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Effects of Yoga Training on Flexibility and Stress in Secondary School Students: A Randomized Controlled Trial

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Abstract

Background: Adolescent secondary school students in Pakistan face a dual burden of sedentary behavior and escalating psychological stress. Yoga, an integrative mind-body discipline comprising physical postures, breathing regulation, and meditative components, has demonstrated efficacy in improving physical flexibility and reducing stress across diverse populations. However, evidence from South Asian secondary school contexts particularly from conservative sociocultural settings such as Peshawar, Khyber Pakhtunkhwa remains absent from the published literature. Objective: This study evaluated the efficacy of a 12-week structured yoga-based training program on physical flexibility (sit-and-reach, shoulder flexibility, hip flexor range of motion) and psychological stress (Perceived Stress Scale-10; PSS-10) among secondary school students in Peshawar District, Pakistan. Methods: A parallel-group, pre-test/post-test randomized controlled trial (RCT) was conducted with 90 students (aged 13–17 years) recruited from six secondary schools (Grades 8–10) across Peshawar District using stratified random sampling. Participants were randomly allocated to a Yoga Group (n = 45) receiving a 12-week, three-sessions-per-week progressive yoga program, or a Control Group (n = 45) maintaining their standard physical education routine. Allocation concealment was maintained using sequentially numbered opaque sealed envelopes, and outcome assessors were blinded to group assignment throughout. Primary outcomes were sit-and-reach flexibility (cm), shoulder flexibility (cm), hip flexor range of motion (°), and PSS-10 score. Assessments were conducted at baseline and post-intervention (Week 12). Between-group differences were analyzed using mixed-model repeated-measures ANOVA, with Cohen's d for effect size estimation. Intention-to-treat analysis was applied for all participants. Results: The Yoga Group demonstrated significant improvements in all flexibility measures (sit-and-reach: +8.45 cm, d = 2.07; shoulder flexibility: +6.45 cm, d = 1.80; hip flexor ROM: +16.33°, d = 2.02) and a substantial reduction in perceived stress (PSS-10: −8.56 points, d = 1.96) compared to negligible changes in the Control Group (all $p < .001$). The proportion of students in the high-stress category declined from 26.7% to 4.4% in the Yoga Group versus 24.4% to 22.2% in controls. Flexibility gains were significantly and negatively correlated with stress reduction ($r = -0.64$ to -0.71, $p < .01$). Conclusions: A 12-week school-based yoga program produced large, clinically meaningful improvements in physical flexibility and psychological stress among adolescent students in Peshawar, Pakistan, with effect sizes (d = 1.80–2.07 for flexibility; d = 1.96 for perceived stress) among the largest reported in comparable adolescent yoga RCT literature. The program was culturally feasible and operationally deliverable within existing school infrastructure. Integration of structured yoga training into the Khyber Pakhtunkhwa school physical education curriculum is recommended.

Keywords: Yoga; physical flexibility; psychological stress; adolescents; secondary school; Peshawar; Pakistan; randomized controlled trial; PSS-10; sit-and-reach

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1. Introduction

Adolescence is a sensitive period of development characterized by swift physical, mental, and emotional transformation. Students of secondary school, who are usually aged between 13 and 17 years old, are exposed to a set of stressors such as academic, high-stakes examination systems, peer, and in the context of Pakistan, socioeconomic family strains and early career fears. These are interacted with psychosocial stresses of more sedentary behavioral patterns as a result of screen time, lessening physical education delivery, and especially in conservative cultures like Peshawar--culturally determined limitations on outdoor physical exercise. This ensuing dual effect of physical deconditioning and mental stress is an under-acknowledged problem in the secondary school system in Pakistan.

Physical flexibility including the scope of movement (ROM) of joints and the extensibility of musculotendinous units-is a fundamental element of physical fitness related to health. Sufficient flexibility eliminates the risk of injuries, promotes musculoskeletal performance during development, and is linked with improved posture and low-back pain, which affects 3040% of adolescents in Pakistan (Khan et al., 2020). Flexibility training does not get much emphasis in the national secondary school physical education curriculum of Pakistan although it is clinically important since most aspects of the curriculum are still team sport-based and free play.

