Research Square

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Efficacy of Sensorimotor Training (SMT) and Motor Control Exercise (MCE) on Smash Velocity, Accuracy and Balance in Badminton Players: A Randomized Controlled Trial Running Title: Exercise Protocol for Performance of Badminton Players

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Abstract

Context- Badminton is a highly competitive racquet sport that necessitates a high level of neuromuscular coordination, fitness, and technical ability. It is distinguished by high-intensity intermittent play, which involves swift decelerations, lunges, accelerations, jumps, and rapid directional changes within short periods. The study aims to investigate the effects of SMT and MCE on smash velocity, smash accuracy, and balance in badminton players.

Design- A randomised controlled study with three arms and parallel groups.

Methods- The study included badminton players from Haryana and Punjab academies in India. Eighty-four badminton players (47 males and 37 females; mean age = 20.22 ± 2.83 y) aged 17 to 25 years with at least 1 year of playing experience were randomly assigned to SMT, MCE, or control groups (n = 28 per group). Participants in the SMT and MCE groups received 6 weeks of training, with 5 sessions per week (30 sessions total), in addition to conventional badminton training. The SMT group performed progressive sensorimotor exercises, whereas the MCE group performed Pilates and Swiss ball-based motor control exercises. The control group received only conventional badminton training. Smash velocity was assessed using a radar gun, smash accuracy by the forehand overhand smash test, and dynamic balance by the Y-balance test. Outcomes were measured at baseline, postintervention, and follow-up.

Results—Significant between-group differences were observed for smash velocity ($F=8.21$, $P<0.001$), smash accuracy ($F=4.70$, $P=0.012$), left balance composite score ($F=15.02$, $P<0.001$), and right balance composite score ($F=6.24$, $P=0.003$). The MCE group outperformed the control group and had the most significant improvement across all outcomes. The SMT group also showed improvements, although the effects were smaller and less consistent than those of MCE.

Conclusions- SMT and MCE improved badminton performance compared with conventional training alone; however, MCE produced the most consistent improvements in smash velocity, accuracy, and dynamic balance.

Introduction

Badminton is among the fastest and most popular racquet sports worldwide, played by both recreational and elite players.[1,2] Better performance requires agility, explosive movement, upper-limb rapid movements, and sensorimotor coordination. In addition, muscle strength, balance, and dynamic postural control are critical for producing powerful, accurate smashes, regaining stability after high-velocity movements, and maintaining stroke precision under fatigue. [3–11]

Impaired postural control may reduce stroke efficiency and movement quality, while better dynamic balance can support more stable smash production and faster repositioning.[12] During a badminton match, smashing performance is crucial for gaining points and is often executed from various postures and locations on the court. The smash stroke is often the move that gives one player an edge over another throughout the game. Its effectiveness is primarily determined by two factors: smashing velocity and accuracy.[13,14]

Conventional badminton training programs focus on strengthening specific muscle groups involved in sport-specific movements to enhance physical fitness and mental well-being.[15] Warm-ups, flexibility drills, endurance training, and badminton-specific exercises are common components of these treatment plans. Thus, a new training protocol, incorporating conventional training, may be needed to achieve greater performance gains by focusing on the underlying physiological components of smash performance.

Exercises that enhance both neuromuscular control and stroke-related performance may be particularly useful for badminton players, since precise execution, postural control, and physical conditioning all interact to determine performance.[1,16]

Motor Control Exercise (MCE), Swiss ball training, Pilates, and Sensorimotor Training (SMT) are common methods for enhancing neuromuscular function and athletic performance. When combined with Pilates and Swiss ball training, MCE focuses on activating deep trunk muscles to support pelvic and spinal stability, as well as trunk control, proprioception, and dynamic stability. These components may be beneficial because they facilitate force transfer, improve movement efficiency, and enhance postural regulation during overhead stroke production.[5,12,16,19] SMT enhances joint stability and neuromuscular control by activating sensorimotor pathways when exercising on unstable surfaces. [21–22]. These training methods have shown positive effects on neuromuscular function, balance, and stability, but their direct impact on badminton-specific outcomes remains to be fully explored.[111,17,19] Sensorimotor training (SMT) and motor control exercise (MCE) as separate exercise regimens have not been studied to date for badminton players; prior research has focused on general core strengthening, Pilates, or mixed balance training. To assess the training's effectiveness and advantages for stroke performance and dynamic balance beyond traditional training alone, a randomized controlled experiment comparing SMT and MCE in badminton players may be necessary.[11,16]

The purpose of this randomized controlled trial is to examine the effectiveness of sensorimotor training (SMT) and motor control exercise (MCE) on smash velocity, smash accuracy, and dynamic balance in badminton players.

