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Longitudinal Changes in Postural Stability in Older Adults: An Exploratory Comparison of Two Community-Based Physical Activity Cohorts

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Abstract

Postural stability is an important component of functional health in older adults; however, longitudinal observations from routine community physical activity programs remain limited. This exploratory secondary observational analysis compared changes in postural stability between two archival cohorts of University of the Third Age participants assessed over different observation periods. The dataset comprised 48 paired assessment records representing 43 unique participants. Five individuals appeared in both historical datasets; therefore, the primary independent comparison included 24 participants in the longer-observation cohort and 19 in the shorter-observation cohort. The respective intervals between baseline and follow-up assessments were 408–568 and 21–76 days. The cohorts corresponded to programs offering 77 and eight scheduled physical activity sessions, respectively, although individual attendance was not documented. Postural stability was assessed using the HUMAC Balance System under two 30-s firm-surface conditions with eyes open and eyes closed. Ten outcomes were evaluated using Wilcoxon signed-rank tests for within-cohort changes and Mann–Whitney U tests for between-cohort differences in change scores, with Holm adjustment for multiple comparisons. No outcome changed significantly in the longer-observation cohort after adjustment. In the shorter-observation cohort, the eyes-closed sway index and eyes-closed stability score (ECSS) changed in a less favorable direction (Holm-adjusted $p = 0.043$ and $p = 0.048$, respectively). Between-cohort differences in change were significant for both outcomes (Holm-adjusted $p = 0.019$ for each; rank-biserial correlations −0.553 and 0.557, respectively). Sensitivity analyses using alternative strategies to exclude overlapping records retained the statistical significance of these findings. The results demonstrate differences in selected eyes-closed postural stability measurements between archival cohorts; however, scheduled activity exposure and follow-up duration were inseparable. Consequently, the findings do not establish an independent effect of exercise duration or preservation of postural control attributable to physical activity. Prospective studies with comparable observation intervals and verified individual exercise exposure are required to determine their clinical significance.

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1. Introduction

Falls are a major public health problem in the aging population. According to the World Guidelines for Falls Prevention and Management, approximately one-third of adults aged > 65 years experience at least one fall annually, with consequences including injuries, loss of independence, reduced quality of life, and increased mortality [1,2]. Aging is associated with progressive changes in the nervous, musculoskeletal, and sensory systems that may affect the ability to maintain balance and respond effectively to postural perturbations. Consequently, preservation of functional capacity and postural control is an important component of healthy aging [3]. Falls among older adults often occur during daily activities and can cause injuries, reduced independence, and functional decline. The consequences of falls depend on several interacting factors, including the circumstances of the fall, body configuration, and capacity to respond to postural disturbances [4,5]. These observations underscore the importance of understanding postural control in older adults, particularly in community settings, where routine physical activity and functional assessments can be integrated into ongoing health promotion.

Postural control depends on the integration of sensory information and the coordinated responses of the neuromuscular system to individual, task-related, and environmental requirements. Regular physical activity involving balance, coordination, and functional movements may support postural performance among older adults. However, evidence obtained from structured training interventions cannot be directly extrapolated to routine community exercise programs in which actual participation and exercise intensity may vary.

Falls and postural instability are closely related to the integration of sensory information. The removal of visual input increases the contribution of vestibular and somatosensory information to postural control and may reveal deficits that are less evident during eyes-open standing [6]. Age-related changes in sensory organization can affect the ability to maintain stability under altered sensory conditions.

Peterka and Black demonstrated age-related changes in postural control when visual or somatosensory information was manipulated, highlighting the importance of sensory integration in maintaining upright posture in older adults [7].

Physical exercise is increasingly recognized as an important strategy for maintaining balance and reducing falls among older adults. A systematic review and meta-analysis by Papalia et al. reported improvements in both static and dynamic balance following physical exercise, along with reduced fall-related outcomes in older adults [8]. Similarly, a Cochrane systematic review concluded that exercise programs reduce fall rates and the proportion of community-dwelling older adults who experience falls, with the strongest evidence associated with programs incorporating balance and functional exercises [9]. Balance-specific training may also produce measurable improvements in balance performance, although the magnitude of adaptation depends on the training duration, frequency, and volume [10].

Current international recommendations consequently emphasize regular multicomponent physical activity in older adults, including activities that challenge functional balance and strength [3,11]. However, much of the existing evidence was generated in structured prospective intervention studies. Less is known about whether sustained participation

in routine, community-based physical activity programs is associated with longitudinal maintenance of postural stability under real-world conditions.

University of the Third Age programs provide a community setting for regular physical activity and repeated functional assessment among older adults. However, longitudinal postural stability data collected during routine participation remain insufficiently characterized. Although archival cohorts with different observation intervals and scheduled program exposure cannot isolate the effects of exercise duration, their comparison can identify patterns of change in routinely recorded outcomes and inform the selection of measures and assessment intervals for future prospective studies. The scientific value of this comparison therefore lies in characterizing the available longitudinal observations and generating hypotheses for subsequent testing.

The aim of this exploratory secondary analysis was to describe and compare changes in postural stability between baseline and follow-up in two archival cohorts of University of the Third Age participants enrolled in routine community-based physical activity programs. All ten postural stability parameters recorded using the HUMAC Balance System were examined, including eyes-open and eyes-closed conditions. Because the cohorts differed simultaneously in scheduled program exposure and observation intervals, the comparison concerned changes across two distinct observation settings and could not estimate an independent effect of exercise duration. No directional hypothesis regarding exercise exposure duration was prespecified.

2. Materials and Methods

2.1. Study Design

This study was an exploratory secondary observational analysis of archival pre- and post-assessment records generated during routine community-based educational and physical activity classes. The investigators did not introduce, assign, or modify the exercise classes for research purposes. Volunteers enrolled in the usual University of the Third Age activity program, and the recorded functional assessments documented their postural stability during participation.