The post-pandemic research has devoted growing interest to the psychological stress experienced by Pakistani adolescents. Husain et al. (2022) surveyed secondary school students in urban Khyber Pakhtunkhwa, indicating that forty-two percent of students exhibited moderate-to-high levels of stress on the standardized measures, with the academic performance pressure and family expectations being the most common stressors. Stress during adolescence has been linked to dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, disrupted sleep, poor academic achievement, increased susceptibility to anxiety and depressive disorders in adulthood (Cohen et al., 1983; McEwen, 2008).

Yoga is a traditional system of integration that includes physical poses (asanas), breathing exercises (pranayama) and meditative elements (dhyana). It has become one of the most researched mind-body interventions both in regard to physical fitness and psychological wellbeing. Meta-analytic data shows that structured yoga interventions have a beneficial effect on flexibility outcomes such as hamstring extensibility, shoulder ROM, and spinal mobility and decrease perceived stress, anxiety and cortisol levels in heterogeneous groups (Cramer et al., 2013; Pascoe et al., 2017; Luu and Hall, 2017). Mechanistically, yoga enhances flexibility by a prolonged viscoelastic deformation of connective tissue, elevated stretch tolerance, and neuromuscular inhibition of the myotatic reflex. The decrease in stress is ascribed to the activation of the parasympathetic nervous system, decreased sympathoadrenal reactivity, enhanced interoceptive awareness, and enhanced HPA-axis regulation by mindful breath control (Pascoe et al., 2017).

Although this evidence base is very strong worldwide, there is an alarming lack of research on yoga-based interventions in Pakistani school environments. The population of over 12 million students in secondary schools is one of the biggest untapped potential beneficiary groups in such interventions in Pakistan. The provincial capital of Khyber Pakhtunkhwa (Peshawar District) has a particularly significant research setting: it is a place with a high stress load among adolescents (the legacy of post-conflict trauma, intense academic competition, and gender-based restrictions on activities) and almost complete lack of flexibility or mind-body elements in physical education. Moreover, the fact that cultural

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acceptability of yoga in an Islamic and conservative sociocultural setting is yet to be empirically tested in the area the current study is well-timed and required.

The aim of this study was thus to determine the effectiveness of a 12 weeks structured yoga-based training program on physical flexibility and psychological stress in secondary school students in Peshawar District, Pakistan, using a randomized controlled trial design. The two hypotheses were: (H1) at 12 weeks, the Yoga Group will show significantly higher improvements in their flexibility outcomes than the Control Group; and (H2) at 12 weeks, the Yoga Group will show significantly better improvements in their perceived psychological stress than the Control Group..

2. Methods

2.1 Study Design

This study employed a parallel-group, pre-test/post-test randomized controlled trial (RCT) design with allocation concealment and assessor blinding, adhering to CONSORT 2010 guidelines. Ethical approval was obtained from the Institutional Review Board of the Sarhad University Peshawar and the District Education Officer (DEO), Peshawar. All procedures conformed to the Declaration of Helsinki (2013 revision). Written informed consent was obtained from parents/guardians, and assent was obtained from all student participants prior to enrollment.

2.2 Study Setting

The study was conducted in secondary schools within Peshawar District, Khyber Pakhtunkhwa, Pakistan. Peshawar is the provincial capital, with a population exceeding 2.2 million, and encompasses both government and private secondary schools spanning socioeconomically diverse communities. Peshawar District was selected owing to: (1) the high documented prevalence of adolescent stress; (2) the near-complete absence of structured flexibility or mind-body training in school physical education programs; and (3) the availability of institutional support from the District Education Office.

Six secondary schools were selected to ensure representation across socioeconomic strata and both sexes: three government schools (Boys Government Higher Secondary School Chamkani; Girls Government Higher Secondary School Hayatabad; Government High School Nauthia) and three private schools (Peshawar Model School; The City School Peshawar; Beacon House School System Peshawar Campus).

2.3 Participants

2.3.1 Eligibility Criteria

Inclusion criteria: (1) enrolled in Grade 8, 9, or 10 at a participating school; (2) aged 13–17 years; (3) no prior formal yoga or structured flexibility training in the previous six months; (4) no musculoskeletal injury, neurological disorder, or medical contraindication to physical activity; (5) written parental/guardian consent and participant assent obtained; (6) willingness to attend scheduled sessions for 12 weeks.

Exclusion criteria: (1) pharmacological treatment of anxiety, depression or psychiatric disorders currently; (2) enrolled in another structured exercise program; (3) more than 20% absenteeism during the intervention; (4) unsafe performance of simple standing poses.

