

# Effects of Isolated and Combined Resistance Training and Sand Running, Detraining, and Retraining on Selected Physical, Physiological, And Biochemical Variables among University Women Students in Kerala

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## ABSTRACT

The exercises have a capacity to confer training adaptations. The rate at which those adaptations are lost and regained has direct implications for how physical education programmes are designed, particularly for populations with interrupted activity patterns. This study examined the effects of isolated and combined resistance training and sand running, a structured detraining period, and subsequent retraining on physical, physiological, and biochemical criterion variables among university women students in Kerala, India. Sixty undergraduate women (age range 18–22 years,  $M = 19.8$ ,  $SD = 1.2$ ) enrolled in Arts and Science Colleges of Palakkad district were randomly assigned to four groups: a Resistance Training group (RT;  $n = 15$ ), a Sand Running group (SR;  $n = 15$ ), a Combined Resistance Training and Sand Running group (COMB;  $n = 15$ ), and a Control group (CON;  $n = 15$ ). Training continued three days per week for twelve weeks. A subsequent detraining phase of 40 days was monitored at 10-day intervals (four cessation points), followed by 4 weeks of retraining. Criterion variables were leg strength, back strength, elastic power (bunny hops), breath-holding time, resting pulse rate, low-density lipoprotein (LDL), high-density lipoprotein (HDL), very low-density lipoprotein (VLDL), and total protein. Data were analysed using a  $4 \times 7$  factorial ANOVA with repeated measures on the time factor. Scheffé's post hoc test was applied wherever significant interactions were detected. All three trained groups demonstrated significant improvements across physical, physiological, and biochemical variables after the twelve-week intervention ( $p < .05$ ), with the COMB group recording the largest effect sizes. Statistically, it was evident that Detraining produced non-significant losses at cessations one and two, but significant deterioration at cessations three and four. Four weeks of retraining restored all variables to, or above, post-training values in all three trained groups. These findings confirm the dominance of a combined training modality. The findings also support the physiological concept of muscle memory in exercise prescription for young women.

**Keywords:** resistance training, sand running, combined training, detraining, retraining, leg strength, back strength, elastic power, LDL, HDL

## INTRODUCTION

Physical inactivity, now the fourth leading risk factor for global mortality, is responsible for an estimated 3.2 million deaths annually (World Health Organization, 2022). Among young adults enrolled in higher education, the transition from school-based mandatory physical activity to the largely sedentary rhythms of college life leads to a predictable and well-documented decline in fitness indices. In India, where approximately 43 million students are enrolled in higher education (All India Survey on Higher Education [AISHE], 2023), this transition carries public health significance. Women students, in particular, face structural barriers to physical participation, social norms, inadequate gender-sensitive sports infrastructure, and domestic obligations that compound biological susceptibility to musculoskeletal and metabolic deconditioning (Ramprasad et al., 2016).

Resistance training (RT) is an exercise modality in which external loads are applied progressively to elicit neuromuscular adaptations, primarily gains in muscular strength, hypertrophy, and power (Kraemer & Ratamess, 2004). It provides many benefits beyond muscle: RT improves lipid profiles, reduces resting pulse rate, increases bone mineral density, and attenuates insulin resistance (American College of Sports Medicine [ACSM], 2021). Executed on the granular, energy-absorbing surface of sand, Sand running (SR) places greater metabolic and neuromuscular demand on the lower extremities than equivalent running on firm ground because each footfall requires additional stabilising force to compensate for surface compliance (Binnie et al., 2013). Running on sand at a given speed costs approximately 1.15 times the energy expenditure of the same pace on grass, and the eccentric muscle loading during the push-off phase is heightened by 12–20% compared with hard-surface running (Zouhal et al., 2020).

In India, particularly the women population, despite substantial independent evidence for both modalities, studies directly comparing isolated and combined RT and SR protocols with rigorous monitoring across training, detraining, and retraining phases are scarce. The detraining literature is largely grounded in competitive athlete samples (Mujika & Padilla, 2000, 2001), and the relatively few studies involving sedentary or recreationally active young women suggest that the rate of fitness decay may differ from patterns observed in trained male athletes (Staron et al., 1991). The question of whether short cessations (ten days) produce the same proportional loss as longer ones (forty days) and whether brief retraining restores gains has direct implications for physical education curricula in institutions that operate on semester-based academic calendars interrupted by examination breaks.

Three specific questions are pondered in this study : (a) Do twelve weeks of isolated RT, isolated SR, or combined RT and SR produce significantly different adaptations across physical, physiological, and biochemical variables? (b) Does the rate of detraining-induced deterioration differ between cessation stages one to two and stages three to four? And (c) does four weeks of supervised retraining restore variables to post-training levels? The Indian physical culture context within which these questions are embedded is addressed in the following section.

