

Research article

Changes in Static Postural Alignment Following a 12-Week Core - Strengthening Program in University Students: A Prospective APECS-Based Study

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Abstract: Static postural alignment can be quantified non-invasively using smartphone-based photogrammetric tools. This study examined changes in APECS-derived postural-alignment variables after a 12-week core-strengthening program delivered within university physical education. In this prospective pre-post study, 219 non-sport students from Transilvania University of Braşov were enrolled; 213 completed paired baseline and post-intervention APECS assessments. Participants attended one 50-minute session per week for 12 weeks. Static posture was assessed using Apecs-AI 4.2.1 under a standardized acquisition protocol. Paired analyses estimated baseline-to-post changes, Cohen's d_z , 95% confidence intervals, and Holm-adjusted p values across 22 APECS outputs. Mean attendance was 11.05 ± 0.95 sessions, and protocol fidelity was $91.4 \pm 4.9\%$. Significant reductions were observed in 10 of 22 APECS variables after multiplicity correction. The prespecified trunk/pelvic outcomes showed reductions: anterior trunk inclination decreased by 0.32° (95% CI, 0.24 – 0.40), posterior trunk inclination by 0.17° (0.10 – 0.24), and sagittal pelvic tilt by 1.00° (0.90 – 1.10). Eleven adverse events were recorded, all resolved, with no serious event. A once-weekly core-strengthening program was associated with measurable reductions in APECS-derived static postural-alignment deviations, most notably sagittal pelvic tilt; the clinical meaning of these changes remains uncertain, and controlled trials are needed to determine whether the changes are attributable to the intervention.

Keywords: posture, APECS, core stability, trunk strengthening, university students, photogrammetry, physical education, pre-post study

1. Introduction

Static postural alignment is commonly evaluated in preventive, educational and rehabilitation settings because sustained asymmetries or maladaptive alignment patterns may coexist with musculoskeletal discomfort, reduced physical activity tolerance or altered movement strategies. In university students, long periods of sitting, screen use and limited structured exercise may contribute to unfavorable trunk, pelvic and head-positioning habits. Although postural assessment should not be interpreted as a diagnostic substitute for clinical evaluation, objective monitoring can help identify change over time and guide health-promoting interventions.

Smartphone-based photogrammetric approaches have become attractive in applied settings because they are non-invasive, low-cost and easier to implement than laboratory-based motion-analysis systems. The Apecs-AI Posture Evaluation and Correction System (APECS) has been studied as a digital method for postural evaluation in young adults, with reproducibility varying by parameter but with several outputs

showing high reliability [1]. Systematic reviews of mobile and smartphone-based posture assessment have emphasized the value of standardized acquisition protocols, transparent reporting of landmarks and cautious interpretation of angular measures [2,3].

Core and trunk-stabilization training is frequently used to improve lumbopelvic control and trunk function. The core contributes to force transfer between upper and lower limbs, spinal stability and postural control during static and dynamic tasks [4]. Previous reviews indicate that isolated or integrated core-stability programs can influence performance, trunk strength and neuromuscular control, although effects depend on program content, dose, population and outcome selection [5,6]. Less is known about whether a low-frequency, curriculum-embedded core-strengthening program is associated with measurable changes in static alignment in non-sport university students.

The aim of this study was to examine changes in APECS-derived static postural-alignment variables after a 12-week core-strengthening program delivered during university physical education classes. We hypothesized that the intervention would be associated with reductions in trunk and pelvic alignment deviations, especially sagittal pelvic tilt, while recognizing that the pre-post design does not permit definitive causal attribution.

2. Materials and Methods

2.1. Study Design and Setting

This was a prospective pre-post intervention study conducted at Transilvania University of Braşov, Braşov, Romania. The study began in May 2026 and continued for 12 consecutive weeks. The intervention was embedded in the regular university physical education and sport class, which was delivered once weekly for 50 minutes. The study was planned and reported according to the principles of transparent intervention description and nonrandomized intervention reporting [7,8].

The study included students from all faculties of Transilvania University of Braşov except the Faculty of Physical Education and Mountain Sports. The sports faculty was excluded because its students have specialized physical training exposure that differs from the target non-sport student population.

2.2. Participants and Ethics

A total of 219 students were enrolled. Eligible participants were university students who provided informed consent, were registered in a university physical education and sport class, and were available for baseline APECS assessment. Students from the Faculty of Physical Education and Mountain Sports were not included. Participants without a complete paired baseline and post-intervention APECS assessment were excluded from paired outcome analyses but were retained in the participant-flow description.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Physical Education and Mountain Sports, Transilvania University of Braşov (approval no. 438/19.04.2025). Informed consent was obtained from all participants before data collection. Data were analyzed using coded participant identifiers only.