2.3.2 Sample Size Calculation

Sample size was calculated a priori using G*Power 3.1 (Faul et al., 2009) for a mixed ANOVA (between-within interaction) design. Based on a medium-to-large effect size ($f = 0.35$) derived from comparable yoga-flexibility RCTs in adolescent populations (Manjunath & Telles, 2001; Birdee et al., 2009), with power = 0.80, $\alpha = 0.05$, two groups, and two measurement points, a minimum of 36 participants per group was calculated. To account for an estimated 20%

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attrition rate in a school-based setting, the target sample was set at 45 participants per group (total N = 90).

2.3.3 Recruitment and Sampling

Stratified random sampling was employed across the six schools and Grades 8, 9, and 10, ensuring proportional representation. Within each school, class lists were obtained from school administration, eligible students were identified, and a random sample was drawn using computer-generated random numbers (Research Randomizer, v4.0). Fifteen students per grade level were targeted (5 per grade per group), yielding 30 students per grade (15 Yoga, 15 Control) and 90 in total. Demographic balance between groups was confirmed at baseline (Table 1).

2.4 Randomization and Allocation Concealment

Following baseline assessment, participants were randomly allocated in a 1:1 ratio to either the Yoga Group or the Control Group using a computer-generated block randomization sequence (block size = 6) stratified by school and sex. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes (SNOSE method) prepared by an independent statistician not involved in recruitment or assessment. The allocation sequence was revealed only after baseline assessment was complete for each participant. The intervention instructor was not blinded to group assignment (inherent to intervention delivery); however, outcome assessors were blinded to group allocation throughout the trial.

2.5 Intervention: Yoga-Based Training Program

The Yoga Group received a 12-week structured yoga-based training program specifically designed for Pakistani secondary school adolescents, developed in consultation with a certified Hatha yoga instructor (RYT-200, Yoga Alliance) and a sports physiotherapist. The program was designed to be culturally sensitive: all sessions were gender-segregated; gender-appropriate attire guidance was provided; and postures inconsistent with conservative Islamic modesty norms were excluded. Sessions were conducted in designated school assembly halls or multipurpose rooms.

The program followed a progressive periodization model across three phases: Foundation (Weeks 1–4), Development (Weeks 5–8), and Integration (Weeks 9–12). Sessions were held three times per week (Monday, Wednesday, Friday). Each session began with a 5-minute warm-up (gentle joint mobilization), followed by the main yoga practice, and concluded with a 5-minute guided relaxation (Savasana). Session duration increased progressively from 30 minutes (Weeks 1–2) to 50 minutes (Weeks 11–12). The detailed weekly protocol is presented in Table 4.

The Control Group continued their standard school physical education classes, comprising approximately 40 minutes of unstructured recreational activities (football, cricket, netball) twice weekly, with no flexibility or mind-body training component. Control participants were instructed not to engage in yoga or structured flexibility training outside school during the study period; compliance was verified through fortnightly self-report logs.

2.6 Outcome Measures

2.6.1 Physical Flexibility

Three validated field-based flexibility assessments were employed. First, the Sit-and-Reach Test (SRT) served as the primary measure of posterior chain flexibility (hamstrings and lower back). Participants sat with legs fully extended against a standardized box (Wells & Dillon, 1952) and reached forward maximally; the best of three trials (cm) was recorded. This test demonstrates high test-retest reliability in adolescent populations (ICC = 0.96–0.98; Hui & Yuen, 2000). Second, the Back-Scratch Test measured bilateral shoulder and shoulder-girdle

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flexibility using the American College of Sports Medicine (ACSM) standardized protocol; the overlapping or gap distance (cm) was recorded. Third, passive hip flexor range of motion was measured using a standard goniometer (360°, 30 cm arm length) in the supine Thomas Test position, with the contralateral hip stabilized; the mean of bilateral measurements was recorded. All assessments were performed by the same trained assessor (physiotherapy graduate; inter-rater reliability ICC = 0.94) at baseline and Week 12.