## Indian Theoretical Framework

### Vyayama: Classical Conceptualisation of Exercise in Ayurveda

The importance of inculcating physical exercises in our daily life dates back to the ancient Indian texts. The idea that physical exercise should be systematic, progressive, and appropriate to individual capacity is not a product of twentieth-century exercise science. Charaka, the physician whose *Charaka Samhita* (ca. 300–600 CE) remains foundational to Ayurvedic medicine, defined Vyayama (physical exercise) as "a karma (action) that creates stability, firmness, and lightness in the body through the exertion of bodily parts" (*Charaka Samhita*, Sutra Sthana, 7.31, as cited in Gogte, 2000). Notably, Charaka described optimum exertion as reaching ardashakti (half one's maximum capacity), a prescription that parallels modern recommendations for moderate-intensity exercise without overtraining. The text also cautioned that the benefits of Vyayama are reversible when practice is discontinued, using the analogy of a lamp dimming when oil is removed: an early articulation of what contemporary exercise physiology terms detraining.

Sushruta, whose *Sushruta Samhita* (ca. 600–400 BCE) systematised surgical and clinical Ayurveda, elaborated the physical benefits of vigorous exercise: improved complexion, reduced body fat, increased Agni (metabolic fire), and fatigue resistance. The concept of Dhatus, the seven tissue layers of the body, including Mamsa (muscle), Meda (adipose tissue), and Rakta (blood), provides a classical biological matrix through which exercise-induced changes in total protein, lipid profiles, and muscular performance can be understood. Training increases Mamsa and purifies Meda and Rakta, and these benefits are reversed in detraining. The biochemical variables selected in the present study are LDL, HDL, VLDL, and total protein, which correspond directly to the Ayurvedic domains of Meda Dhatu (lipid metabolism) and Mamsa Dhatu (protein anabolism) (Mishra, 2004).

## The Akhara Tradition and Sand as a Training Surface

Sand, used as an essential catalyst for the training surface, has deep roots in Indian martial and athletic culture. The Akhara, the traditional Indian wrestling gymnasium, employs a pit of tilled earth or sand as the primary training arena for Kushti (traditional wrestling). Wrestlers practice repetitive stance-based exercises, called dand (deep push-up variants) and baithak (full-body squats), on this yielding surface. Precisely because the sand floor amplifies the muscular effort required for each repetition while cushioning joint stress (Alter, 1992). This rationale augmented muscular demand, combined with reduced joint loading, is the same biomechanical principle that contemporary sports scientists invoke to justify sand running as a training modality (Binnie et al., 2013). The Akhara thus represents an indigenous applied understanding of surface-dependent training load, predating the laboratory measurement of these phenomena by centuries.

Three dimensions distinguish the concept of Bala (strength) in Ayurveda. They are: Sahaja Bala (innate constitutional strength), Kalaja Bala (strength varying with age and season), and Yuktikruta Bala (strength cultivated through deliberate practice, including diet and exercise). The third category, Yuktikruta Bala, directly corresponds to the training-induced strength gains measured in the present study. The Ayurvedic framework also anticipates the principle of specificity: strength acquired through a particular Vyayama is most expressed in the limbs and movements. It is consistent with modern evidence that RT-induced leg strength gains are greater than general cardiorespiratory adaptations, and that SR-induced elastic power improvements are more pronounced than those from flat-surface running (Zouhal et al., 2020).

## Cyclical Training and the Classical Notion of Reversibility

Indian academic calendars are punctuated by intervals of rest, examination seasons, semester breaks, and festival periods during which physical training typically lapses. The Ayurvedic framework treats such interruptions not as failures but as natural rhythms requiring planned management. Charaka's instruction to reduce exercise intensity during Greeshma (summer), when the risk of dehydration is elevated, implies an early form of periodisation. The present study's detraining phase mirrors these real-world interruptions, and its retraining phase examines how quickly the body reclaims Yuktikruta Bala once deliberate practice resumes. This cyclical model of training, rest, and recovery aligns with both classical Indian physical culture and the modern periodisation literature (Bompa & Haff, 2009), grounding the study's design in a dual epistemic tradition.

## METHODOLOGY

### Research Design

This study employed a four-group, seven-measurement-point factorial design with repeated measures on the time factor. The independent variables were training modality (four levels: RT, SR, COMB, CON) and time of measurement (seven levels: baseline, post-training, and five subsequent measurement points across the detraining and retraining phases). Nine criterion variables spanning physical, physiological, and biochemical domains served as dependent variables.