2.3. APECS Postural Assessment

Static postural alignment was assessed at baseline and after the 12-week intervention using the Apecs-AI Posture Evaluation and Correction System (Apecs-AI, version 4.2.1). APECS is a smartphone-based photogrammetric system that derives postural-alignment measures from standardized digital photographs. Previous research in

young adults has reported reproducible measurements for several APECS-derived parameters, although reliability differs among individual variables [1]. More broadly, smartphone-based photogrammetry has been proposed as a practical method for quantitative postural assessment when image acquisition and participant positioning are carefully standardized [2,3].

All measurements were obtained using the same smartphone (iPhone 14 Pro) and the same assessment environment. The smartphone was fixed in position with the camera located 250 cm from the participant and at a height of 95 cm from the floor. The position of the camera and the participant was maintained between baseline and post-intervention testing. Participants were assessed barefoot and wore standardized clothing that allowed visualization of the principal body segments required for postural analysis. Lighting conditions were kept consistent, and the participant's foot position was marked on the floor to improve reproducibility between assessments.

Three standardized images were acquired for each assessment: an anterior view, a posterior view, and a right-lateral view. Image quality was verified at the time of acquisition. All baseline and post-intervention assessments were conducted by the same assessor to reduce inter-rater variability. No blinding procedure to assessment time point was documented for image acquisition.

APECS uses image-processing and landmark-based analysis to quantify the spatial relationships between body segments. Measurements were exported directly from the application and recorded in degrees. No categorical diagnosis of a postural deformity was assigned on the basis of the application alone. Instead, all APECS outputs were retained as continuous variables for statistical analysis. The numerical magnitude reported by APECS was interpreted as the magnitude of postural deviation or asymmetry according to the definition of the corresponding variable; therefore, a lower value at post-intervention assessment was interpreted as a reduction in the measured deviation. For statistical description, a lower value was therefore described only as a lower application-defined deviation/asymmetry; it was not assumed to represent a clinically better, normalized, or “corrected” posture, and zero was not treated as a universal optimum.

The application generated 22 postural variables distributed across the anterior coronal, posterior coronal, and sagittal views. Eight variables were obtained from the anterior view, eight from the posterior view, and six from the right-lateral view. The variables and their operational interpretation in the present study are described in Table 1.

Table 1. APECS-derived postural variables and their operational interpretation

Field code	APECS output	View/plane	Postural characteristic quantified
APECS_Var01	Body alignment (anterior)	Anterior coronal	Overall frontal-plane alignment of the body, reflecting deviation of the global body axis from the vertical reference.
APECS_Var02	Head alignment (anterior)	Anterior coronal	Frontal-plane head asymmetry/inclination identified from the relative position of cranial landmarks.
APECS_Var03	Acromion alignment (anterior)	Anterior coronal	Difference in shoulder level represented by the inclination of the line connecting the left and right acromial regions relative to the horizontal reference.
APECS_Var04	Axillae alignment	Anterior coronal	Frontal-plane asymmetry of the axillary region, representing differences in the relative level of the right and left sides of the upper trunk.
APECS_Var05	Trunk inclination (anterior)	Anterior coronal	Magnitude of lateral inclination of the trunk relative to the vertical reference when viewed anteriorly.
APECS_Var06	Ribcage tilt	Anterior coronal	Frontal-plane inclination/asymmetry of the ribcage relative to the horizontal reference.
APECS_Var07	ASIS inclination	Anterior coronal	Frontal pelvic obliquity estimated from the relative alignment of the left and right anterior superior iliac spine regions.

APECS_Var08	Knee angle (anterior)	Anterior coronal	Frontal-plane alignment of the knee and adjacent lower-limb segments as derived from the anterior image.
APECS_Var09	Body alignment (posterior)	Posterior coronal	Overall frontal-plane alignment of the body relative to the vertical reference when assessed from the posterior view.
APECS_Var10	Head alignment (posterior)	Posterior coronal	Frontal-plane head inclination/asymmetry derived from the posterior image.
APECS_Var11	Shoulder alignment (posterior)	Posterior coronal	Difference in the relative height/alignment of the shoulders when viewed posteriorly.
APECS_Var12	Scapulae alignment	Posterior coronal	Relative frontal-plane alignment of the scapular regions, reflecting right–left scapular asymmetry.
APECS_Var13	Trunk inclination (posterior)	Posterior coronal	Lateral inclination of the trunk relative to the vertical reference when viewed posteriorly.
APECS_Var14	PSIS alignment	Posterior coronal	Frontal pelvic asymmetry estimated from the relative alignment of the left and right posterior superior iliac spine regions.
APECS_Var15	Knee angle (posterior)	Posterior coronal	Frontal-plane alignment of the knee and lower-limb segments as derived from the posterior image.
APECS_Var16	Foot angle (posterior)	Posterior coronal	Posterior foot/rearfoot alignment relative to the lower-limb or application-defined reference axis.
APECS_Var17	Body alignment (sagittal)	Right sagittal	Overall anterior–posterior inclination of the body relative to the vertical reference.
APECS_Var18	Head inclination (sagittal)	Right sagittal	Sagittal-plane inclination of the head relative to the application-defined postural reference, reflecting the magnitude of forward/backward head positioning.
APECS_Var19	Acromion alignment (sagittal)	Right sagittal	Sagittal position/alignment of the acromial region relative to the trunk reference.
APECS_Var20	Pelvic tilt (sagittal)	Right sagittal	Magnitude of pelvic inclination in the sagittal plane, representing anterior/posterior pelvic tilt according to the APECS measurement definition.
APECS_Var21	Tibia shift	Right sagittal	Sagittal alignment or inclination of the tibial segment relative to the vertical/postural reference.
APECS_Var22	Foot angle (sagittal)	Right sagittal	Sagittal-plane orientation of the foot relative to the application-defined reference axis.