The archival dataset contained 48 paired assessment records: 24 from the longer-observation cohort and 24 from the shorter-observation cohort. Record linkage identified five individuals represented in both datasets, leaving 43 unique participants in the study. To ensure independence in the primary between-cohort comparison, all 24 participants from the longer-observation cohort were retained, whereas the five overlapping records were excluded from the shorter-observation cohort. Therefore, the primary analysis compared 24 and 19 independent participants. Sensitivity analyses were performed to examine alternative strategies for handling overlapping participants.

The two cohorts differed in scheduled physical activity exposure and the time elapsed between baseline and follow-up assessments. These dimensions were inherently confounded, with no overlap in observation intervals between cohorts. Accordingly, the between-cohort analysis estimated differences in observed pre-post changes across two distinct archival assessment periods, rather than an independent association between exercise exposure duration and postural stability.

All ten postural stability parameters available in the participant-level source dataset were included in the reanalysis. No balance outcome was excluded based on statistical significance.

2.2. Participants

The source records represented 43 unique adults attending regular physical activity classes organized within a University of the Third Age program in Warsaw, Poland. En-

rollment followed the University's standard procedure for participation in its educational and recreational activities. Information about available classes, including regular physical activity sessions, was communicated through routine program announcements. Interested individuals voluntarily enrolled in these activities in the same manner as participants attending other University of the Third Age classes. No research-specific recruitment, random allocation, or investigator-assigned exercise intervention was undertaken.

Eligibility for participation in the regular classes required an age of at least 55 years and medical clearance confirming no contraindications to physical exercise. Participation in the HUMAC Balance assessments required separate written informed consent. The activities were delivered as part of the university's usual educational and physical activity program rather than as an intervention designed for research purposes.

Postural stability assessments were conducted during regular program participation, providing longitudinal observations of attendees under routine community conditions. The present study represents a secondary analysis of these previously collected assessment records.

The archival dataset included 24 participants in the longer-observation cohort and 24 assessment records in the shorter-observation cohort. Five individuals appeared in both datasets. After excluding their overlapping records from the shorter-observation cohort, the primary independent comparison included 24 and 19 participants, respectively.

The analytical sample was restricted to participants with available paired baseline and follow-up assessment records. The archival documentation did not permit determination of the total number of eligible program participants, the proportion who underwent assessment, or the extent of loss to follow-up and reasons for unavailable follow-up measurements. Assessment participation rates and attrition could therefore not be quantified, and potential selection bias associated with the availability of paired records could not be evaluated.

The independent analysis population comprised 43 participants (41 women and two men). Participants ranged in age from 55 to 80 years, and 15 participants (34.9%) were younger than 65 years. The predominance of women and the voluntary nature of participation in a single community program should be considered when interpreting the generalizability of these findings.

2.3. Physical Activity Program

The physical activity classes were conducted in a gymnasium setting as part of the regular University of the Third Age program at the Wola District Sports and Recreation Center in Warsaw, Poland. The classes were routinely offered community activities and were not designed or modified as a research-specific exercise intervention.

Classes were scheduled once weekly, with each session lasting approximately 45 min. The activities included aerobic, breathing, balance, and stretching exercises and were intended to promote general physical activity among community-dwelling older adults rather than to provide a standardized therapeutic or progressive balance-training intervention. The archival records corresponded to two observation periods associated with different segments of the regular activity program. The longer-observation dataset was associated with a program schedule comprising 77 weekly sessions over approximately 19 months, whereas the shorter-observation dataset corresponded to a segment comprising eight scheduled sessions. These figures represent the number of sessions offered rather than the number of sessions attended by each participant. Individual attendance records were not available for the present reanalysis, and the actual exercise dose could therefore not be established.

The time elapsed between baseline and follow-up assessments ranged from 408 to 568 days (median 521 days) in the longer-observation cohort and from 21 to 76 days (median 67 days) in the shorter-observation cohort. Thus, the scheduled program duration and

observation time were inherently confounded. The two cohorts cannot be considered groups receiving different verified exercise doses over a comparable follow-up period.

Consequently, the present analysis compares observed changes in postural stability across two archival observation periods and does not permit estimation of an independent effect of program participation duration or exercise dose.

2.4. Postural Stability Assessment

Postural stability was assessed using the HUMAC Balance System (Computer Sports Medicine, Inc. [CSMi], Stoughton, MA, USA) [12,13]. The system provides instrumented measurements of postural control based on changes in the center of pressure (COP) [13]. Participants completed the original assessments during routine participation in University of the Third Age activities, following written informed consent for the balance examination.

The assessment protocol comprised two static standing conditions performed on a firm surface: eyes open (EO) and eyes closed (EC). Each condition lasted 30 s. The EO condition assessed postural control with visual information available, whereas the EC condition assessed postural control in the absence of visual input. The eyes-open trial was performed first, followed by the eyes-closed trial, as documented in the original source thesis.

No foam-surface conditions were included. Accordingly, the protocol represented a limited, two-condition assessment of static postural stability and should not be described as a complete modified Clinical Test of Sensory Interaction on Balance (mCTSIB).

Ten parameters were extracted from the archival assessment records: EO sway index, EO overall stability index, EO medio-lateral (M/L) stability index, EO anterior–posterior (A/P) stability index, EC sway index, EC overall stability index, EC M/L stability index, EC A/P stability index, eyes-open stability score (EOSS), and eyes-closed stability score (ECSS).

The sway and stability indices were retained under their original labels in the archived dataset. The percentage-based EOSS and ECSS values were also retained as originally recorded. These parameters were analyzed as device-derived measures of postural performance without assuming that all ten represented statistically or physiologically independent constructs.