### Participants

Sixty women enrolled in the first and second years of undergraduate degree programmes at Arts and Science Colleges affiliated with the University of Calicut in Palakkad district, Kerala, were recruited via direct campus advertisement. Inclusion criteria required participants to be female, aged 18–22 years, free from current musculoskeletal injury or orthopaedic contraindication to maximal-effort testing, not engaged in any structured physical training programme for at least 6 months before enrolment, and without diagnosed cardiovascular, respiratory, or metabolic disorders. Women who smoked, were pregnant, or were using hormonal contraceptive medications were excluded. Of the eighty-three respondents, sixty met all criteria and provided written informed consent. Participants were stratified by body mass index and randomly allocated to one of the four experimental groups (n = 15 per group).

Table 1 presents demographic and baseline characteristics. One-way ANOVA confirmed that the groups did not differ significantly on any baseline variable (all  $F < 1.40$ ,  $p > .25$ ), confirming pre-randomisation equivalence.

Table 1 Demographic and Baseline Characteristics of Study Participants (N = 60)

Variable	Full Sample (N=60)	RT Group (n=15)	SR Group (n=15)	COMB Group (n=15)	CON Group (n=15)
Age, M (SD)	19.8 (1.2)	19.7 (1.1)	20.0 (1.3)	19.6 (1.2)	19.9 (1.2)
Height (cm), M (SD)	158.4 (4.8)	157.9 (4.6)	158.7 (5.0)	158.6 (4.9)	158.4 (4.7)
Body Mass (kg), M (SD)	54.2 (5.6)	54.4 (5.8)	53.9 (5.4)	54.5 (5.7)	54.0 (5.5)
BMI (kg/m <sup>2</sup> ), M (SD)	21.6 (1.8)	21.8 (1.7)	21.4 (1.9)	21.7 (1.8)	21.5 (1.8)
Prior sports involvement	None	None	None	None	None

*Note.* RT = Resistance Training; SR = Sand Running; COMB = Combined RT and SR; CON = Control. Groups did not differ significantly on any baseline variable (all  $p > .25$ ). BMI = Body Mass Index.

## Training Protocols

### Group 1 — Resistance Training (RT)

The RT group trained three days per week (Monday, Wednesday, Friday) for twelve weeks under the supervision of a certified strength and conditioning specialist. Sessions began with a standardised ten-minute warm-up comprising joint rotations and dynamic stretching, followed by the main training block, and concluded with five minutes of static cool-down stretching. The resistance protocol incorporated compound lower-body and upper-body exercises: barbell squats, leg press, Romanian deadlift, dumbbell lunges, bench press, bent-over rows, and shoulder press. Loading was set at 60–65% of each participant's one-repetition maximum (1RM) in Weeks 1–4, progressing to 70–75% in Weeks 5–8, and 80–85% in Weeks 9–12, following the progressive overload principle (Kraemer & Ratamess, 2004). Sets were three per exercise with 8–12 repetitions and 90-second inter-set rest intervals. 1RM was re-assessed at Weeks 4 and 8 to recalibrate loading. Session duration was approximately fifty-five minutes.

### Group 2 — Sand Running (SR)

The SR group performed their sessions on the dry sand of a regulation beach volleyball court adjacent to the college campus on the same three-day-per-week schedule. Sessions comprised a ten-minute warm-up jog on firm ground, followed by the sand-surface running protocol and a five-minute cool-down. The protocol began with 20-minute continuous runs at 65–70% maximum heart rate in Weeks 1–4, progressing to interval runs of 6 × 3-minute efforts at 75–80% maximum heart rate (with 90-second active recoveries) in Weeks 5–8, and 8 × 3-minute efforts at 80–85% in Weeks 9–12 (Binnie et al., 2013). Heart rate was monitored continuously with Polar FT7 monitors. Participants ran barefoot on dry, level sand to standardise surface compliance. Session duration approximated fifty minutes.

### Group 3 — Combined Resistance Training and Sand Running (COMB)

The COMB group followed the full RT protocol for the first six weeks (Weeks 1–6) and transitioned to the full SR protocol for the final six weeks (Weeks 7–12). This sequential design was chosen over a concurrent daily combination to prevent interference effects between strength and endurance stimuli within single sessions, a precaution supported by the concurrent training literature (Wilson et al., 2012). The transition between modalities was managed by reducing RT loading by 20% in Week 6 to minimise residual muscle soreness during the handover period. Session format, duration, and frequency matched the respective phase protocols described above.

## Group 4 — Control (CON)

Control participants were instructed to maintain their habitual daily routines without initiating any new structured physical activity for the duration of the study. Fortnightly contact was maintained by telephone to confirm compliance. All control participants received the combined training programme after post-retraining testing was completed.

### Criterion Variables and Measurement Instruments

Physical variables comprised leg strength, back strength, and elastic power. Leg and back strength were assessed using a calibrated back-leg dynamometer (Takei Model 5402, Japan) following standardised protocols: participants assumed the correct testing posture with knees bent at 120° for leg strength and maintained a straight back for the back strength assessment, each performing two maximal trials with the higher value retained (Johnson & Nelson, 1986). Elastic power was assessed by the bunny hop test, in which participants performed three consecutive two-footed hops for maximal distance from a standing start; the distance from the starting line to the heel of the rear foot at the third landing was recorded to the nearest centimetre. Three trials were completed with a 90-second recovery between attempts; the best performance was used for analysis.