2.3.1. Interpretation of APECS Measurements

APECS measurements were treated as quantitative indicators of static postural alignment rather than diagnostic criteria. Thus, the study did not classify participants as having or not having a specific musculoskeletal deformity on the basis of a predetermined angular threshold. This approach was chosen because postural alignment represents a continuous biological characteristic and because published reliability and normative values differ among APECS variables [1].

For bilateral or coronal-plane alignment variables, the recorded angle represented the magnitude of asymmetry or inclination from the relevant horizontal or vertical reference defined by the application. For sagittal-plane variables, the exported angle represented the magnitude of segmental inclination relative to the sagittal reference used by APECS. The original continuous values exported by APECS were used for all analyses without conversion into qualitative categories such as “normal,” “mild,” “moderate,” or “severe.”

The three principal trunk–pelvic variables were anterior trunk inclination (APECS_Var05), posterior trunk inclination (APECS_Var13), and sagittal pelvic tilt (APECS_Var20). These variables were selected because they most directly reflected the anatomical region targeted by the core-strengthening intervention. The remaining 19 APECS variables were analyzed as secondary outcomes to investigate whether changes were restricted to the trunk–pelvic region or were accompanied by broader alterations in multi-segment postural alignment.

Because the reproducibility of individual APECS measurements is not uniform, interpretation of the findings considered not only statistical significance but also the

published measurement properties of the corresponding parameter [1]. This was particularly relevant when comparing changes across different anatomical regions. The cited APECS reproducibility study reports intraclass-correlation-based reliability but does not provide validated parameter-specific minimal detectable change thresholds for the exact outputs analyzed here; accordingly, the present study did not classify any observed change as exceeding an established APECS-specific minimal detectable change.

2.3.2. Standardization and Quality Control

To minimize measurement variability unrelated to the intervention, identical acquisition procedures were used at baseline and follow-up. The same smartphone, camera distance, camera height, room configuration, lighting conditions, foot-position markings, and photographic views were used throughout the study. Participants were assessed barefoot and in comparable clothing conditions, and all photographs were obtained by the same assessor.

Each image was inspected for adequate visibility of the body segments required for analysis before the assessment was accepted. Measurements were exported directly from APECS and linked to coded participant identifiers. Baseline and post-intervention values were subsequently matched using the participant code. Raw photographs were maintained separately from the numeric analysis dataset because the images could contain potentially identifiable information. The study records did not document whether application-generated landmark positions were manually adjusted, and no separate blinded image-analysis procedure was documented.

2.4. Core-Strengthening Intervention

The intervention consisted of a 12-week progressive core-strengthening program delivered once weekly during the regular 50-minute university physical education and sport class. The program was designed to improve trunk stability, lumbopelvic control, postural endurance, and the ability to maintain neutral spinal and pelvic alignment during static and dynamic tasks. Exercise selection was based on established concepts of core stability and trunk neuromuscular control [4–6], while intervention reporting followed the principles of the TiDieR framework [7].

The intervention was delivered in the existing physical education class groups by qualified physical education instructors. All instructors followed the same progression framework. Particular attention was given to movement quality, maintenance of neutral lumbopelvic alignment, controlled breathing, avoidance of compensatory trunk rotation, and symmetrical execution. Participants were instructed to activate the abdominal wall without breath holding and to maintain controlled movement throughout each repetition.

Each 50-minute session followed a standardized structure: approximately 7 minutes of general and specific warm-up, 8 minutes of trunk activation and movement-control exercises, 30 minutes of progressive core-strengthening exercises, and 5 minutes of recovery and mobility exercises. The principal training component included anterior, posterior, lateral, and anti-rotation trunk exercises in order to provide multi-directional stimulation of the musculature responsible for spinal and pelvic stabilization.

Training difficulty was progressively increased during the 12-week period by increasing the duration of isometric contractions, number of repetitions and sets, lever-arm length, reduction of external support, and complexity of limb movements while maintaining trunk stability. Exercise progression was permitted only when the participant could complete the prescribed volume while maintaining correct technique. The intended exercise intensity was moderate, corresponding approximately to 4–7 on the 0–10 session rating of perceived exertion scale.