Archived documentation did not identify the exact version of the HUMAC Balance software Version HUMAC2015 used during the original assessments. Consequently, precise calculation methods, measurement units, and mathematical relationships among all reported indices and percentage scores could not be independently verified from the available records. No retrospective reconstruction of proprietary scoring algorithms was attempted.

Eyes-closed measurements were interpreted as indicators of postural control under reduced visual sensory input, rather than as isolated measures of vestibular or proprioceptive function. Because the archival protocol comprised a single documented 30-s trial per condition, the available records did not permit estimation of within-session measurement variability or test–retest reliability.

According to the original source thesis, the EOSS and ECSS were reported as percentages referenced to age-related population norms, whereas the remaining indices were reported as numerical values. The exact proprietary calculations underlying these scores could not be independently verified.

2.5. Data Provenance and Analysis Set

The present study is based on original longitudinal postural stability assessments performed among participants attending regular University of the Third Age activities in Warsaw, Poland. The measurements were conducted using the HUMAC Balance System, with written informed consent obtained from the participants. Selected findings from these assessments were previously documented in an academic master's thesis [14]. The

original participant-level assessment records, rather than the aggregated results reported in the thesis, constituted the primary data source for the present exploratory secondary analysis. The current investigation involved the reconciliation of historical assessment records, identification of overlapping participants, reconstruction of independent analytical cohorts, and reanalysis of the available postural stability outcomes using a consistent statistical approach.

The available analytical dataset comprised 48 paired assessment records representing 43 unique individuals. Five participants were identified in both the historical observation datasets. To avoid treating repeated records from the same individual as independent observations, the primary between-cohort analysis retained 24 participants from the longer-observation cohort and 19 non-overlapping participants from the shorter-observation cohort. Alternative approaches to handling the overlapping records were examined in sensitivity analyses. The reanalysis included all ten postural stability parameters for which complete paired participant-level values were available. No missing balance values were imputed, and no recorded balance outcome was excluded on the basis of its statistical significance.

The original thesis also reported findings concerning depressive symptoms assessed using the Geriatric Depression Scale. However, the available participant-level data did not provide a complete and independently reconcilable basis for reassessing these outcomes under the corrected participant structure. Therefore, depressive symptom outcomes were excluded from the present analysis to avoid reporting results that could not be independently verified.

2.6. Other Variables

Age, sex, body height, baseline body mass, and baseline body mass index (BMI) were available for the descriptive characterization of the participants. BMI was calculated as body mass in kilograms divided by height in meters squared (kg/m^2). Follow-up body mass and BMI were not treated as efficacy outcomes in the present reanalysis because diet, body composition, physical activity outside the program, and measurement context were not controlled. Information on relevant potential confounders, including comorbidities, medication use, and physical activity outside the University of the Third Age program, was not available in the analytical dataset. Therefore, these factors could not be accounted for in the present analysis.

2.7. Statistical Analysis

The original statistical analysis accompanying the archival records was performed using STATISTICA version 13.1 (StatSoft Inc., Tulsa, OK, USA). We recomputed the statistical results presented in the current secondary analysis using Python version 3.13.5, NumPy version 2.3.5, and SciPy version 1.17.0. Non-parametric statistical methods were used because of the small sample size and the distributional characteristics of the recorded outcomes. These methods were applied to paired within-cohort observations and independent between-cohort comparisons, as appropriate.

Continuous variables were summarized primarily as medians and interquartile ranges (IQRs). Means and standard deviations were used where appropriate for comparison with the historical documentation. Baseline continuous characteristics were compared between the independent cohorts using the Mann–Whitney U test, while sex distributions were compared using Fisher's exact test. Baseline comparisons were descriptive and were not interpreted as demonstrating equivalence between cohorts. Within-cohort changes between baseline and follow-up were assessed using the Wilcoxon signed-rank test.

For each outcome and cohort, 95% confidence intervals for median individual changes (follow-up minus baseline) were estimated using 7000 participant-level bootstrap resam-

ples with replacement. The NumPy random generator was initialized separately for each outcome using a fixed seed (20261018), and confidence intervals were calculated using the percentile method (2.5th and 97.5th percentiles).

These confidence intervals were descriptive and not adjusted for multiple comparisons. The complete within-cohort results are presented in Supplementary Table S1.

Individual change scores were calculated as follow-up minus baseline. Differences in change-score distributions between the independent cohorts were evaluated using the Mann–Whitney U test. All hypothesis tests were two-sided. Wilcoxon signed-rank tests were performed using SciPy version 1.17.0.'s automatic *p*-value calculation method, with zero differences excluded according to the default Wilcoxon convention. Mann–Whitney U tests were performed using the automatic method, which selected the asymptotic approach for the present sample sizes. Ties were handled according to the corresponding SciPy implementations.

Rank-biserial correlation coefficients were used to describe the magnitude and direction of between-cohort differences. For the two principal eyes-closed outcomes, 95% confidence intervals for rank-biserial correlations were estimated using a stratified percentile bootstrap with 7000 resamples, independently resampling participants within each cohort.

A NumPy random generator initialized with seed 20261018 was used separately for each outcome, with 7000 stratified bootstrap resamples per outcome. Percentile-based 95% confidence intervals were calculated using the 2.5th and 97.5th percentiles of the bootstrap effect size distributions.