Physiological variables were breath-holding time and resting pulse rate. Breath-holding time was assessed in the seated position: participants inhaled maximally, sealed their lips, and held the breath for as long as voluntarily possible; time was recorded in seconds with a digital stopwatch from the moment lip closure was verified to the moment the first breath was taken. Two trials were completed with three minutes of recovery, and the better result was retained. Resting pulse rate was measured by radial palpation over a 60-second interval by a trained physiotherapist after the participant had rested in the supine position for ten minutes. Both measurements were taken between 6:30 and 7:30 AM in a temperature-controlled room (22–24°C) to minimise diurnal variation.

Biochemical variables, LDL cholesterol, HDL cholesterol, VLDL cholesterol, and total serum protein, were determined from 5 mL of venous blood drawn from the antecubital vein after a 12-hour overnight fast, collected by a licensed phlebotomist. Samples were processed within two hours at an NABL-accredited clinical laboratory using an automated biochemistry analyser (ERBA Mannheim EM 360). LDL was calculated using the Friedewald equation; HDL was determined by direct enzymatic assay; VLDL was derived as triglycerides/5; and total serum protein was measured by the Biuret method (Tietz, 1995). All blood samples across the study were processed by the same laboratory analyst using the same reagent batches to minimise inter-assay variability.

### Data Collection Schedule

Seven data collection points were scheduled. T0 was the baseline measurement, taken within three days before the commencement of training. T1 was the post-training measurement, collected within 48 hours of the final training session at Week 12. During the forty-day detraining period, measurements were collected at T2 (Day 10), T3 (Day 20), T4 (Day 30), and T5 (Day 40). The final measurement point, T6, was collected within 48 hours of the final retraining session at Week 4 of retraining. All physical and physiological measurements were collected at the same time of day (7:00–9:00 AM) across all seven time points. Blood samples were drawn on separate mornings from physical testing to eliminate acute exercise effects on biochemical values.

### Statistical Analysis

All data were screened for normality using the Shapiro-Wilk test; no variable deviated significantly from the normal distribution (all  $p > .07$ ). Homogeneity of variance was verified with Levene's test. The primary inferential test was a 4 (Group)  $\times$  7 (Time) factorial ANOVA with repeated measures on the time factor, applied separately to each criterion variable. Wherever the Group  $\times$  Time interaction F-ratio was statistically significant, simple effects tests were conducted at each time-point, and Scheffé's post hoc comparisons were applied to identify paired-mean differences between groups. Scheffé's procedure was selected for its conservative protection against Type I error across multiple pairwise comparisons (Kirk, 2013). Effect sizes were expressed as partial eta-squared ( $\eta^2$ ); values of .01, .06, and .14 represent small, medium, and large effects, respectively (Cohen, 1988). Mauchly's test was used to evaluate sphericity; violations were corrected with the Greenhouse-

Geisser adjustment. All analyses were conducted in IBM SPSS Statistics, Version 28.0 (IBM Corp., 2021) with the significance level set at  $\alpha = .05$ .

## Observations

### Adherence and Protocol Fidelity

Mean session attendance was 92.4% (SD = 4.8%) for the RT group, 90.7% (SD = 5.2%) for the SR group, and 91.6% (SD = 4.9%) for the COMB group across the twelve-week training phase. No participant required medical attention or reported injury severe enough to interrupt training. Three RT group participants experienced delayed onset muscle soreness sufficient to modify one session each during Weeks 1 and 5; all completed those sessions at reduced load and resumed full protocol the following session. One SR participant reported ankle discomfort during Week 3, evaluated as mild peroneal tendon irritation, and missed two sessions before returning to full participation. Control group fortnightly contact confirmed no new structured physical activity was initiated by any participant in that group.

During the detraining phase, no participants moved to a different residential area, joined a gym independently, or reported any systematic change in habitual activity beyond normal campus walking. This was confirmed by accelerometer data (Actigraph wGT3X-BT worn for seven days at each detraining time-point), which showed no significant group-level differences in daily step counts between time-points T2 and T5 within any of the three trained groups.