The program, presented in Table 2, was divided into four progressive three-week phases. The first phase emphasized awareness of neutral pelvic and spinal position and activation of the deep trunk musculature. The second phase increased postural endurance and introduced longer lever arms. The third phase emphasized dynamic stabilization and resistance to trunk rotation. The final phase integrated more demanding multiplanar stabilization exercises and longer isometric contractions.

Individual modifications were permitted when necessary. These included shorter isometric holding times, supported exercise variants, or omission of anti-rotation exercises when the standard version could not be performed comfortably or with adequate technique. These modifications were documented during the intervention. Participants were encouraged to work within a pain-free range of motion, and exercise was stopped or modified if pain, dizziness, or another adverse symptom occurred.

Table 2. Detailed progression of the 12-week core-strengthening intervention

Week	Training objective	Main exercises	Prescription
1	Familiarization, neutral spine and abdominal activation	Abdominal bracing in supine; pelvic tilt/control; bilateral glute bridge; quadruped arm lift; modified forearm plank; modified side plank	2 sets; 8–10 repetitions for dynamic exercises; 15–20 s for isometric exercises; 30–40 s recovery
2	Basic lumbopelvic stabilization	Dead-bug heel taps; glute bridge; quadruped leg extension; modified forearm plank; modified side plank; standing anti-rotation stabilization	2 sets; 8–10 repetitions/side; 15–20 s holds; 30–40 s recovery
3	Consolidation of trunk control	Dead bug with alternating limbs; bridge with 2–3 s hold; bird-dog; forearm plank; side plank from knees; anti-rotation press/hold	2 sets; 10 repetitions/side; 20–25 s holds; 30–40 s recovery
4	Increased postural endurance	Dead bug with contralateral arm/leg movement; bridge march preparation; bird-dog with 2–3 s pause; full or modified plank; side plank; anti-rotation exercise	2–3 sets; 10–12 repetitions/side; 20–30 s holds
5	Increased lever-arm demand	Full dead bug; bridge march; bird-dog with longer reach; forearm plank; side plank; anti-rotation press with increased range	3 sets; 10–12 repetitions/side; 25–30 s holds; 30 s recovery
6	Trunk endurance and pelvic stability	Dead bug progression; alternating bridge march; bird-dog; plank with controlled weight shift; side plank; anti-rotation isometric hold	3 sets; 10–12 repetitions/side; 25–35 s holds
7	Dynamic stabilization	Dead bug with slower eccentric phase; single-leg bridge preparation; bird-dog elbow-to-knee; plank shoulder taps; side plank progression; anti-rotation press	3 sets; 8–12 repetitions/side; 30–35 s holds
8	Multiplanar control	Dead bug progression; bridge march/single-leg bridge according to ability; bird-dog with controlled trunk rotation avoidance; plank shoulder taps; side plank with controlled hip movement; anti-rotation exercise	3 sets; 10–12 repetitions/side; 30–40 s holds
9	Increased anti-extension and anti-rotation demand	Extended-lever dead bug; single-leg bridge; bird-dog progression; plank with alternating limb movement; side plank progression; anti-rotation press with step or longer lever	3 sets; 10–12 repetitions/side; 30–40 s holds
10	Advanced integrated stabilization	Dead bug with contralateral extension; single-leg bridge; bird-dog with extended hold; plank with alternating arm/leg movement; side plank; anti-rotation hold	3 sets; 10–12 repetitions/side; 35–45 s holds
11	Postural endurance under greater demand	Advanced dead bug; single-leg bridge; bird-dog progression; plank with controlled limb movement; full side plank; anti-rotation stabilization	3 sets; 10–15 repetitions/side; 35–45 s holds
12	Consolidation and maximal technical quality	Selected advanced versions of dead bug, bridge, bird-dog, front plank, side plank, and anti-rotation stabilization	3 sets; 10–15 repetitions/side; 40–45 s holds; emphasis on movement quality rather than maximal fatigue

Session structure

Each session began with approximately 7 minutes of low- to moderate-intensity dynamic warm-up consisting of walking or light jogging, upper- and lower-limb mobilization, controlled trunk rotations, hip mobility exercises, and dynamic movements intended to prepare the participants for trunk stabilization work. This was followed by approximately 8 minutes of specific activation exercises, including diaphragmatic breathing, abdominal bracing, controlled pelvic tilting, and spinal–pelvic positioning exercises.

The main 30-minute training period was organized as a circuit. Exercises were performed bilaterally where applicable, and approximately 30–45 seconds of recovery was allowed between exercises and 60–90 seconds between circuits. Dynamic exercises were generally performed using a controlled tempo, with approximately 2 seconds during the concentric or positioning phase and 2 seconds during the return phase. Isometric exercises were performed without breath holding. The instructor continuously monitored pelvic position, excessive lumbar extension, trunk rotation, shoulder elevation, and loss of postural alignment.

The final approximately 5 minutes consisted of low-intensity recovery, controlled breathing, and mobility exercises for the lumbar spine, thoracic region, hip flexors, hamstrings, and gluteal musculature.

