presents the main characteristics of the evaluated population, classified as fallers ($n = 18$; 64.61 ± 2.85 years) and non-fallers ($n = 56$; 65.21 ± 2.22 years). Considering the BMI cutoff points,⁴³ both groups had a relative degree of obesity ($p = 0.29$). The Mini-Mental Health Status Examination (MMSE) did not indicate any possible cases of dementia

Table 2. Main characteristics of the study participants.

Variable	Fallers (n = 18)	Non-fallers (n = 56)	p-value
Age (years)	63.22 ± 1.88	65.21 ± 2.22	0.17
60-69 (f)	11 (61.2%)	44 (78.50%)	
70-79 (f)	7 (38.8%)	12 (21.50%)	
Mass (kg)	71.79 ± 9.90	68.66 ± 11.24	0.46
Height (cm)	153.00 ± 0.88	162.00 ± 0.60	0.46
BMI (kg/m²)	30.70 ± 7.10	28.40 ± 6.90	0.29
MMSE	27.28 ± 2.12	27.40 ± 3.74	0.38
Medicines (day)	3.60 ± 1.50	2.40 ± 1.20	0.05
Exercise time (months)	19.70 ± 4.20	20.30 ± 4.50	0.06
Falls (last 12 months)	1.80 ± 0.90	-----	-----
Comorbidities			
Visual (f)			
Yes	16 (88.80%)	44 (78.52%)	0.76
No	2 (11.22%)	12 (21.44%)	
Hearing (f)			
Yes	6 (33.31%)	2 (3.61%)	0.45
No	12 (66.40%)	54 (96.46%)	
Vestibular dysfunction (f)			
Yes	8 (44.42%)	12 (21.43%)	0.73
No	10 (55.61%)	44 (78.67%)	
Hypertension (f)			
Yes	12 (66.64%)	11 (19.62%)	0.35
No	6 (33.42%)	45 (80.45%)	
Diabetes mellitus (f)			
Yes	1 (5.50%)	2 (3.60%)	0.15
No	17 (94.50%)	54 (96.42%)	
Body balance			
TEC	3.33 ± 3.72	5.74 ± 2.85	<0.001

F: frequency; BMI: Body Mass Index; MMSE: Mini-Mental State Examination; TEC: Body Balance Test; *Mann-Whitney *U* test ($p < 0.05$).

($p = 0.32$). No significant differences were observed for daily medication use and comorbidities ($p = 0.05$). The average Pilates practice time of the evaluated population was 19.95 ± 5.3 months ($p = 0.43$).

Regarding the total balance test score (TEC), according to the pass/fail norm of the test (Table 1), participants from the faller group showed poor performance and risk of falling. Conversely, participants with no history of falls attested good performance without risk of falling.

Table 3 presents the average results of the static and dynamic balance performance of both groups in the four dimensions considered for the examination of sensory regulation of body balance. Comparatively, non-fallers had higher performance scores on the SBIR, DBER, and DBIR dimensions. The lowest score observed for both groups was in the SBIR dimension ($p = 0.12$). Significant difference between fallers and non-fallers were found in the DBER ($p = 0.001$) and DBIR ($p = 0.03$) dimensions.

Figure 2 comparatively illustrates performance on the sensory condition of static and dynamic balance between fallers and non-fallers. Panel A shows the results of SBIR evaluation. Zero (0) scores were reported by 44.42% of participants (8/18) in the faller group and 10.74% (6/56) in the non-faller group. Panel B shows performance on the SBIR dimension. In this sensory condition, the largest deficit of the present study was verified, with 72.22% (13/18) of fallers and 66.15% (37/56) of non-fallers failing tasks. Panel C illustrates the results of DBER assessment. Impairments were verified in 44.42% (8/18) of the fallers and 8.93% (5/56) of non-fallers. Finally, panel D shows the results of DBIR assessment ($p = 0.020$). Impairments were observed in 66.74% (12/18) of fallers group and in 28.62% (16/56) of non-fallers ($p = 0.029$).

Figure 3 shows the ROC curve used to determine the levels of sensitivity and specificity of the identification

Table 3 – Average results of balance regulation performance, according to the dimensions of the TEC test.