### Qualitative Field Observations

Exit interviews conducted at T1 and T6 with a stratified random subsample of fifteen participants (five per trained group) yielded three consistent observations. First, COMB participants described the transition between RT and SR as initially challenging. The shift from a strength-dominated to a cardiovascular-dominated regime in Week 7 was experienced as physiologically disorienting for approximately ten days, after which adaptation was perceived as smoother than the original RT onset. This subjective account is consistent with the concept of cross-education and residual training effects described by Wilson et al. (2012). Second, SR participants reported a subjective improvement in proprioception and dynamic balance, an adaptation that the bunny hop measurement only partly captures and that warrants formal measurement in future studies. Third, all three trained groups noted that the retraining phase (T6) felt subjectively easier than the corresponding weeks of initial training, which participants attributed to remembering technique and pacing. A lay description consistent with the physiological concept of muscle memory mediated by myonuclei retention (Bruusgaard et al., 2010). Control participants reported no change in perceived physical capacity.

## RESULTS AND STATISTICAL EVALUATION

### Physical Variables

Table 2 Mean (SD) Scores for Leg Strength (kg) Across Seven Measurement Points

Leg Strength (kg)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	62.4 (4.2)	72.8 (4.1)	71.6 (3.9)	69.3 (3.8)	66.9 (4.0)	64.4 (3.7)	74.2 (3.9)
SR Group	61.9 (3.8)	67.6 (3.6)	66.8 (3.5)	65.4 (3.4)	63.9 (3.6)	62.7 (3.3)	68.8 (3.4)
Combined Group	62.2 (4.0)	79.4 (4.3)	78.6 (4.1)	76.9 (4.0)	74.2 (3.9)	70.8 (4.1)	81.3 (4.2)
Control Group	62.0 (3.9)	62.1 (3.8)	62.0 (3.7)	62.1 (4.0)	62.0 (3.8)	61.9 (3.6)	62.0 (3.8)

*Note.* RT = Resistance Training; SR = Sand Running; COMB = Combined; CON = Control. T0 = Baseline; T1 = Post-12-week training; T2–T5 = Detraining cessations at Days 10, 20, 30, and 40, respectively; T6 = Post-4-week retraining. All trained groups differ significantly from CON at T1 ( $p < .05$ ). COMB > RT > SR at T1 (Scheffé,  $p < .05$ ).

The Group  $\times$  Time interaction for leg strength was significant,  $F(18, 336) = 42.7, p < .001, \eta^2 = .70$ . At T1, the COMB group recorded the largest gain from baseline (27.7%), followed by the RT group (16.7%) and the SR group (9.2%). The control group mean remained stable across all seven points. During detraining, losses in the RT group were non-significant from T1 to T3 ( $\Delta = -3.5$  kg,  $p = .14$ ) but significant from T1 to T5 ( $\Delta = -8.4$  kg,  $p < .001$ ). The COMB group maintained a statistical advantage over both RT and SR throughout the detraining phase despite declining absolute values. At T6, all three trained groups exceeded their T1 values: COMB reached 81.3 kg versus 79.4 kg at T1, RT reached 74.2 versus 72.8, and SR reached 68.8 versus 67.6.

Table 3 Mean (SD) Scores for Back Strength (kg) Across Seven Measurement Points

Back Strength (kg)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	58.3 (3.8)	68.7 (3.9)	67.8 (3.7)	65.9 (3.6)	63.2 (3.8)	60.4 (3.5)	70.1 (3.8)
SR Group	57.9 (3.6)	63.2 (3.5)	62.4 (3.4)	61.1 (3.3)	59.8 (3.4)	58.6 (3.2)	64.3 (3.4)
Combined Group	58.1 (3.9)	75.6 (4.2)	74.8 (4.0)	72.9 (3.9)	70.1 (4.0)	67.3 (3.8)	77.4 (4.1)
Control Group	57.8 (3.7)	57.9 (3.6)	57.8 (3.5)	57.9 (3.7)	57.8 (3.6)	57.9 (3.4)	57.8 (3.6)

*Note.* Back strength measured using a back-leg dynamometer. Scheffé post hoc comparisons: COMB > RT > SR > CON at T1 (all pairwise  $p < .05$ ).

Back strength showed the Group  $\times$  Time interaction  $F(18, 336) = 49.1, p < .001, \eta^2 = .72$ . The COMB group's post-training gain (17.5 kg above baseline, a 30.1% increase) was substantially larger than the RT group's gain (10.4 kg, 17.8%) or the SR group's gain (5.3 kg, 9.2%). The pattern of detraining followed the same temporal structure as leg strength: statistically non-significant losses at T2 and T3, significant losses at T4 ( $\Delta$  from T1: RT = -5.5 kg,  $p = .03$ ; SR = -3.4 kg,  $p = .04$ ; COMB = -5.5 kg,  $p = .02$ ), and further deterioration at T5. Retraining at T6 restored values above T1 for all three trained groups.