2.4.1. Exercise Progression and Individualization

Progression was based primarily on technical execution rather than completion of a predetermined maximal workload. Participants progressed to a more demanding exercise variation when they were able to complete the prescribed repetitions or holding time without visible loss of neutral trunk and pelvic alignment, excessive compensatory movement, or pain. Progression involved one or more of the following: increasing isometric hold duration by approximately 5–10 seconds, adding 2–4 repetitions, increasing from two to three sets, extending the upper or lower limb lever arm, decreasing the base of support, or introducing controlled contralateral limb movement.

When participants were unable to maintain correct alignment, the exercise was regressed by shortening the lever arm, reducing the duration of the isometric contraction, decreasing repetitions, or using additional support. Consistent with the study records, specific modifications included reduced holding times, supported exercise variants, and omission of anti-rotation exercises where necessary. The goal of individualization was to preserve correct movement quality while allowing participants of different fitness levels to complete the same overall intervention framework.

2.4.2. Intervention Monitoring and Fidelity

Attendance was recorded at every session. The number of minutes completed by each participant was also documented, allowing calculation of cumulative intervention exposure. Immediately following each attended session, exercise intensity was recorded using a 0–10 session rating of perceived exertion scale. Instructor identity, deviations from the planned exercise protocol, participant-specific modifications, and adverse events were recorded prospectively.

Protocol fidelity was expressed as the percentage of the planned session content delivered according to the intervention protocol. In the final study sample, mean protocol fidelity exceeded 90%, supporting consistency of intervention delivery across instructors and physical education groups. A priori, participation in at least 10 of the 12 planned sessions was considered adequate adherence for the per-protocol sensitivity analysis.

2.4.3. Safety Procedures

Before each session, participants were asked whether any new pain, injury, illness, or other condition could affect safe participation. Exercises were performed within a

pain-free range of motion. Instructors were permitted to reduce exercise volume or intensity, provide a supported version, or discontinue an exercise if symptoms occurred. Any undesirable medical or musculoskeletal event arising during the intervention period was recorded in the adverse-event log together with its severity, possible relationship to the intervention, action taken, and resolution status.

2.5. Outcomes

The primary outcome family consisted of baseline-to-12-week changes in anterior trunk inclination, posterior trunk inclination and sagittal pelvic tilt. Secondary outcomes included the remaining 19 APECS variables. All outcomes were analyzed as continuous variables in degrees. Intervention feasibility outcomes were attendance, total minutes completed, session-RPE and protocol fidelity. Safety outcomes were adverse-event frequency, severity, relatedness and resolution status as recorded in the dedicated adverse-event log.

2.6. Statistical Analysis

Analyses were performed using Python-based statistical packages. The primary analysis used participants with complete paired baseline and post-12-week APECS data. Continuous variables were summarized as mean $\pm$ standard deviation; categorical variables were summarized as number and percentage. For each APECS output, post-intervention minus baseline change was calculated. Paired comparisons estimated the mean change, 95% confidence interval and Cohen's d_z , defined as the mean paired difference divided by the standard deviation of the paired differences. The primary/secondary distinction was retained for interpretation, while multiplicity was controlled conservatively by applying Holm adjustment globally across all 22 APECS outcomes rather than separately by outcome family.

Sensitivity analyses were performed in two prespecified analysis sets: participants who attended at least 10 of 12 sessions and participants with strict measurement chronology, defined as baseline assessment on or before the first attended intervention session and post-intervention assessment on or after the last attended intervention session. The threshold for statistical significance was $p < 0.05$ after multiplicity correction. Statistical interpretation prioritized effect estimates, confidence intervals and consistency of direction over p values alone.

3. Results

3.1. Participant Flow and Baseline Characteristics

Of 219 enrolled students, 213 completed paired baseline and post-intervention APECS assessments and were included in the paired analysis (retention 97.3%). Six participants withdrew before the post-intervention assessment because of unrelated medical reasons, personal reasons, loss to follow-up or schedule conflict (Figure 1).

The paired-analysis sample included 213 participants: 121 women (56.8%) and 92 men (43.2%). Mean age was 20.09 ± 1.61 years and mean BMI was 23.08 ± 3.60 kg/m². Table 3 summarizes participant characteristics, exposure and safety indicators.

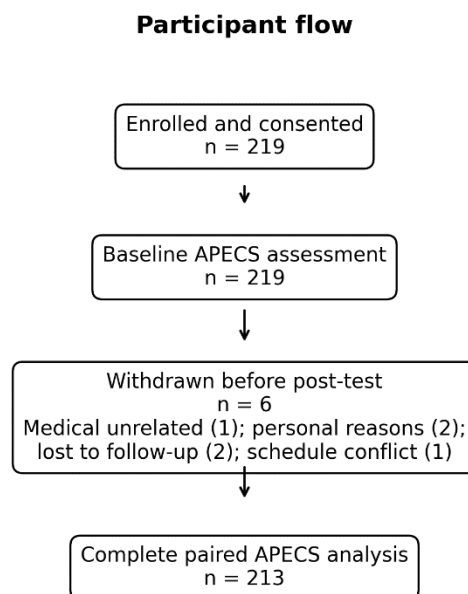


Figure 1. Participant flow through enrollment, follow-up and paired APECS analysis.