Sensory balance regulation system	Fallers (n = 18)	Non-fallers (n = 56)	p-value
SBIR	1.38 $\pm$ 1.41	1.98 $\pm$ 1.09	0.09
SBIR	0.44 $\pm$ 0.85	0.43 $\pm$ 0.65	0.80
DBER	0.88 $\pm$ 1.02	2.00 $\pm$ 0.93	< 0.001
DBIR	0.61 $\pm$ 1.14	1.37 $\pm$ 1.20	0.02

SBIR: Static Balance Exteroceptive regulation; SBIR: Static Balance Interoceptive Regulation; DBER: Dynamic Balance Exteroceptive Regulation; DBIR: Dynamic Balance Interoceptive Regulation; * $p < 0.05$ (Mann-Whitney *U*).

Figure 2 – Static and dynamic balance performance evaluation scores, according to their corresponding exteroceptive and interoceptive regulation.

Figure 3 – ROC curve, sensitivity, and specificity values for determining the cutoff point of risk of falling (95%CI).

criteria for risk of falling in the evaluated population. Statistical analysis showed an area under the curve (AUC) of 0.738 (95%CI 0.58–0.88; $p = 0.003$), with a sensitivity level of 42.32%. Based on these coefficients, the test can be assumed to detect falls in older women who were considered fallers. The specificity obtained was 84.82%, which

denotes a high capacity of the TEC to discriminate older women who are not at risk of falling among those considered as such.

DISCUSSION

The aim of this study was to analyze the performance of the static and dynamic balance sensory strategies of 74 older women, all regular practitioners of physical exercise, with and without a prior history of falls. Secondly, we also sought to examine the sensitivity and specificity of the TEC test and determine its cutoff point for assessment of fall risk. Maintaining the upright position requires constant anticipatory adjustments to compensate for body oscillations and to keep body segments aligned.²² Disturbances in the visual, vestibular, and somatosensory systems make it difficult for the CNS to construct effective representations of the relationship between body segments and the environment.⁴⁴ For this reason, older adults with changes in functioning of these three systems are more susceptible to falls.^{6,21}

The relationship between falls and female sex is concise. In a study that interviewed women ($n = 878$; 72.20 ± 4.81) by phone in Lithuania to assess falls sustained in the past

12 months and to estimate their health costs, the authors found that one woman in three had fallen two or more times.¹⁰ In another investigation, based on examination of cross-sectional associations of data extracted from the Longitudinal Study of English Aging ($n = 4,301$), the main risk factors for falls in the older population were highlighted in men and women. Among women, incontinence ($OR = 1.48$), frailty ($OR = 1.69$), age ($OR = 1.02$), and depressive symptoms ($OR = 1.33$) were noted, while for men, inability to remain stable on single-leg support ($OR = 3.32$) was most prominent. For this reason, the authors suggested that planning of fall prevention strategies should consider specific interventions for each sex.¹¹

Previous studies have highlighted the benefits of exercise for sensory organ function and maintenance of postural control, especially in older adults.^{45,46} In one study that analyzed the effects of exercises based on the Pilates method (12 weeks) on confidence in balance, fear of falling, and postural control in postmenopausal women (≥ 60 years), the Pilates group had a lower fall fear score than the control group, as well as better response of the anteroposterior pressure center with eyes open and closed.⁴⁷ An experimental study subjected healthy German women (age 69.60 ± 3.00 years) to ten weeks of Pilates training and examined balance with the GGT. The results attested to a significant improvement in the ability of the three sensory systems to integrate information about static and dynamic posture.⁴⁸

The present study provides an important finding: although the faller group had an average time of 19 months of Pilates practice, their total TEC score still indicated a risk of falling. This result does not mean that exercise is not a protective factor against falls,^{14,49} but it does serve as a warning of the need for a detailed examination of the sensory regulation of body balance in older adults with a history of falls, since changes in postural control are directly linked to the aging process. Another interesting finding was that participants in the non-faller group also showed evidence of weak to moderate sensory dysfunction in the regulation of static and dynamic balance, although they did not show a risk of falling in the overall TEC test score.