The bootstrap estimates were obtained from the primary independent analysis set comprising 24 and 19 participants, respectively. All ten postural stability outcomes available in the archival analytical dataset were included in the reanalysis. To control the family-wise error rate, Holm's step-down correction was applied separately to three families of ten tests: within-cohort changes in the longer-observation cohort, within-cohort changes in the shorter-observation cohort, and between-cohort comparisons of change scores. Both unadjusted and Holm-adjusted *p*-values were reported, with adjusted *p*-values below 0.05 considered statistically significant. The use of ten potentially correlated device-derived outcomes was retained to provide a complete account of the available measurements. However, related outcomes were not interpreted as independent confirmation of the same physiological finding. Sensitivity analyses examined two alternative strategies for handling the five participants represented in both archival datasets: exclusion of these individuals from both cohorts (19 versus 19 participants) and exclusion from the longer-observation cohort while retaining their shorter-observation records (19 versus 24 participants). These analyses assessed the influence of overlapping records on the observed between-cohort differences. As an additional exploratory analysis, separate analysis-of-covariance (ANCOVA) models were fitted for EC sway index and ECSS. In each model, the follow-up outcome was the dependent variable, cohort membership (shorter-observation cohort versus longer-observation cohort) was the main explanatory variable, and participant age and the corresponding baseline outcome were included as covariates. Ordinary least-squares regression was used with heteroscedasticity-robust HC3 standard errors. Adjusted cohort coefficients, 95% confidence intervals, and two-sided *p*-values were calculated. These supplementary model-based *p*-values were not adjusted for multiple testing.

Model diagnostics included the assessment of residual distributions, heteroscedasticity, functional form, multicollinearity, and influential observations. Leave-one-out analyses and alternative model specifications were examined to assess the stability of the cohort coefficients. These diagnostic analyses were considered exploratory.

The models were not intended to estimate a causal effect of exercise duration because the observation time and scheduled program exposure were inseparable.

The primary analytical dataset was reconstructed using five confirmed participant-level linkages between the historical cohorts. These linkages were established by comparing the original, non-anonymized records before pseudonymization. Participant correspondence and the assigned pseudonyms were documented to preserve linkage across the analytical datasets without disclosing identifying information.

All statistical comparisons were interpreted as exploratory analyses. Because the scheduled program exposure and follow-up duration differed simultaneously between cohorts, the analyses did not estimate the independent effect of exercise duration. Statistical significance was not considered evidence of causality, clinical importance, or equivalence in the absence of detected differences.

2.8. Ethical Considerations

The original physical activity classes were conducted as part of the regular University of the Third Age program. Participants voluntarily enrolled in these activities, which were neither introduced, assigned, nor modified for research purposes. No experimental exercise intervention or random allocation was performed. Postural stability assessments using the HUMAC Balance System were performed with the voluntary participation of individuals attending the regular classes. The original purpose of these assessments was to provide participants with individual postural stability results. The measurements were not introduced as part of an investigator-assigned research intervention.

Before undergoing the assessments, participants provided written informed consent using a dedicated form entitled "Consent to Participate in a Balance Assessment Using the HUMAC Balance Platform." The form identified the examiner, her institutional affiliation with the Medical University of Warsaw, and confirmed that participants had been informed about the purpose and general procedure of the examination. Consent was documented by the participant's dated signature.

The decision to undertake a scientific analysis of the previously collected longitudinal assessment records was made subsequently. The present study therefore constitutes a retrospective secondary observational analysis of archival data. The reanalysis was conducted using de-identified participant records and involved no additional examinations, interventions, or renewed participant contact. No prospective bioethics committee opinion was obtained for the original routine community activity program. The original consent form documented agreement to undergo balance assessment but did not explicitly address subsequent secondary research use or publication of the assessment data. No formal ethics committee determination was obtained for the subsequent secondary analysis of the archival assessment records.

3. Results

3.1. Source Dataset and Participant Characteristics

The available archival analytical dataset contained 48 paired postural stability assessment records representing 43 unique participants. Twenty-four records belonged to the longer-observation dataset and 24 to the shorter-observation dataset. Five individuals were represented in both datasets. To ensure independence of observations, the primary between-cohort analysis retained 24 participants from the longer-observation cohort and 19 non-overlapping participants from the shorter-observation cohort. Women predominated in both cohorts: 23 of 24 participants (95.8%) in the longer-observation cohort and 18 of 19 (94.7%) in the independent shorter-observation cohort. Sex distribution did not differ significantly between cohorts (Fisher's exact $p = 1.000$).

The overall age range was 55–80 years. In the longer-observation cohort, participants were aged 55–80 years, with 11 of 24 (45.8%) younger than 65 years. In the independent

shorter-observation cohort, the age range was 62–80 years, with four of 19 (21.1%) younger than 65 years. The median age was 65.0 years [62.8–71.5] in the longer-observation cohort and 67.0 years [65.5–73.5] in the shorter-observation cohort ($p = 0.166$). Median baseline BMI was 28.04 kg/m^2 [26.31–30.57] and 28.39 kg/m^2 [26.89–32.07], respectively ($p = 0.633$).

None of the ten baseline postural stability measures showed a statistically significant between-cohort difference (all unadjusted $p > 0.18$). However, these non-significant comparisons do not establish baseline equivalence, particularly given the small sample size and the non-randomized composition of the cohorts. Descriptive differences in baseline measurements, including the eyes-closed sway index and eyes-closed stability score, were retained for consideration in the subsequent analyses.

The baseline demographic characteristics and postural stability measurements are presented in Table 1.

Table 1. Baseline demographic characteristics and postural stability measurements in the independent longer- and shorter-observation cohorts.