Table 3. Participant characteristics, intervention exposure and safety summary.

Characteristic	Value	Notes
Participants enrolled	219	
Completed paired APECS assessment	213 (97.3%)	
Age, years	20.09 ± 1.61	mean ± SD
Female sex at birth	121 (56.8%)	
Male sex at birth	92 (43.2%)	
Height, cm	170.6 ± 9.0	mean ± SD
Body mass, kg	67.1 ± 11.3	mean ± SD
BMI, kg/m ²	23.08 ± 3.60	mean ± SD
Outside physical activity, min/week	84.1 ± 86.1	self-reported
Sedentary time, h/day	6.5 ± 1.8	self-reported
Current neck pain	42 (19.7%)	
Current low-back pain	48 (22.5%)	
Relevant injury/surgery history	14 (6.6%)	
Sessions attended, of 12	11.05 ± 0.95	mean ± SD
Adherence ≥10 sessions	200 (93.9%)	per-protocol threshold
Total exercise exposure, min	544.8 ± 50.0	mean ± SD
Session-RPE	5.49 ± 1.20	0–10 scale
Protocol fidelity	91.4% ± 4.9%	observed sessions
Adverse-event log entries	11 events in 11 students	all resolved; no serious event recorded

3.2. Intervention Exposure and Safety

Participants attended a mean of 11.05 ± 0.95 of 12 sessions, corresponding to 92.1% of the planned sessions. A total of 200 participants (93.9%) attended at least 10 sessions. Mean session-RPE across attended sessions was 5.49 ± 1.20 , and mean protocol fidelity was $91.4 \pm 4.9\%$.

The adverse-event log contained 11 events in 11 students. Ten events were mild and one was moderate; 4 events were rated as probably or possibly related to the intervention. All recorded events resolved, and no serious adverse event was recorded.

3.3. APECS Postural-Alignment Outcomes

All three prespecified trunk/pelvic outcomes showed reductions in their APECS-derived values after 12 weeks. Anterior trunk inclination decreased by 0.32° (95% CI 0.24 to 0.40), posterior trunk inclination decreased by 0.17° (95% CI 0.10 to 0.24), and sagittal pelvic tilt decreased by 1.00° (95% CI 0.90 to 1.10). The largest standardized change was observed for sagittal pelvic tilt (Cohen's $d_z = -1.34$). For sagittal pelvic tilt, the SD of the paired differences was approximately 0.75° , corresponding to the reported Cohen's d_z of -1.34; this standardized effect should be interpreted together with the 1.00° absolute change.

After Holm correction across the 22 APECS variables, 10 outcomes showed statistically significant reductions: anterior trunk inclination, ribcage tilt, ASIS inclination, anterior knee angle, posterior trunk inclination, PSIS alignment, posterior knee angle, posterior foot angle, sagittal head inclination and sagittal pelvic tilt (Table 4; Figure 2). The remaining APECS variables did not retain statistical significance after multiplicity correction. Of the 10 Holm-significant outcomes, three were prespecified primary outcomes and seven were secondary/exploratory.

Table 4. Primary outcomes and Holm-significant secondary APECS outcomes at baseline and after 12 weeks.

Field code	APECS output	View/plane	n	Baseline, mean $\pm$ SD	Post-12 weeks, mean $\pm$ SD	Change, degrees	95% CI	Cohen's d_z	Holm-adjusted p
APECS_Var05	Trunk inclination (anterior)	Anterior coronal	213	1.77 ± 1.08	1.45 ± 0.98	-0.32	-0.40 to -0.24	-0.54	<0.001
APECS_Var13	Trunk inclination (posterior)	Posterior coronal	213	1.67 ± 0.98	1.50 ± 0.97	-0.17	-0.24 to -0.10	-0.32	<0.001
APECS_Var20	Pelvic tilt (sagittal)	Sagittal	213	4.16 ± 2.04	3.16 ± 1.59	-1.00	-1.10 to -0.90	-1.34	<0.001
APECS_Var06	Ribcage tilt	Anterior coronal	213	2.18 ± 1.35	1.94 ± 1.26	-0.24	-0.32 to -0.17	-0.43	<0.001
APECS_Var07	ASIS inclination	Anterior coronal	213	2.44 ± 1.35	2.15 ± 1.21	-0.30	-0.37 to -0.23	-0.57	<0.001
APECS_Var08	Knee angle (anterior)	Anterior coronal	213	6.53 ± 3.20	6.14 ± 3.08	-0.39	-0.47 to -0.31	-0.69	<0.001
APECS_Var14	PSIS alignment	Posterior coronal	213	2.14 ± 1.27	1.74 ± 1.07	-0.40	-0.49 to -0.32	-0.63	<0.001
APECS_Var15	Knee angle (posterior)	Posterior coronal	213	5.72 ± 2.67	5.30 ± 2.53	-0.42	-0.49 to -0.35	-0.80	<0.001
APECS_Var16	Foot angle (posterior)	Posterior coronal	213	3.27 ± 1.84	3.05 ± 1.79	-0.22	-0.30 to -0.15	-0.40	<0.001
APECS_Var18	Head inclination (sagittal)	Sagittal	213	3.60 ± 1.98	3.39 ± 1.95	-0.21	-0.28 to -0.13	-0.38	<0.001