2.6.2 Psychological Stress

Psychological stress was assessed using the Perceived Stress Scale-10 (PSS-10; Cohen, Kamarck & Mermelstein, 1983), a validated 10-item self-report instrument measuring the degree to which situations are appraised as stressful over the past month. Items are rated on a 5-point Likert scale (0 = Never to 4 = Very Often), with total scores ranging from 0 to 40; higher scores indicate greater perceived stress. Scores are categorized as low (0–13), moderate (14–26), and high (27–40). The PSS-10 has demonstrated strong psychometric properties in South Asian adolescent populations (Cronbach's α = 0.78–0.84; Khan et al., 2021) and was translated into Urdu and Pashto using the back-translation method with expert panel review. Questionnaires were administered by a trained research assistant in group classroom settings at baseline and Week 12.

2.7 Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics version 26. Descriptive statistics (means, standard deviations, frequencies, and percentages) were computed for all demographic and outcome variables. Baseline group equivalence was tested using independent-sample t-tests (continuous variables) and chi-square tests (categorical variables). The primary efficacy analysis employed 2×2 mixed-model repeated-measures ANOVA, with group (Yoga vs. Control) as the between-subjects factor and time (baseline vs. Week 12) as the within-subjects factor; the group × time interaction was the primary test of efficacy. Levene's test was used to verify homogeneity of variance; Mauchly's test assessed sphericity. Post-hoc comparisons used Bonferroni correction. Effect sizes were calculated as Cohen's d for between-group post-test differences, interpreted as trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), and large (≥0.80). Pearson correlation coefficients examined associations between flexibility change scores and PSS-10 change scores within the Yoga Group. The alpha level was set at .05 (two-tailed) for all tests. Intention-to-treat analysis was conducted; missing data were handled via last observation carried forward (LOCF) for the three participants who withdrew during the intervention.

3. Results

3.1 Participant Flow and Baseline Characteristics

A total of 148 students were assessed for eligibility. Fifty-eight were excluded (32 did not meet inclusion criteria; 26 declined participation). Ninety students were enrolled and randomly allocated: 45 to the Yoga Group and 45 to the Control Group. Three participants in the Yoga Group missed >20% of sessions due to family obligations and were retained in the intention-to-treat analysis via LOCF. No adverse events were reported. The final per-protocol analysis included 42 participants in the Yoga Group and 45 in the Control Group. Baseline demographic characteristics are presented in Table 1. No significant between-group differences were observed on any demographic or baseline outcome variable (all $p > .05$), confirming successful randomization.

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Table 1: ***Baseline Demographic Characteristics of Yoga and Control Groups (N = 90)***

Characteristic	Yoga Group (n=45)	Control Group (n=45)	Total (N=90)	p-value
Age (years)				
Mean ± SD	14.62 ± 1.18	14.71 ± 1.24	14.67 ± 1.21	.762
Range	13–17	13–17	13–17	—
Sex				
Male	23 (51.1%)	22 (48.9%)	45 (50.0%)	.841
Female	22 (48.9%)	23 (51.1%)	45 (50.0%)	—
School Type				
Government	28 (62.2%)	27 (60.0%)	55 (61.1%)	.821
Private	17 (37.8%)	18 (40.0%)	35 (38.9%)	—
Grade				
Grade 8	15 (33.3%)	15 (33.3%)	30 (33.3%)	1.00
Grade 9	15 (33.3%)	15 (33.3%)	30 (33.3%)	—
Grade 10	15 (33.3%)	15 (33.3%)	30 (33.3%)	—
BMI (kg/m²)				
Mean ± SD	20.34 ± 2.87	20.51 ± 2.93	20.43 ± 2.89	.764
Prior Yoga Experience				
None	45 (100%)	45 (100%)	90 (100%)	—

Note. Values are Mean ± SD or n (%). p-values from independent t-tests (continuous) and chi-square tests (categorical). BMI = body mass index; SD = standard deviation.

3.2 Physical Flexibility Outcomes

Mixed-model repeated-measures ANOVA revealed a significant group × time interaction for all three flexibility measures (all $p < .001$), indicating that the Yoga Group improved significantly more than the Control Group over the 12-week intervention. Within the Yoga Group, all flexibility measures improved significantly from baseline to Week 12 ($p < .001$). Within the Control Group, no significant changes were observed on any flexibility measure (all $p > .05$).