Detailed diagnosis of the sensory condition of the SBIR dimension of the TEC test alerted to a possible impairment of optical flow in the evaluated population. The function of the exteroceptive sensory system is to provide the CNS with information about changes in body movement relative to objects placed in space. Campelo et al.²³ and Souza et al.²⁴ highlighted that regulation of gaze-foot coupling (termed the “vision-foot axis” by these authors) contributes substantially to the recovery of body balance, preventing fall events.

In the present study, optical flow performance issues were examined by tasks 1, 2, and 3 of the TEC, performed on single-leg support with eyes open. Oddsson et al.⁴⁵ and Zhao and Chung⁴⁹ highlighted the importance of this type of assessment, because proper functioning of static balance control demonstrates the individual's competence for independent functional walking. This ability is decisive for carrying out activities of daily living. In a study that examined and compared the performance of healthy young and older individuals on timed balance tests, Bohannon et al.⁵⁰ showed that many participants had difficulty balancing on one leg for 30 seconds. The authors found that, with decreasing age, both the duration of balance in single-leg stance and the number of individuals able to do so was greater. No participant over 70 years of age was able to balance with his or her eyes closed for more than 13 seconds on one leg; on the other hand, more than 75% of study participants aged 20 to 39 years were able to maintain stable balance on one leg for 30 seconds with their eyes closed.

In the same study, Bohannon et al.⁵⁰ found that the average duration of static balance of 70-year-olds was 14.20 ± 9.30 seconds with eyes open and 4.30 ± 3.00 seconds with the eyes closed. In the present study, the high prevalence of zero (0) scores in the SBIR category can be viewed as a red flag of vestibular system dysfunction in the study population (Figure 2). Caixeta et al.⁵¹ conducted a study with 86 older adults (age 60 to 81 years) with vestibular dysfunction. The authors found low functional balance capacity and observed a relationship of vestibular system disorders with body balance performance and cognitive processing capacity. This attests to the fact that falls are multifactorial events,^{23,26} and highlights the need for a multifactorial assessment to identify the risk of falls in older adults.^{3,15}

The performance deficit in the SBIR dimension may also be an indicator of impairments in sensory receptors located in the plantar region of the foot and ankle joints (changes in the somatosensory system). In older adults, these problems limit perception of plantar pressure and outflow of postural information to the CNS.¹⁵

In a study carried out with healthy individuals aged 65 to 76 years ($n = 20$), not practicing regular physical activity, and with no history of falls, use of benzodiazepines or antidepressants, prosthetics or orthotics, Toledo and Barela⁵² observed a relative increase in the level of anteroposterior postural oscillations resulting from reduced sensitivity of the plantar region. The authors observed the participants' limitations to perform dorsiflexion and plantarflexion of the ankle. For this reason, examination of body balance should include

procedures that analyze the motor and sensory performance of the body's base-of-support joints.^{33,53,54}

Evaluation of DT is important because, with aging, the performance of executive functions is affected, as is the combined performance of different motor tasks.⁵⁵ For this reason, older adults with cognitive impairment tend to exhibit slow walking patterns,⁵⁶ as well as difficulty with mathematical calculations or verbal tasks while ambulating.⁵⁷ All of these increase the risk of falling.⁴⁵ Among the four dimensions of sensory regulation of body balance examined by the TEC, statistically significant differences were observed for the dimensions of dynamic body balance (DBER, DBIR). Notably, 44.40% of participants in the faller group had a zero (0) score in the DBER (exteroceptive dynamic balance regulation) task set, while in the non-faller group, only 8.9% failed these tasks. Performance on task 13 attested that both groups presented a deficit for postural adjustments for DT task resolution. Literature reviews⁵⁵ and meta-analyses⁴⁶ have highlighted that attempting two or more tasks concomitantly causes interference and conflict in sending postural information to the CNS, particularly in older adults.