Hypothesis

Experimental Hypothesis: -

There may be a significant effect of Sensorimotor training (SMT) and Motor Control Exercise (MCE) on smash velocity, accuracy and balance in badminton players.

Null Hypothesis: -

There may be no significant effect of Sensorimotor training (SMT) and Motor Control Exercise (MCE) on smash velocity, accuracy and balance in badminton players.

Methods

Study Design

A randomized controlled, parallel-group, three-arm study (1:1:1). The Consolidated Standards of Reporting Trials (CONSORT) statement for randomized trials was followed in reporting this study. The prospective registration of the trial was submitted to the Clinical Trial Registry of India (CTRI/2021/03/031967).

Participants:

Male and female badminton players aged 17–25 years with at least 1 year of playing experience from academies in Haryana and Punjab were included. Players with shoulder injuries, low back pain, recent fractures, or other conditions likely to interfere with participation in the intervention were excluded. The “Institutional Ethical Committee of the Department of Physiotherapy at Guru Jambheshwar University of Science and Technology in Hisar, Haryana”, India, provided ethical permission by letter number (A. Psy/20/8487), dated December 29, 2020. 72 participants were allocated (24 per group) as per the estimated sample size determination using the G* Power software with an effect size of 0.30, which was obtained from pilot data gathered from 24 participants, an alpha level of 0.05, and a statistical power of 80% with 10% dropout rate. To randomly divide the participants into three groups, a computer-generated sequence of

numbers in Microsoft Excel was employed. The random sequences for the groups were generated by an unrelated physiotherapist. Before randomization, a sequentially numbered envelope, which was sealed and opaque, was used to conceal the random allocation. Before the intervention started, the therapist had access to this sealed envelope. Players weren't informed of the allocation concealment strategies or the randomization process.

Procedure:

Initially, 93 eligible badminton players were screened, and 84 enrolled according to the predefined selection criteria. After enrolment, baseline demographic details, badminton training history, and sports-specific details were recorded. Before participating, all players were given verbal and written information about the trial in their native language, and they signed an informed consent form. Players were randomly allocated using a computer-generated randomization sequence into three groups: sensorimotor training (SMT), motor control exercise (MCE), and control, with 28 participants in each group. All interventions were delivered by a trained physiotherapist. The intervention period lasted 6 weeks, with 5 sessions per week (30 sessions total), and each session lasted approximately 55 minutes. An active warm-up will be performed by the participants for 10–15 minutes, including jogging, walking, stretching & jumping. Proper stretching of upper and lower limb muscles will be done.

The SMT group received sensorimotor training in three phases—static, dynamic, and functional—together with conventional badminton training, 5 times per week for 6 weeks.[23] The MCE group received motor control exercises in addition to conventional training; the program included Pilates and Swiss ball-based exercises 5 times per week for 6 weeks.[17,19,24] The control group received conventional badminton-specific training.[25] Details of the progression are presented in Tables 1and 2.

Badminton-Specific Training Program:

Light movements, such as jogging, walking, running, and stretching, were included in the warm-up.

1. The training schedule consists of three sets of footwork, shadow stepping a full field corner for 35 seconds in 8*8, and one-minute rest intervals.
2. Training regimen: Each station had a 60% load, five sets of 20 seconds each, rope skipping, leaping work, multi-shuttle, forward and backward court stepping training, and a one-minute rest interval in between.
3. Training Session: Clear, drop, high smash, 20-ball feeding instruction, and continuous backcourt spikes were among the strike drills. Each session consists of twenty distinct shot kinds interspersed with two-minute rest intervals.
4. Training Session: Drill exercises, three sets of 30-second loading, a 10-second rest in between each set, and a stroke session combining front, middle, and backstrokes performed on the court.

Cooldown- Breathing and stretching exercises should be given to prevent injury and soreness, and enhance the recovery of the players.

Outcome measures such as smash velocity, accuracy using a forehand smash stroke performance test, and dynamic balance using the Y balance test were assessed at baseline (0 weeks), post-intervention (6 weeks), and follow-up (10 weeks).