For the Sit-and-Reach Test, the Yoga Group improved by a mean of 8.45 cm (pre: 18.42 ± 4.31 cm; post: 26.87 ± 4.12 cm), representing a large effect ($d = 2.07$). The Control Group's change of 0.42 cm was trivial ($d = 0.09$). For shoulder flexibility, the Yoga Group improved from −4.82 ± 3.74 cm to 1.63 ± 3.51 cm (+6.45 cm), a shift from below-average to above-average bilateral shoulder ROM ($d = 1.80$). For hip flexor ROM, Yoga Group participants gained 16.33° (72.14° to 88.47°), representing a substantial functional improvement ($d = 2.02$), whereas control participants gained only 0.43° ($d = 0.05$). All outcomes are presented in Table 2.

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Table 2: ***Physical Flexibility Outcomes: Pre- and Post-Intervention Means, Changes, and Effect Sizes***

Measure	Yoga Pre	Yoga Post	Control Pre	Control Post	p (G×T)
Sit-and-Reach (cm)					
Mean ± SD	18.42 ± 4.31	26.87 ± 4.12***	18.61 ± 4.47	19.03 ± 4.38	<.001
Change	—	+8.45 cm	—	+0.42 cm	—
Effect size (d)	—	2.07 (large)	—	0.09 (trivial)	—
Shoulder Flexibility (cm)					
Mean ± SD	−4.82 ± 3.74	1.63 ± 3.51***	−4.91 ± 3.88	−4.73 ± 3.79	<.001
Change	—	+6.45 cm	—	+0.18 cm	—
Effect size (d)	—	1.80 (large)	—	0.05 (trivial)	—
Hip Flexor ROM (°)					
Mean ± SD	72.14 ± 8.63	88.47 ± 8.11***	71.98 ± 8.44	72.41 ± 8.52	<.001
Change	—	+16.33°	—	+0.43°	—
Effect size (d)	—	2.02 (large)	—	0.05 (trivial)	—

*Note. ROM = range of motion; G×T = group × time interaction; d = Cohen's d. *** p < .001 within-group pre–post comparison (Yoga Group). Effect size benchmarks: trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), large (≥0.80).*

3.3 Psychological Stress Outcomes

A significant group × time interaction was observed for total PSS-10 score ($F(1,88) = 186.42$, $p < .001$, partial $\eta^2 = 0.68$). The Yoga Group demonstrated a mean reduction of 8.56 points (pre: 22.87 ± 4.62; post: 14.31 ± 4.18), representing a large effect ($d = 1.96$). The Control Group's negligible reduction of 0.27 points ($d = 0.06$) was not statistically significant. Significant group × time interactions were also observed for both PSS-10 subscales (perceived helplessness and perceived self-efficacy; both $p < .001$).

Clinically meaningful stress category shifts were observed in the Yoga Group: the proportion in the high-stress category declined from 26.7% to 4.4% ($\chi^2 = 8.31$, $p = .003$), while the proportion in the low-stress category increased from 11.1% to 46.7%. In the Control Group, stress category distribution remained stable throughout the intervention (all $p > .05$). Outcomes are presented in Table 3.

Table 3: ***Psychological Stress Outcomes: PSS-10 Total and Subscale Scores Pre- and Post-Intervention***

PSS-10 Measure	Yoga Pre	Yoga Post	Control Pre	Control Post	p
Total PSS-10 Score (0–40)					
Mean ± SD	22.87 ± 4.62	14.31 ± 4.18***	22.71 ± 4.58	22.44 ± 4.61	<.001
Change	—	−8.56	—	−0.27	—
Effect size (d)	—	1.96 (large)	—	0.06 (trivial)	—

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PSS-10 Measure	Yoga Pre	Yoga Post	Control Pre	Control Post	p
Perceived Helplessness Subscale					
Mean ± SD	13.44 ± 2.91	8.23 ± 2.68***	13.38 ± 2.84	13.21 ± 2.88	<.001
Effect size (d)	—	1.84 (large)	—	0.06 (trivial)	—
Perceived Self-Efficacy Subscale					
Mean ± SD	9.43 ± 2.18	6.08 ± 1.94***	9.33 ± 2.21	9.23 ± 2.19	<.001
Effect size (d)	—	1.60 (large)	—	0.05 (trivial)	—
Stress Category Shift					
High stress (≥27)	12 (26.7%)	2 (4.4%)**	11 (24.4%)	10 (22.2%)	.003
Moderate stress (14–26)	28 (62.2%)	22 (48.9%)	29 (64.4%)	30 (66.7%)	—
Low stress (<14)	5 (11.1%)	21 (46.7%)	5 (11.1%)	5 (11.1%)	—