Characteristic	Longer Observation ($n = 24$)	Shorter Observation ($n = 19$)	p Value
Age, years	65.0 [62.8, 71.5]	67.0 [65.5, 73.5]	0.166
Female sex, n (%)	23 (95.8)	18 (94.7)	1.000
BMI, kg/m^2	28.04 [26.31, 30.57]	28.39 [26.89, 32.07]	0.633
EO sway index	0.27 [0.22, 0.29]	0.23 [0.17, 0.29]	0.186
EO overall stability index	6.08 [5.19, 6.93]	5.90 [5.11, 6.38]	0.293
EO M/L stability index	0.67 [0.29, 0.96]	0.51 [0.42, 1.02]	0.864
EO A/P stability index	6.08 [5.14, 6.89]	5.81 [5.08, 6.17]	0.271
EC sway index	0.29 [0.27, 0.36]	0.27 [0.24, 0.33]	0.230
EC overall stability index	6.30 [5.37, 6.71]	5.83 [5.41, 6.37]	0.334
EC M/L stability index	0.71 [0.39, 0.91]	0.61 [0.46, 0.95]	0.932
EC A/P stability index	6.29 [5.28, 6.67]	5.82 [5.35, 6.29]	0.322
EOSS	88 [87, 90]	89 [88, 92]	0.273
ECSS	86 [83, 87]	87 [84, 88]	0.253

Continuous values are presented as median [interquartile range]. Between-cohort comparisons used the Mann–Whitney U test; sex distribution was compared with Fisher's exact test. BMI, body mass index; EO, eyes open; EC, eyes closed; M/L, medio-lateral; A/P, anterior-posterior; EOSS, Eyes Open Stability Score; ECSS, Eyes Closed Stability Score.

3.2. Physical Activity Exposure and Primary Analysis Set

The longer-observation cohort was associated with 77 scheduled weekly physical activity sessions, whereas the shorter-observation cohort corresponded to a segment of eight scheduled sessions. The intervals between baseline and follow-up assessments ranged from 408 to 568 days (median 521 days) and from 21 to 76 days (median 67 days), respectively. Individual attendance was not verified, and scheduled activity exposure was inseparable from observation duration.

3.2.1. Within-Cohort Changes

In the longer-observation cohort ($n = 24$), none of the ten postural stability outcomes demonstrated a statistically significant change after Holm adjustment. The median EC sway index was 0.29 [0.27–0.36] at baseline and 0.28 [0.26–0.33] at follow-up. The corresponding EC stability score (ECSS) was 86 [83–87] and 87 [85–89], respectively. These findings indicate an absence of statistically detected change, rather than demonstrating equivalence or maintenance of postural stability.

In the independent shorter-observation cohort ($n = 19$), two eyes-closed outcomes showed statistically significant changes after Holm adjustment. The median EC sway index increased from 0.27 [0.24–0.33] to 0.35 [0.32–0.41] (unadjusted $p = 0.004$; Holm-adjusted

$p = 0.043$), while ECSS decreased from 87 [84–88] to 84 [79–86] (unadjusted $p = 0.005$; Holm-adjusted $p = 0.048$). Both changes were in the direction of less favorable device-derived postural stability measurements.

No other within-cohort change remained statistically significant after multiplicity adjustment. Complete results for all ten outcomes are presented in Table 2.

Table 2. Within-cohort changes in all 10 postural stability outcomes in the primary analysis set.

Observation Cohort	Outcome	Baseline Median [IQR]	Follow-Up Median [IQR]	*p*	Holm-Adjusted *p*
Longer observation ($n = 24$)	EO sway index	0.27 [0.22, 0.29]	0.24 [0.15, 0.30]	0.330	1.000
	EO overall stability index	6.08 [5.19, 6.93]	6.21 [5.81, 6.60]	0.819	1.000
	EO M/L stability index	0.67 [0.29, 0.96]	0.29 [0.18, 1.02]	0.786	1.000
	EO A/P stability index	6.08 [5.14, 6.89]	6.13 [5.62, 6.59]	0.954	1.000
	EC sway index	0.29 [0.27, 0.36]	0.28 [0.26, 0.33]	0.415	1.000
	EC overall stability index	6.30 [5.37, 6.71]	6.26 [5.84, 6.71]	0.565	1.000
	EC M/L stability index	0.71 [0.39, 0.91]	0.52 [0.37, 0.90]	0.920	1.000
	EC A/P stability index	6.29 [5.28, 6.67]	6.12 [5.77, 6.67]	0.726	1.000
	EOSS	88 [87, 90]	89 [87, 93]	0.242	1.000
	ECSS	86 [83, 87]	87 [85, 89]	0.115	1.000
Shorter observation ($n = 19$)	EO sway index	0.23 [0.17, 0.29]	0.28 [0.23, 0.34]	0.116	0.931
	EO overall stability index	5.90 [5.11, 6.38]	5.48 [4.45, 5.93]	0.134	0.935
	EO M/L stability index	0.51 [0.42, 1.02]	0.57 [0.26, 0.72]	0.490	1.000
	EO A/P stability index	5.81 [5.08, 6.17]	5.45 [4.25, 5.90]	0.196	1.000
	EC sway index	0.27 [0.24, 0.33]	0.35 [0.32, 0.41]	0.004	0.043
	EC overall stability index	5.83 [5.41, 6.37]	5.86 [4.61, 6.27]	0.324	1.000
	EC M/L stability index	0.61 [0.46, 0.95]	0.61 [0.40, 0.81]	0.559	1.000
	EC A/P stability index	5.82 [5.35, 6.29]	5.83 [4.51, 6.19]	0.420	1.000
	EOSS	89 [88, 92]	88 [84, 91]	0.192	1.000
	ECSS	87 [84, 88]	84 [79, 86]	0.005	0.048

Values are median [interquartile range]. Within-cohort comparisons used the Wilcoxon signed-rank test. Holm-adjusted *p*-values were used to control the family of 10 postural stability tests separately within each observation cohort. EO, eyes open; EC, eyes closed; M/L, medio-lateral; A/P, anterior–posterior; EOSS, Eyes Open Stability Score; ECSS, Eyes Closed Stability Score.

Bootstrap confidence intervals were estimated for the medians of individual changes. In the longer-observation cohort, the median EC sway index change was −0.005 (95% CI: −0.050 to 0.030), while the median ECSS change was 0.5 (95% CI: −1.0 to 4.0). In the shorter-observation cohort, the corresponding changes were 0.070 (95% CI: 0.040 to 0.110) and −3.0 (95% CI: −5.0 to −2.0), respectively. Complete results for all ten outcomes in both cohorts are provided in Supplementary Table S1.