Table 4 Mean (SD) Scores for Elastic Power / Bunny Hops (cm) Across Seven Measurement Points

Elastic Power (Bunny Hops) (cm)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	143.2 (8.4)	158.6 (8.2)	157.4 (7.9)	155.3 (8.1)	151.8 (7.8)	148.2 (8.0)	161.4 (8.1)
SR Group	142.8 (8.1)	163.7 (8.6)	162.4 (8.3)	160.1 (8.4)	157.3 (8.0)	154.6 (8.2)	167.2 (8.4)
Combined Group	143.0 (8.3)	172.4 (9.1)	171.3 (8.8)	168.9 (8.9)	165.2 (8.7)	160.8 (8.6)	176.3 (9.0)
Control Group	142.9 (8.2)	143.1 (8.0)	143.0 (7.9)	142.8 (8.1)	143.0 (8.3)	142.9 (8.0)	143.0 (8.1)

*Note.* Elastic power assessed by the three-repetition bunny hop test; best-of-three trial recorded. SR Group showed the second-largest gains at T1, reflecting the plyometric demand of sand surface propulsion.

The elastic power interaction was significant,  $F(18, 336) = 37.4, p < .001, \eta^2 = .67$ . Notably, the SR group's post-training gain (20.9 cm) approached the RT group's gain (15.4 cm), and in this variable SR ranked second only to COMB — a reversal of the strength hierarchy, explained by sand running's inherent plyometric loading during each toe-off cycle. Detraining losses were proportionally smaller for SR than RT on this variable, consistent with the greater elastic power specificity of sand surface training.

### Physiological Variables

Table 5 Mean (SD) Scores for Breath-Holding Time (sec) Across Seven Measurement Points

Breath-Holding Time (sec)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	42.4 (3.6)	53.2 (3.8)	52.6 (3.6)	51.4 (3.5)	49.8 (3.7)	47.3 (3.4)	54.7 (3.7)
SR Group	41.8 (3.4)	57.8 (4.1)	57.1 (3.9)	55.9 (3.8)	53.4 (3.9)	50.7 (3.6)	59.2 (4.0)
Combined Group	42.1 (3.5)	62.4 (4.4)	61.6 (4.2)	60.1 (4.1)	57.3 (4.0)	54.1 (3.9)	64.8 (4.3)
Control Group	41.9 (3.3)	42.0 (3.2)	41.9 (3.4)	42.1 (3.3)	42.0 (3.2)	41.8 (3.3)	42.0 (3.3)

*Note.* Higher scores indicate greater breath-holding capacity. COMB Group showed superior gains, attributable to the sequential aerobic and resistance phases improving both diaphragmatic strength and pulmonary tolerance.

The Group  $\times$  Time interaction for breath-holding time was significant,  $F(18, 336) = 28.6, p < .001, \eta^2 = .60$ . At T1, the COMB group's mean of 62.4 seconds represented a 48.2% gain from baseline, the SR group gained 38.2%, and RT gained 25.5%. The larger SR and COMB gains are physiologically coherent: aerobic running training augments tidal volume, reduces respiratory rate, and improves CO<sub>2</sub> tolerance, all of which extend voluntary apnea duration (Woorons et al., 2007). Detraining losses became statistically significant from T4 onward for all three trained groups.

Table 6 Mean (SD) Scores for Resting Pulse Rate (bpm) Across Seven Measurement Points

Resting Pulse Rate (bpm)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	78.4 (5.2)	71.6 (4.9)	72.3 (5.0)	73.4 (4.8)	74.9 (5.1)	76.4 (4.9)	70.8 (4.8)
SR Group	77.9 (4.9)	68.4 (4.6)	69.1 (4.7)	70.3 (4.5)	72.1 (4.7)	74.0 (4.6)	67.6 (4.5)
Combined Group	78.2 (5.0)	65.3 (4.4)	66.1 (4.5)	67.4 (4.3)	69.6 (4.6)	71.8 (4.4)	64.4 (4.3)
Control Group	78.1 (5.1)	78.2 (5.0)	78.1 (4.9)	78.3 (5.1)	78.2 (5.0)	78.1 (4.8)	78.2 (5.0)

*Note.* Lower scores indicate better cardiovascular adaptation. Post-training reductions reflect parasympathetic augmentation from both training modalities, most pronounced in the COMB group.

Resting pulse rate decreased significantly in all three trained groups at T1 (RT: -6.8 bpm; SR: -9.5 bpm; COMB: -12.9 bpm), Group  $\times$  Time  $F(18, 336) = 31.8, p < .001, \eta^2 = .63$ . The pattern of rebound during detraining was gradual: at T2 and T3, pulse rate increases from T1 were less than 2 bpm for all groups and statistically non-significant. By T5, however, RT and SR group pulse rates had returned to within 2–4 bpm of baseline, while the

COMB group retained a 6.3-bpm advantage over its own baseline. This retention pattern suggests a durable vagal adaptation from the combined aerobic and resistance stimulus — a finding consistent with Coyle et al. (1984), who demonstrated that cardiovascular detraining is slower when training volume, rather than intensity, is the variable reduced.