*Note. PSS-10 = Perceived Stress Scale-10 (range 0–40; higher scores indicate greater stress). *** $p < .001$ within-group change (Yoga Group); ** $p < .01$ stress-category chi-square. d = Cohen's d effect size.*

3.4 Yoga Intervention Protocol Summary

Table 4: ***12-Week Progressive Yoga-Based Training Protocol***

Weeks	Phase	Asanas (Poses)	Duration	Primary Focus
1–2	Foundation & Breath Awareness	Tadasana, Balasana, Sukhasana, Pranayama (diaphragmatic breathing)	30 min × 3/week	Breath regulation, postural alignment, participant trust-building
3–4	Foundational Flexibility	Uttanasana, Paschimottanasana, Janu Sirsasana, Adho Mukha Svanasana	40 min × 3/week	Hamstring and spinal flexibility
5–6	Core Stability & Balance	Virabhadrasana I & II, Trikonasana, Vrksasana, Plank	40 min × 3/week	Balance, functional strength, attentional focus
7–8	Intermediate Flexibility & Relaxation	Setu Bandhasana, Ardha Matsyendrasana, Gomukhasana, Yoga Nidra	45 min × 3/week	Deep flexibility, progressive stress reduction
9–10	Stress & Emotional Regulation	Supta Baddha Konasana, Viparita Karani, Savasana, Nadi Shodhana Pranayama	45 min × 3/week	Parasympathetic activation, anxiety reduction
11–12	Integration & Full Practice	Surya Namaskar (Sun Salutation), combined full-body flow, mindfulness meditation	50 min × 3/week	Full integration of flexibility and stress management skills

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Note. All sessions include a 5-minute warm-up (joint mobilization) and 5-minute cool-down (guided Savasana relaxation). Asana names are provided in Sanskrit; English functional equivalents were used verbally in all instruction. All sessions were conducted in gender-segregated groups.

3.5 Correlation Between Flexibility and Stress Outcomes

Within the Yoga Group, Pearson correlation analysis revealed significant moderate-to-large negative correlations between all three flexibility change scores and PSS-10 change score (Table 5), indicating that greater improvements in flexibility were associated with greater reductions in perceived stress. Correlation coefficients were: sit-and-reach change $r = -0.71$ ($p < .01$); shoulder flexibility $r = -0.64$ ($p < .01$); hip flexor ROM $r = -0.66$ ($p < .01$). Flexibility measures were also significantly positively intercorrelated ($r = 0.61–0.74$, $p < .01$).

Table 5: ***Pearson Correlation Matrix: Flexibility Change Scores and PSS-10 Change Score (Yoga Group, n = 45)***

Variable	1	2	3	4
1. Sit-and-Reach Change (cm)	1.00	0.74**	0.68**	−0.71**
2. Shoulder Flexibility Change (cm)	—	1.00	0.61**	−0.64**
3. Hip Flexor ROM Change (°)	—	—	1.00	−0.66**
4. PSS-10 Score Change	—	—	—	1.00

*Note. Change scores = Post − Pre values. PSS-10 change is scored as Post − Pre (negative values indicate improvement). ** $p < .01$ (two-tailed).*

4. Discussion

4.1 Principal Findings

This randomized controlled trial provides the first empirical evidence from Peshawar District and among the first from any secondary school setting in Khyber Pakhtunkhwa that a 12-week structured yoga-based training program produces large-magnitude improvements in physical flexibility and substantial reductions in perceived psychological stress in adolescent students. All three primary flexibility outcomes and the PSS-10 stress measure showed statistically significant and clinically meaningful changes in the Yoga Group relative to an active-education Control Group, with effect sizes in the large range ($d = 1.80–2.07$ for flexibility; $d = 1.96$ for stress). These findings align with and extend the international literature on school-based yoga interventions.

4.2 Physical Flexibility

The sit-and-reach improvement of 8.45 cm over 12 weeks is consistent with, and at the upper end of, gains reported in comparable adolescent yoga RCTs internationally. Manjunath and Telles (2001) reported a 5.1 cm SRT gain in Indian school students following a 10-week yoga program; Birdee et al. (2009) reported mean gains of 4–6 cm in North American youth studies. The larger magnitude of gains observed in the present study may reflect the greater baseline flexibility deficit in the Peshawar sample (SRT baseline mean: 18.42 cm), which was notably lower than Indian (24–26 cm) and Western (22–28 cm) normative values for adolescents. This suggests that populations with lower initial flexibility may have greater absolute gain potential in response to structured yoga training.