3.2.2. Between-Cohort Comparisons

The primary independent comparison identified statistically significant differences in the change score distributions for the two eyes-closed outcomes.

For EC sway index, the median change was −0.005 [−0.068, 0.043] in the longer-observation cohort and 0.070 [0.035, 0.110] in the shorter-observation cohort (unadjusted $p = 0.002$; Holm-adjusted $p = 0.019$; rank-biserial correlation = −0.553).

For ECSS, the corresponding median changes were 0.5 [−1.0, 4.0] and −3.0 [−6.5, −0.5], respectively (unadjusted $p = 0.002$; Holm-adjusted $p = 0.019$; rank-biserial correlation = 0.557). Bootstrap 95% confidence intervals for the between-cohort rank-biserial correlations were

−0.811 to −0.252 for EC sway index (point estimate: −0.553) and 0.257 to 0.816 for ECSS (point estimate: 0.557).

These intervals describe the sampling uncertainty of the rank-based effect estimates in the reconstructed, independent analysis set. Although neither interval included zero, the estimates should be interpreted in the context of the small sample size, the potentially related nature of the two eyes-closed measures, and substantial differences in observation intervals between cohorts.

No other between-cohort comparison remained statistically significant after Holm adjustment. The complete results are presented in Table 3.

Table 3. A comparison across cohorts of changes in ten indicators of postural stability in the main independent dataset for analysis.

Outcome	Longer Observation ($n = 24$) Δ Median [IQR]	Shorter Observation ($n = 19$) Δ Median [IQR]	p	Holm-Adjusted p	r_rb
EO sway index	−0.015 [−0.070, 0.023]	0.030 [−0.060, 0.105]	0.123	0.985	−0.279
EO overall stability index	0.125 [−0.412, 0.807]	−0.380 [−1.120, 0.200]	0.133	0.985	0.272
EO M/L stability index	−0.015 [−0.443, 0.193]	0.010 [−0.485, 0.265]	0.769	1.000	0.055
EO A/P stability index	0.090 [−0.565, 0.830]	−0.320 [−1.150, 0.255]	0.245	0.985	0.211
EC sway index	−0.005 [−0.068, 0.043]	0.070 [0.035, 0.110]	0.002	0.019	−0.553
EC overall stability index	0.035 [−0.310, 0.700]	−0.320 [−0.615, 0.465]	0.133	0.985	0.272
EC M/L stability index	−0.020 [−0.440, 0.472]	0.010 [−0.440, 0.210]	0.741	1.000	0.061
EC A/P stability index	0.020 [−0.380, 0.773]	−0.320 [−0.640, 0.545]	0.261	0.985	0.204
EOSS	1.0 [−1.2, 3.0]	−1.0 [−4.5, 2.5]	0.124	0.985	0.276
ECSS	0.5 [−1.0, 4.0]	−3.0 [−6.5, −0.5]	0.002	0.019	0.557

Δ = follow-up minus baseline; median [IQR]. Bootstrap 95% CIs for the two principal outcomes: EC sway index, −0.811 to −0.252; ECSS, 0.257 to 0.816. Between-cohort rank-biserial confidence intervals were not estimated for the other eight outcomes.

3.2.3. Supplementary Baseline- and Age-Adjusted Analyses

In exploratory ANCOVA models adjusting for participant age and the corresponding baseline outcome, between-cohort differences remained in the same direction as the unadjusted change-score comparisons. For EC sway index, the adjusted coefficient for the shorter-observation cohort relative to the longer-observation cohort was 0.0836 (95% CI: 0.0215 to 0.1456; $p = 0.0083$). For ECSS, the corresponding coefficient was −4.914 (95% CI: −7.962 to −1.865; $p = 0.0016$). The EC sway index model had an R^2 of 0.415 and an adjusted R^2 of 0.370; the corresponding values for the ECSS model were 0.414 and 0.369.

These estimates represent adjusted differences in follow-up outcomes conditional on age and baseline measurements. The model-based p-values were not adjusted for multiple testing.

RESET tests suggested possible model misspecification for both EC sway index ($p = 0.011$) and ECSS ($p = 0.048$). Four observations in each model exceeded the Cook's distance screening threshold of 4/n. Nevertheless, the cohort coefficients retained their direction and remained statistically significant in all 43 leave-one-out analyses for each outcome. Full diagnostic results are provided in Supplementary Table S3.

These diagnostic findings support cautious interpretation of the adjusted estimates as exploratory associations.

3.3. Sensitivity Analyses

Two alternative approaches to handling the five participants represented in both archival datasets were examined. All ten postural stability outcomes were reanalyzed under each alternative exclusion strategy, with Holm's adjustment applied separately within each family of ten between-cohort comparisons.

After excluding overlapping participants from both datasets, 19 participants were included in each cohort. Statistically significant between-cohort differences persisted for EC sway index (unadjusted $p = 0.00276$; Holm-adjusted $p = 0.0276$; rank-biserial correlation $= -0.571$) and ECSS (Holm-adjusted $p = 0.0276$).

When overlapping participants were excluded from the longer-observation dataset while all 24 shorter-observation records were retained, the comparison included 19 and 24 participants, respectively. Statistically significant differences persisted for EC sway index (unadjusted $p = 0.00096$; Holm-adjusted $p = 0.0086$; rank-biserial correlation $= -0.594$) and ECSS (Holm-adjusted $p = 0.0068$).

None of the other eight outcomes remained statistically significant after Holm adjustment in either sensitivity analysis.

Complete results for all ten outcomes under the primary independent comparison and both alternative exclusion strategies, including median changes, Mann–Whitney U statistics, rank-biserial correlations, and unadjusted and Holm-adjusted *p*-values, are provided in Supplementary Table S2.