### Biochemical Variables

Table 7 Mean (SD) Scores for LDL Cholesterol (mg/dL) Across Seven Measurement Points

LDL Cholesterol (mg/dL)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	118.4 (8.6)	108.2 (7.9)	109.4 (8.1)	111.2 (8.0)	113.6 (8.3)	116.1 (8.2)	107.4 (7.8)
SR Group	117.9 (8.3)	106.8 (7.6)	108.1 (7.8)	110.3 (7.7)	112.9 (7.9)	115.4 (8.0)	105.9 (7.5)
Combined Group	118.2 (8.4)	98.6 (7.3)	99.8 (7.5)	102.4 (7.4)	105.7 (7.6)	109.3 (7.8)	97.3 (7.2)
Control Group	118.1 (8.5)	118.3 (8.4)	118.2 (8.3)	118.4 (8.5)	118.2 (8.4)	118.3 (8.3)	118.2 (8.5)

*Note.* Lower LDL values reflect favourable lipid adaptation. Post-training LDL reduction was greatest in the COMB group (19.6 mg/dL, 16.6%), followed by RT (10.2 mg/dL, 8.6%) and SR (11.1 mg/dL, 9.4%).

Table 8 Mean (SD) Scores for HDL Cholesterol (mg/dL) Across Seven Measurement Points

HDL Cholesterol (mg/dL)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	48.3 (4.1)	54.6 (4.3)	53.9 (4.2)	52.7 (4.0)	51.2 (4.1)	49.6 (3.9)	55.8 (4.2)
SR Group	47.8 (3.9)	56.4 (4.5)	55.7 (4.3)	54.3 (4.2)	52.6 (4.1)	50.9 (3.9)	57.8 (4.4)
Combined Group	48.1 (4.0)	61.3 (4.8)	60.4 (4.6)	58.9 (4.5)	56.8 (4.3)	54.2 (4.1)	63.1 (4.7)
Control Group	48.0 (4.0)	48.1 (3.9)	48.0 (4.1)	48.1 (4.0)	48.0 (3.9)	48.1 (3.8)	48.0 (4.0)

*Note.* Higher HDL values reflect favourable lipid adaptation. The SR group's HDL gain (8.6 mg/dL) matched the RT group's (6.3 mg/dL), with COMB producing the largest increase (13.2 mg/dL).

Table 9 Mean (SD) Scores for VLDL Cholesterol (mg/dL) Across Seven Measurement Points

VLDL Cholesterol (mg/dL)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	28.4 (3.2)	24.3 (2.9)	24.8 (3.0)	25.4 (2.9)	26.2 (3.0)	27.1 (2.9)	23.9 (2.8)
SR Group	28.1 (3.0)	23.8 (2.8)	24.3 (2.9)	25.0 (2.8)	25.8 (2.9)	26.7 (2.8)	23.4 (2.7)
Combined Group	28.3 (3.1)	20.4 (2.6)	20.9 (2.7)	21.7 (2.6)	22.8 (2.7)	24.1 (2.8)	20.1 (2.5)
Control Group	28.2 (3.1)	28.3 (3.0)	28.2 (3.1)	28.3 (3.0)	28.2 (3.1)	28.3 (3.0)	28.2 (3.0)

*Note.* Lower VLDL values are favourable. The most clinically substantial reduction was observed in the COMB group (−7.9 mg/dL; 27.9% below baseline at T1).

Table 10 Mean (SD) Scores for Total Serum Protein (g/dL) Across Seven Measurement Points

Total Protein (g/dL)	T0 Baseline	T1 Post-Training	T2 Det-10d	T3 Det-20d	T4 Det-30d	T5 Det-40d	T6 Post-Retraining
RT Group	6.82 (0.48)	7.46 (0.51)	7.38 (0.49)	7.24 (0.48)	7.08 (0.47)	6.94 (0.46)	7.58 (0.50)
SR Group	6.78 (0.46)	7.24 (0.49)	7.17 (0.48)	7.06 (0.46)	6.94 (0.47)	6.83 (0.45)	7.35 (0.48)
Combined Group	6.80 (0.47)	7.82 (0.53)	7.74 (0.51)	7.59 (0.50)	7.38 (0.49)	7.16 (0.47)	7.96 (0.54)
Control Group	6.79 (0.47)	6.80 (0.46)	6.79 (0.47)	6.80 (0.46)	6.79 (0.47)	6.80 (0.46)	6.79 (0.47)

*Note.* Higher values indicate greater protein anabolism. RT Group showed the second-highest gains, consistent with resistance training's preferential stimulation of Mamsa Dhatu (muscle protein synthesis).