The mechanistic basis for flexibility improvements through yoga is well-established. Sustained static and dynamic stretching during asana practice induces viscoelastic creep in the musculotendinous unit, reducing tissue stiffness over time (Magnusson et al., 1996). Regular stretching also increases stretch tolerance the neural threshold at which stretch sensation

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becomes uncomfortable allowing greater ROM without pain inhibition (Weppler & Magnusson, 2010). The progressive periodization of the 12-week protocol, which systematically advanced participants from foundational to complex postures, likely amplified these adaptations.

The hip flexor ROM gain of 16.33° has particular practical significance for the Peshawar student population, among whom prolonged classroom sitting and low recreational physical activity are expected to produce chronic hip flexor shortening. Reduced hip flexor flexibility is a recognized contributor to anterior pelvic tilt, lumbar hyperlordosis, and low back pain in adolescents (Khamis & Yizhar, 2007) a condition with a 30–40% prevalence in Pakistani secondary school students (Khan et al., 2020). The yoga program's systematic targeting of hip flexors through warrior poses (Virabhadrasana), bridge pose (Setu Bandhasana), and reclining butterfly (Supta Baddha Konasana) directly addressed this clinically relevant musculoskeletal deficit.

4.3 Psychological Stress

The reduction of 8.56 points on the PSS-10 in the Yoga Group shifting mean scores from the moderate-stress range (22.87) to the low-moderate range (14.31) and reducing high-stress prevalence from 26.7% to 4.4% represents a clinically and epidemiologically meaningful change. This magnitude of reduction exceeds the PSS-10's estimated minimal clinically important difference (MCID) of 4–5 points established in adult population studies (Norris & Norris, 2002) and is consistent with effect sizes reported in meta-analyses of yoga-based stress interventions in adolescents (Khalsa et al., 2012; Weaver & Darragh, 2015).

Multiple mechanisms likely contributed to the observed stress reductions. First, pranayama exercises particularly Nadi Shodhana (alternate-nostril breathing) introduced in Weeks 9–10 directly engage the parasympathetic nervous system via the vagal pathway, reducing heart rate, blood pressure, and cortisol secretion (Jerath et al., 2006). Second, the mindfulness components embedded in yoga practice particularly the focused attentional demands of asana execution and Yoga Nidra relaxation have been shown to reduce rumination and negative cognitive appraisal of stressors, key processes underlying the PSS-10's perceived helplessness subscale. Third, the large negative correlations between flexibility gains and stress reductions ($r = -0.64$ to -0.71) suggest a shared neurophysiological pathway: the same parasympathetic shift and muscle spindle desensitization that enables greater flexibility may simultaneously reduce physiological and perceived stress reactivity.

The particularly elevated baseline stress levels in this Peshawar sample (mean PSS-10 = 22.87; 26.7% in the high-stress category) merit contextual interpretation. Pakistan's secondary school examination system characterized by high-stakes Grade 10 matriculation exams (SSC), rote-learning pedagogy, large class sizes, and intense family expectations around academic performance creates a stressor-dense environment. Residual post-conflict trauma in Khyber Pakhtunkhwa's student population (Pervez et al., 2020) may further elevate baseline stress burden. The yoga program's demonstrated efficacy in this high-baseline-stress context is clinically encouraging and suggests that the intervention is particularly well-suited to populations carrying elevated psychosocial stress loads.

4.4 Cultural Feasibility in Peshawar

A novel and practically significant finding of this study is the high attendance rate and sociocultural acceptance of yoga practice within the conservative context of Peshawar. Mean session attendance in the Yoga Group was 87.4% (range: 76–100%), and exit interviews with a random subsample of 20 participants (10 male, 10 female; data not shown) indicated high program satisfaction and perceived personal benefit. No objections related to religious or

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cultural concerns were raised during the 12-week program. This outcome is directly attributable to deliberate program design features: gender-segregation of all sessions; avoidance of Sanskrit spiritual terminology in instruction (poses were described functionally); substitution of 'mindful breathing' for explicitly meditative language; and provision of a cultural briefing to school principals and parents prior to recruitment.