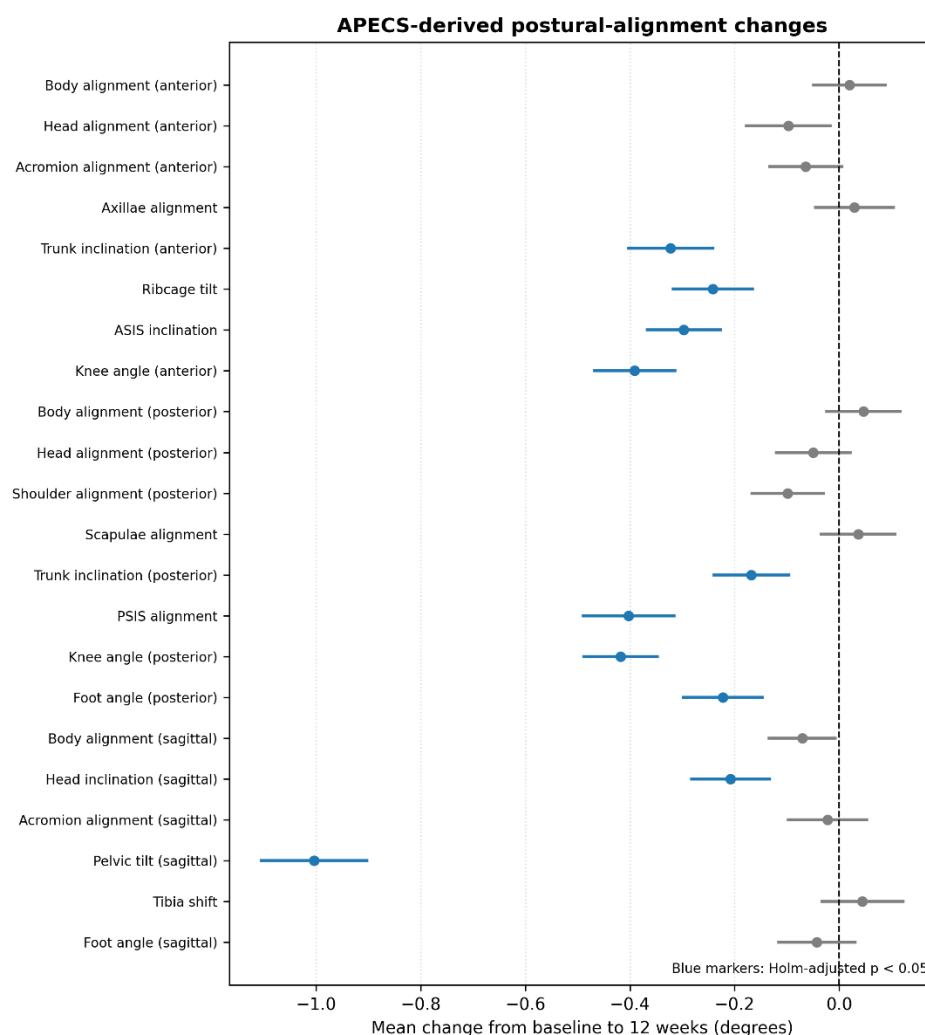


Figure 2. Mean changes and 95% confidence intervals for all 22 APECS-derived postural-alignment variables. Negative values indicate lower post-intervention deviation/asymmetry.

3.4. Sensitivity Analyses

Findings were consistent in participants who attended at least 10 sessions (n=200): anterior trunk inclination changed by -0.32° , posterior trunk inclination by -0.16° , and sagittal pelvic tilt by -1.01° .

Strict chronology analysis (n=123) also confirmed the same pattern: anterior trunk inclination changed by -0.33° , posterior trunk inclination by -0.17° , and sagittal pelvic tilt by -1.07° . All eight PE classes showed mean change in the same direction for the three main outcomes.

4. Discussion

This prospective pre-post study found that a 12-week core-strengthening program embedded in university physical education was associated with measurable reductions in APECS-derived static postural-alignment deviations among non-sport students. The clearest change involved sagittal pelvic tilt, which decreased by approximately 1 degree and showed a large standardized within-participant effect. Additional reductions were observed in secondary trunk, pelvic, knee, foot and sagittal head-

alignment outputs; these multi-segment findings were exploratory and should not be interpreted as evidence of direct training effects at each body region.