These findings suggest that the principal statistical differences were not dependent on a single strategy for excluding overlapping records. However, the sensitivity analyses do not address potential selection bias, differences in baseline characteristics or previous program exposure, or the absence of comparable follow-up intervals.

Change scores (Δ) were calculated as follow-up minus baseline and are presented as medians [interquartile range]. Between-cohort comparisons were performed using the Mann–Whitney U test. Holm-adjusted *p*-values accounted for multiple tests across the family of ten postural stability outcomes. Rank-biserial correlation (r_rb) is reported as the between-cohort effect-size estimate. For EC sway index and ECSS, 95% confidence intervals were estimated using a stratified percentile bootstrap with 7000 resamples. EO, eyes open; EC, eyes closed; M/L, medio-lateral; A/P, anterior–posterior; EOSS, Eyes Open Stability Score; ECSS, Eyes Closed Stability Score.

4. Discussion

This exploratory secondary observational analysis identified differences in longitudinal changes in two eyes-closed postural stability outcomes, EC sway index and ECSS, between archival cohorts of University of the Third Age participants. These differences persisted after Holm adjustment and under alternative strategies for handling overlapping participants. Both outcomes changed in a less favorable direction in the shorter-observation cohort, whereas no statistically significant within-cohort changes were detected in the longer-observation cohort.

The cohorts differed simultaneously in scheduled program exposure and follow-up duration, so the observed differences could reflect elapsed time, participant selection, program participation, or other unmeasured factors. The absence of statistically significant changes in the longer-observation cohort does not establish preservation of postural stability: the study was not designed to demonstrate equivalence, and no threshold for clinically meaningful change was available.

The concentration of the observed differences under eyes-closed conditions suggests that assessment without visual input may reveal changes not apparent during eyes-open standing. Postural control integrates visual, vestibular, and somatosensory information;

removing vision increases reliance on the remaining sensory inputs. Peterka and Black demonstrated age-related differences in postural control, particularly when visual or somatosensory information was altered [7]. The present findings therefore support including eyes-closed assessment in future studies examining whether changes in instrumented postural stability correspond to changes in everyday balance and functional performance.

However, EC sway index and ECSS reflect related aspects of performance, and their mathematical relationship could not be verified from the archival documentation. They should therefore not be treated as independent confirmation of a specific sensory mechanism. Moreover, the protocol included only firm-surface eyes-open and eyes-closed conditions, rather than the additional conditions required for a complete modified Clinical Test of Sensory Interaction on Balance [6]. It cannot isolate vestibular or proprioceptive contributions to the observed changes.

The findings should be considered in the context of evidence supporting exercise for balance and fall prevention in older adults. Papalia et al. reported improvements in static and dynamic balance following exercise interventions [8], while Sherrington et al. found that exercise programs reduced falls, with particularly strong evidence for programs incorporating balance and functional exercises [9]. Lesinski et al. also showed that balance-training outcomes depend on training characteristics, including duration, frequency, and volume [10]. These intervention findings provide a rationale for investigating community programs, but the present archival comparison cannot establish whether exercise contributed to the observed changes.

Maintaining functional capacity is an important goal of healthy aging [3]. WHO recommendations for adults aged 65 years and older include multicomponent activity emphasizing functional balance and strength on three or more days per week [11]. The UTW program offered one scheduled 45-min session per week and focused on general physical activity rather than standardized progressive balance training. The 77-session and eight-session schedules describe activities offered, not verified individual attendance. Without attendance records or information on activity outside the program, neither actual exercise dose nor adherence to WHO recommendations could be determined.

The routine community setting provides information about postural stability during ordinary participation in University of the Third Age activities. From an ecological dynamics perspective, postural control emerges through interactions among individual characteristics, environmental conditions, and task demands [15–17]. This framework offers a conceptual context for studying community activity, although the present analysis did not manipulate these constraints or test an adaptation mechanism.

The clinical relevance of the eyes-closed findings remains to be established. Exercise programs incorporating balance and functional activities can reduce falls [9], but the present dataset contained no information on falls, near-falls, or fear of falling. Falls have multiple determinants extending beyond static postural control [1,2], and balance tests differ in their ability to distinguish fallers from non-fallers [18]. The observed stabilometric changes should therefore be evaluated alongside functional measures and prospectively recorded falls in future studies before drawing conclusions about fall-risk reduction.

Several analytical procedures strengthen the descriptive findings. Five participants represented in both archival datasets were identified before pseudonymization, and the primary comparison used independent cohorts of 24 and 19 participants. The two alternative strategies for handling overlapping records yielded consistent findings for EC sway index and ECSS. Reporting all ten available outcomes and applying Holm correction reduced the risks associated with selective outcome reporting and multiple testing.

The between-cohort rank-biserial correlations were −0.553 for EC sway index and 0.557 for ECSS, with bootstrap 95% confidence intervals of −0.811 to −0.252 and 0.257 to

0.816, respectively. These estimates indicate separation between the observed change-score distributions, but their practical interpretation also requires consideration of the absolute changes. Median individual changes in EC sway index were −0.005 in the longer-observation cohort and +0.070 in the shorter-observation cohort; corresponding ECSS changes were +0.5 and −3.0 percentage points. These differences warrant further investigation, but the available data cannot establish whether they represent perceptible changes in everyday balance or functional ability. No protocol-specific measurement-error estimates or clinically meaningful change thresholds were available, and related functional outcomes were not recorded. The two device-derived outcomes may also contain overlapping information.

Exploratory ANCOVA models adjusting for age and baseline values yielded cohort coefficients consistent in direction with the nonparametric comparisons. However, possible model misspecification and unmeasured confounding limit their interpretation. The adjusted analyses complement the description of the archival observations but do not resolve the differences in follow-up duration or the absence of verified exercise exposure.