This feasibility evidence is significant for scale-up planning. Prior implementation barriers to yoga in Pakistani institutional settings have included concerns about cultural appropriateness, religious sensitivity, and instructor availability. The present trial demonstrates that a carefully adapted, functionally framed yoga program can be conducted without cultural friction in Peshawar District secondary schools, supporting its potential for integration into the Khyber Pakhtunkhwa School Physical Education framework.

4.5 Comparison with Prior Literature

The present findings extend and support a growing body of school-based yoga RCT evidence. Khalsa et al. (2012) demonstrated significant reductions in perceived stress and anxiety in US high school students following a 10-week yoga program; Weaver and Darragh (2015) reported comparable improvements in a systematic review of nine school-based yoga studies. Butzer et al. (2015) found that classroom yoga improved attention and self-regulatory behavior in middle school students, outcomes likely mediated by stress reduction. The present study extends this literature by providing: (1) RCT evidence from a lower-middle-income country (Pakistan); (2) evidence from a conservative religious-cultural context (Peshawar, KP) where yoga has not previously been formally evaluated; (3) one of the largest school-based yoga RCT samples reported in South Asia; and (4) the first simultaneous measurement of both flexibility and stress outcomes with large-effect-size RCT confirmation in this geographic and sociocultural setting.

4.6 Limitations

Several limitations must be acknowledged. First, the absence of a follow-up assessment beyond Week 12 precludes evaluation of the durability of gains; a follow-up at 6 and 12 months post-intervention is planned. Second, while assessor blinding was maintained for outcome measurement, blinding of participants and the intervention instructor was not feasible, introducing potential performance and detection bias. Third, the absence of biochemical stress biomarkers (e.g., salivary cortisol, DHEA-S) limits mechanistic conclusions; the PSS-10, while well-validated, is a self-report instrument subject to social desirability bias. Fourth, the sample was drawn from six schools in Peshawar District and may not generalize to students from rural Khyber Pakhtunkhwa or other provinces. Fifth, the control condition standard physical education—was not a fully inert comparator; nonspecific effects of group participation and instructor attention may have contributed to observed Yoga Group gains.

5. Conclusion

This randomized controlled trial provides robust evidence that a 12-week school-based yoga training program produces large, statistically significant, and clinically meaningful improvements in physical flexibility and psychological stress reduction among secondary school students in Peshawar District, Pakistan. The effect sizes observed ($d = 1.80–2.07$ for flexibility; $d = 1.96$ for perceived stress) are among the largest reported in the comparable adolescent yoga RCT literature. The significant negative correlations between flexibility gains and stress reductions ($r = –0.64$ to $–0.71$) indicate a shared psychophysiological pathway warranting further mechanistic investigation.

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The program was culturally feasible, logistically deliverable within existing school infrastructure, and associated with high student attendance and acceptability. Given Pakistan's dual burden of adolescent physical deconditioning and escalating psychological stress both acutely concentrated in Peshawar's secondary school population the integration of structured yoga-based training into the Khyber Pakhtunkhwa school physical education curriculum is both evidence-supported and urgently warranted. Policy recommendations include: (1) pilot scale-up to all district government secondary schools in Peshawar under the KP Education Department; (2) development of a national yoga-in-schools teacher training certification under the Higher Education Commission (HEC) and Pakistan Sports Board; (3) longitudinal follow-up studies to assess durability of gains and academic performance correlates; and (4) cost-effectiveness analysis to support national physical education curriculum reform.

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Author Declarations

Ethical Approval: Obtained from the Institutional Review Board of the University of Peshawar (UOP-IRB-2024-031) and the District Education Officer, Peshawar. All procedures conform to the Declaration of Helsinki (2013 revision).

Informed Consent: Written parental/guardian consent and student assent were obtained from all participants prior to enrollment.

Trial Registration: Pakistan Health Research Council — PHRC/HEC/REC/2024/PES-042.

Funding: This study received no external funding. Yoga instruction was provided pro bono by a certified RYT-200 instructor in collaboration with the University of Peshawar Department of Sports Sciences and Physical Education.

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

Data Availability: De-identified participant data supporting the findings of this study are available upon reasonable request to the corresponding author.

Author Contributions: Manahil: data collection, intervention coordination, statistical analysis, manuscript preparation. Ghulam Mustafa: study conception and design, supervision, critical revision of the manuscript. Both authors approved the final version for submission.

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