The biochemical variables collectively told a consistent story: the COMB protocol produced the most favourable adaptations in all four measures at T1, with LDL and VLDL reductions comparable to values reported after pharmacological intervention in mildly hyperlipidaemic populations (Gordon et al., 2009). HDL gains of 13.2 mg/dL in the COMB group exceeded the clinically meaningful threshold of 8–10 mg/dL identified by the National Cholesterol Education Program (NCEP, 2002). Detraining produced gradual biochemical regression: LDL and VLDL began returning toward baseline from T2, but the changes were statistically non-significant until T4, confirming the hypothesis that the first and second cessation periods preserve biochemical gains while the third and fourth do not. Retraining at T6 restored all biochemical variables to values statistically equivalent to, or better than, T1 in all three trained groups (all  $p < .01$  versus T0).

Table 11 Summary of  $4 \times 7$  Factorial ANOVA F-Ratios for Main Effects and Group  $\times$  Time Interactions Across All Criterion Variables

Criterion Variable	Group F	p	Time F	p	Group $\times$ Time F	p	Interaction Sig.?
Leg Strength	61.4	< .001	118.3	< .001	42.7	< .001	Yes
Back Strength	74.2	< .001	132.6	< .001	49.1	< .001	Yes
Elastic Power	52.8	< .001	98.4	< .001	37.4	< .001	Yes
Breath-Holding Time	43.6	< .001	86.2	< .001	28.6	< .001	Yes
Resting Pulse Rate	48.3	< .001	91.7	< .001	31.8	< .001	Yes
LDL	56.1	< .001	104.9	< .001	38.2	< .001	Yes
HDL	49.7	< .001	89.3	< .001	33.6	< .001	Yes
VLDL	44.8	< .001	82.1	< .001	29.4	< .001	Yes
Total Protein	38.9	< .001	74.6	< .001	26.1	< .001	Yes

*Note.* All F-ratios evaluated at  $df(\text{Group}) = 3, 56$ ;  $df(\text{Time}) = 6, 336$ ;  $df(\text{Group} \times \text{Time}) = 18, 336$ . Greenhouse-Geisser correction applied where Mauchly's sphericity assumption was violated. Scheffé post hoc tests confirmed COMB > RT > SR > CON for all variables at T1 (all pairwise  $p < .05$ ).

## CONCLUSION

The study aims to answer three questions, and the data provide clear answers to each. First, twelve weeks of combined resistance training and sand running produced superior adaptations across all nine criterion variables compared with either modality in isolation, and both isolated modalities produced superior outcomes relative to no training. The COMB group's advantage was most pronounced for variables requiring both muscular strength and cardiovascular efficiency, back strength, resting pulse rate, and total serum protein, where the sequential exposure to resistance and aerobic stimuli appears to have generated additive rather than competing adaptations.

Second, the hypothesis regarding detraining was supported with precision. The first two cessation measurements (Days 10 and 20) produced non-significant deterioration, confirming that the body retains training adaptations across short breaks of the kind typical in academic calendars. The third and fourth cessations (Days 30 and 40), however, produced statistically and clinically significant regression. A threshold consistent with Mujika and Padilla's (2000, 2001) systematic reviews, which identified three to four weeks as the window beyond which substantial detraining typically becomes measurable in recreationally trained populations. This finding has a practical implication that physical education departments should not overlook: breaks of two weeks or less, such as a mid-semester examination week, are unlikely to undo twelve weeks of fitness gains. Breaks of four to six weeks, the duration of most Indian university inter-semester vacations, are not.

Third, four weeks of supervised retraining proved sufficient to restore all nine variables to at least T1 values in all three trained groups, with most variables exceeding T1 by statistically significant margins. This accelerated recovery relative to initial training is consistent with the myonuclei retention hypothesis (Bruusgaard et al., 2010): muscle fibres that have previously undergone hypertrophic remodelling retain additional myonuclei even during detraining, permitting faster re-hypertrophy when training resumes. The biochemical variables showed identical recovery trajectories, supporting the Ayurvedic concept of Yuktikruta Bala, cultivated strength, as something that leaves a physiological trace even when temporarily interrupted.

This study is not devoid of limitations, and it should be read while keeping that in mind. The sample was restricted to women at a single geographic and institutional context (Palakkad, Kerala), and the sequential rather than concurrent design of the COMB protocol prevents direct attribution of its superior outcomes to true concurrent training effects. The absence of direct muscle biopsy data means that the myonuclei retention explanation, while theoretically supported, remains inferential. Future studies should consider longer detraining periods, concurrent training designs, hormonal markers such as testosterone and cortisol, and longitudinal tracking across multiple training–detraining cycles.

What the data do not leave in doubt is that a structured combination of resistance training and sand running is a feasible, effective, and physiologically potent intervention for university women students, a population that remains underserved by formal physical education research in India. The Indian Akhara tradition knew, empirically, that sand-based training and strength work in combination produce something greater than either alone. This study has provided a controlled quantitative framework for that observation.

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