The second highest prevalence of zero (0) scores in both groups was observed in the DBIR dimension (interoceptive dynamic balance regulation); 66.67% of fallers and 28.62% of non-fallers presented postural adjustments deficits in these tasks. Toledo and Barela⁵² warned that proprioceptive balance regulation is not just a sensory task. This evaluation requires the investigation of motor responses that originate in the articular perception of the movements. Deficits in these functions are indicative of changes in the CNS afferent or efferent pathways.

A previous systematic review,⁵⁸ as well as individual experimental^{14,48} and correlational studies,³⁹ highlighted the efficiency and practicality of the TEC for postural examination of older women who engage in regular physical exercise. Therefore, as a secondary objective, we performed analysis of the area under the ROC curve to compare agreement between total mean scores achieved by the faller and non-faller groups and the cutoff point suggested by the TEC norms for diagnosis of fall risk.

The estimated probability model was statistically significant and high. The properties of the test can be considered excellent, with a predictive value able to discriminate 73% of fall events among the evaluated population.⁴² According to the statistical analysis, the best sensitivity and specificity value found was 3.51 tasks solved. This result can be assumed as the gold standard capable of indicating the risk of falling in the evaluated population. Considering that the average performance was 5.74 ± 2.95 tasks among non-fallers and

3.33 ± 3.72 tasks among fallers ($p = 0.000$), the results corroborated the value suggested by the ROC curve to identify risk of falling, as well as confirming the validity of the TEC test norms (Table 1). The specificity coefficient found was high at 84.84%; the sensitivity level of 42.35% is only moderate, however, it should be considered that falls are multifactorial events.^{6,23,26}

It is noteworthy that the results offered by the TEC test measure only one facet of the risk of falling in this particular population (i.e., older women who practice regular exercise). It is known that a model capable of predicting falls more broadly should consider other factors, such as gait pattern,^{36,45} polypharmacy,⁶ executive functions,^{51,55} coefficients of strength and flexibility,²⁶ and related aspects, such as confidence in balance and fear of falling.⁶

Limitations

The present study has limitations. First, the membership of the two groups was disproportionate. However, the number of participants in the faller group represented 24.32% of the total sample. This is very close to the international specialized literature, which estimates the percentage of older adult fallers at 28 to 32%. Secondly, the faller and non-faller groups were composed of sexagenarian and septuagenarian subjects; therefore, the number of individuals in their 70s was small. Thus, although aware that age is a risk factor for falls and a greater probability of disturbances in the sensory balance regulation system, we did not compare the results of the TEC test by age groups. In doing so, we avoided statistical bias due to the small sample size of the faller group. Third, information on hearing problems was self-reported and not attested by clinical examination performed by specialized audiologists; this may have been a source of bias.

CONCLUSION

Among older women engaging in regular physical exercise, there was weak to severe impairment in the systems responsible for sensory regulation of static and dynamic balance, regardless of whether there was a prior history of falls. Statistical analysis confirmed that the TEC test has good reliability and can be used to assess the sensory regulation of body balance in populations similar to that of this study. Although it is accepted that the TEC test cannot replace sophisticated laboratory tests such as force platforms, electromyography, and photo film systems, it has several advantages for clinical use, and allowed evaluation of postural control parameters that are not generally considered by conventional functional tests used in geriatric practice.

What does this article add?

This study provided specific information about the postural control deficit of older women who regularly practice physical exercise. The findings showed that even older adults with adequate levels of physical fitness have problems with their sensory balance regulation systems (vision, hearing, proprioception). This means that the physiological changes caused by the human aging process are present in older adults, especially among individuals with a history of falls. This study also showed that the TEC has good levels of sensitivity and specificity and is an adequate instrument for examining the postural control of healthy older adults who exercise. The test has scoring norms for age groups and sexes. It is able to differentiate performance on static and dynamic balance tasks, according to the interoceptive and exteroceptive sensory regulation systems. Our results offer useful practical information for future

procedures in the area of clinical evaluation and the development of effective interventions based on physical exercise.

CONFLICTS OF INTEREST

The authors declare a potential conflict of interest due to participation in the validation of the TEC test.

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AUTHOR'S CONTRIBUTION

MMN: conceptualization, formal analysis, writing — original draft, writing — review & editing. PSTS: data curation, writing — original draft.

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