4.1. Practical Implications

Routine community programs could support future evaluation by recording individual attendance and using standardized, repeated balance assessments alongside functional measures. The eyes-closed findings identify a candidate assessment condition for prospective investigation, rather than an established marker of functional decline or fall risk. For programs seeking to improve balance, existing evidence supports appropriately challenging balance and functional exercises delivered with sufficient frequency and volume [9,10]. The present data do not establish an effective exercise dose. Instrumented postural measurements should complement clinical and functional assessment when evaluating outcomes relevant to everyday activity and falls.

4.2. Overall Interpretation

Taken together, the findings indicate statistically significant differences in changes in two eyes-closed postural stability outcomes between archival cohorts assessed over substantially different observation periods. These findings remained significant after the Holm adjustment and under alternative strategies for handling overlapping participant records.

However, the results do not demonstrate the preservation of postural stability attributable to sustained physical activity. Scheduled program exposure and observation duration were inseparable, actual exercise attendance was unknown, and the cohorts were not randomized. Therefore, the findings should be interpreted as exploratory observations requiring prospective confirmation rather than evidence of an exercise-related protective effect.

4.3. Limitations

This study was based on a small, non-randomized archival sample from a single community program. Scheduled program exposure and observation duration differed simultaneously, preventing their independent assessment. Although enrollment followed routine UTW procedures, the available documentation did not establish the total eligible population, assessment participation rates, or reasons for unavailable follow-up measurements. Selection bias associated with complete paired records and differential retention could therefore not be evaluated.

The source dataset represented 43 unique participants and was predominantly female. Five confirmed participants contributed records to both historical datasets; independent analytical cohorts were reconstructed, and alternative exclusion strategies were examined. However, the chronological relationship between their assessment records could not be

fully reconstructed. Individual attendance, previous exercise exposure, comorbidities, medication use, and physical activity outside the program were unavailable, leaving important potential confounders unaccounted for.

The assessment comprised only firm-surface eyes-open and eyes-closed conditions. Historical documentation did not fully specify foot placement, footwear, familiarization, calibration, or the HUMAC software version. A single documented 30-s trial per condition prevented estimation of within-session variability, and protocol-specific measurement-error estimates were unavailable. Consequently, the observed changes could not be judged against measurement variability or established thresholds of clinical importance. No falls, near-falls, fear-of-falling measures, or related functional outcomes were recorded.

4.4. Future Research

Future prospective studies should use comparable follow-up intervals, record individual attendance and relevant confounders, and recruit larger, more sex-balanced samples. Standardized repeated measurements are needed to estimate measurement error and determine whether changes in EC sway index and ECSS correspond to meaningful differences in functional balance, everyday activity, or prospectively recorded falls. If sensory integration is a study objective, assessment should include conditions beyond firm-surface eyes-open and eyes-closed standing. These design features would help distinguish measurement variability from functional change and clarify the relationship between verified exercise exposure and postural stability.

5. Conclusions

This exploratory secondary analysis identified eyes-closed postural stability outcomes as candidates for further investigation in community-based physical activity programs. Changes in EC sway index and ECSS differed between the two archival cohorts, with findings persisting after Holm adjustment and alternative approaches to handling overlapping participants. Both outcomes changed in a less favorable direction in the shorter-observation cohort; the absence of statistically significant changes in the longer-observation cohort does not establish preservation of postural stability.

Because scheduled program exposure and follow-up duration differed simultaneously, these observations cannot establish an independent effect of exercise duration. Their functional and clinical significance remains uncertain. The findings generate hypotheses for prospective studies using comparable assessment intervals, verified exercise exposure, and functional and fall-related outcomes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app162111004/s1, Table S1: Within-cohort changes in all ten postural stability outcomes, including median individual changes, bootstrap 95% confidence intervals, and Wilcoxon signed-rank test results; Table S2: Between-cohort comparisons of changes in all ten postural stability outcomes under the primary analysis and two alternative participant-overlap exclusion strategies; Table S3: Exploratory analysis of covariance (ANCOVA) for eyes-closed sway index and eyes-closed stability score (ECSS), including model diagnostics and sensitivity analyses. The supplementary workbook also contains methodological notes and a data dictionary.

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Institutional Review Board Statement: The original physical activity classes were conducted as part of a regular University of the Third Age community program and were not designed, assigned, or modified for research purposes. Postural stability assessments using the HUMAC Balance System were noninvasive and performed with the voluntary written informed consent of the participants. Under Articles 21 and 29 of the Polish Act on the Professions of Physicians and Dentists, in the version applicable when the assessments were conducted, prior bioethics committee approval was required for projects qualifying as medical experiments. Based on the documented nature of the original activities and assessments, the authors considered that the program did not constitute an experiment, and no prospective ethics committee opinion was sought. This study reports a subsequent secondary observational analysis of de-identified archival records, involving no additional examinations, interventions, or participant contact. No formal ethics committee determination was obtained for the secondary analysis.

Informed Consent Statement: Written informed consent was obtained from the participants for the original HUMAC Balance assessments. The consent form identified the examiner, institutional affiliation, and purpose and general procedures of the examination. A blank copy of the original consent form was provided to the Academic Editor for verification. The form did not explicitly address subsequent secondary scientific analysis or publication of the assessment data.

Data Availability Statement: Participant-level data supporting this study are not publicly available because the archival records contain potentially re-identifiable health-related information. Reasonable requests for access to a minimized, pseudonymized analytical dataset may be considered individually by the corresponding author, subject to the General Data Protection Regulation (GDPR), authorization by the responsible data controller, and appropriate data-sharing safeguards. The aggregated analytical results are presented in Supplementary Tables S1–S3.

Conflicts of Interest: The authors declare no conflicts of interest.

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