The emphasis on trunk and lumbopelvic control provides a plausible explanation for the strongest pelvic finding. Core-stability models propose that trunk and pelvic musculature contribute to proximal control, force transfer and postural organization [4]. Reviews of core-stability and trunk-strength interventions indicate that such programs can influence physical performance and trunk-related functional outcomes, although program characteristics and population characteristics strongly affect results [5,6]. The present findings extend that literature by showing that a low-frequency program integrated into a regular university physical education context can be associated with measurable static-alignment changes. Exercise-mediated changes in alignment have also been documented in corrective-exercise research using photographic posture outcomes [14], while recent randomized evidence indicates that core stabilization can improve balance and postural-control-related outcomes in younger populations [15]. Because the program directly targeted trunk and lumbopelvic control, reductions in head, knee, and foot outputs may instead reflect generalized postural adaptation, correlated segmental changes, or measurement variability rather than a specific distal training mechanism.

The findings should be interpreted with appropriate caution. APECS provides accessible digital posture measures, but published reliability differs between specific parameters [1]. Therefore, outcomes with stronger published reproducibility, such as sagittal pelvic tilt and several posterior/anterior alignment measures, should receive greater interpretive weight than parameters with lower reported reliability. Additionally, static postural alignment is only one component of posture and motor control; this study did not assess muscle activation, dynamic balance, pain change, functional performance or long-term retention. The university context is relevant because spinal mobility and functional characteristics vary across young-adult student populations [16], and recent university-based evidence links greater sitting and screen exposure with a higher burden of musculoskeletal pain [17]. These associations do not establish that static alignment itself causes pain, but they reinforce the value of preventive movement programs in student settings. Targeted exercise has been shown to modify sitting posture in chronic neck pain [18], while systematic reviews of stabilization exercise demonstrate heterogeneity in intervention content and comparative effects [19]. Normative three-dimensional photogrammetric data in healthy young adults also show substantial inter-individual variability in spinal and postural morphology [20], supporting interpretation of APECS changes as continuous alignment measures rather than categorical diagnostic “corrections.” Importantly, no validated APECS-specific minimal detectable change or clinically meaningful threshold was available for the exact outputs analyzed. Consequently, none of the 10 Holm-significant reductions can be claimed to exceed an established APECS-specific measurement-error threshold; the nine non-pelvic absolute changes (0.17° – 0.42°) warrant particular caution, and the 1.00° sagittal pelvic-tilt reduction remains of uncertain clinical importance despite its large standardized effect. Static APECS reductions also cannot be assumed to translate into improved function, symptoms, disability, or participation.

Feasibility was a strength of the intervention. Retention was high, mean attendance exceeded 11 of 12 planned sessions, and protocol fidelity was above 90%. These findings indicate that a trunk-focused program can be implemented within the realistic constraints of university physical education. The safety profile was also acceptable in the dedicated adverse-event log, with no serious event recorded and all events resolved.

The most important limitation is the lack of a non-intervention or alternative-intervention control group. Accordingly, the observed changes cannot be attributed

solely to the core-strengthening program; maturation, natural or seasonal variability, changes in activity outside class, measurement familiarity, behavioral adaptation or other contextual factors may have contributed. The study was also conducted in a single university, and the exercise content was delivered by multiple instructors in a curricular setting. Although fidelity was monitored, the pragmatic design may have introduced between-class variability. Although all eight classes showed mean changes in the same direction for the three primary outcomes, class- or instructor-level clustering was not modeled; these class-level summaries are descriptive and standard errors may be underestimated if within-class correlation was material. Potential moderation by baseline neck or low-back pain, sex, BMI, outside physical activity, or sedentary time was not tested; such subgroup or adjusted analyses were not prespecified and would be exploratory. Because the same assessor acquired both time points and no blinding procedure or separate blinded image analysis was documented, measurement-expectation bias cannot be excluded; the study records also did not document manual landmark adjustment. Finally, clinical thresholds for meaningful change in APECS angular outputs are not well established, so the findings should be interpreted as statistically detectable within-participant changes rather than evidence of clinical normalization or correction.

5. Conclusions

In non-sport university students, a 12-week, once-weekly core-strengthening program delivered within regular physical education was associated with significant reductions in multiple APECS-derived static postural-alignment variables. The largest absolute reduction was observed for sagittal pelvic tilt, with additional reductions in trunk, pelvic, lower-limb and sagittal head-alignment outputs. The program was feasible and well tolerated, with high adherence and no serious adverse event recorded. Because the study used a pre-post design without a control group, the findings demonstrate within-participant associations over time but do not establish intervention effectiveness. Future controlled studies should test whether these changes are attributable to the intervention, establish clinically meaningful thresholds for APECS change and evaluate whether static alignment changes correspond to functional or symptom-related benefits.

Supplementary Materials: Supplementary Tables: complete results for all 22 APECS variables; Sensitivity analyses; Supplementary Dataset: de-identified numeric analysis dataset and APECS variable dictionary.

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Data Availability Statement: The de-identified numeric dataset and APECS variable dictionary are provided as supplementary material.

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