Smash velocity was measured using a radar gun. The participants were positioned two meters behind the radar gun. The radar gun was placed beyond the badminton court's strike area and back line, lined up with the shuttlecock's estimated height, and pointed straight ahead to the colored square mark in the upper right corner of the opposing court where the shuttlecock landed. The participants were asked to perform three strokes, pausing every five to ten seconds, following a ten to fifteen-minute warm-up. We look for colored targets

directly in the right service court (on the black point) and behind the left service court. Participants must complete several rehearsals or practices before the test.[12]

The Forehand Smash Stroke Performance Test was used to determine smash accuracy. Following a standardized warm-up, players executed ten maximal forehand smash strokes, resting between attempts for five to ten seconds. In the upper right corner of the singles court, a 60 x 60 cm target was divided into three equal-sized colored zones: red = 3 = 3 points, blue = 2 points, and yellow = 1 point. Accuracy was determined as (total score ÷ 30) × 100, with a maximum score of 30 points.[12,6]

Badminton players' dynamic balance will be evaluated using the Y-balance test. The test will be completed by the subject standing in the position indicated by the test kit with the test leg. Training schedule: Footwork, Shadow stepping, a full-field corner for 35 seconds in 8×8 again, a total of 3 sets, sets of 1-minute rest breaks. Trying to maintain his balance while achieving the maximum mobility with the other leg in anterior, posteromedial, and posterolateral directions. The angle between the posteromedial, posterolateral, and anterior directions should be 135 degrees. The individual must return to the initial condition of the test and contact the kit with the test leg very slowly once they have reached the maximum trapping rate. After dividing the total distance between the anterior, posteromedial, and posterolateral directions by three times the subject's foot length, the result is normalized by multiplying it by 100. This result will be taken as the subject's score. A standard measuring tape will be used to measure the length of the test leg, which is the distance between the medial malleolus and the anterior superior iliac spine (ASIS), while the subject stands with their weight evenly divided between both legs. The subject's record in each of the three directions will consist of no more than three trials. Before the test, each participant will also work out four to six times in each direction independently.[26] According to Plisky PJ et al. (2009), the Y-balance test has strong intra- and inter-tester reliability (ICCs equal 0.48 and 0.78).[27]

Statistical Analysis

IBM-SPSS version 21 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. An analysis of “intention-to-treat” was conducted. The most recent observations were carried forward to impute missing data. The “baseline data were presented as the mean, standard deviation (SD), and p-values for group differences using analysis of variance (ANOVA)”. The data distribution was measured using the “Shapiro-Wilk normality”. A two-factor mixed-design ANOVA: 1) Time, comparing baseline, post-intervention, and follow-up data analysis; 2) Groups, including sensorimotor training, motor control exercise, and control. The impact of interventions was compared using repeated measurements on the first factor (within-group) and ANOVA for multiple comparisons across groups. For both the repeated-measures ANOVA and ANOVA test, the statistically significant value was $p < .05$. “Bonferroni correction was used in post hoc analysis for multiple comparisons”. “Cohen's d coefficient” was used to determine the effect size (ES) between groups. An ES of 0.8 was considered large, 0.5 was considered moderate, and 0.2 was considered modest, according to Cohen (1977).

Result

The trial had 84 participants with a 10% dropout rate, all of whom received treatment, according to the sample size estimate. Due to timing barriers, six of the 84 individuals missed two treatment sessions each. Eighty-eight per cent of participants finished all thirty sessions. Data was collected and examined from each participant. Two participants—one from the MCE group (for an undisclosed reason) and one from the control group (because of a job)—did not provide information about the follow-up period. For intent-to-treat analysis, these missing data were imputed (Fig. 1). Beginning on March 25, 2024, the initial recruitment process was finished on November 28, 2025. The study included 84 people in total, with 55.95% (n = 47) males and 44.04% (n = 37) females. 20.22 ± 2.83 years was the average age of the participants.

Baseline

The baseline comparison of the three groups—Control, Motor Control Exercise, and Sensorimotor Training—revealed that the cohorts were broadly similar in their socio-demographic and pre-intervention performance profiles. Anthropometric attributes (height, weight, and body mass index), age, playing experience, and gender distribution did not differ statistically significantly, indicating that randomization was effective and that there was no systematic allocation bias. Besides that, the pre-intervention values for all sport-specific performance measures, such as average smash velocity, accuracy, and balance-related composite scores, were not significantly different among the groups, which is also confirmed by non-significant ANOVA results for these variables. The mean pre-intervention score for each variable, F2, and p-value2 are displayed in Table 3

Table 1
Sensorimotor training (SMT), along with conventional badminton training

Phase	Duration	Exercise	Progressed By	Frequency
Static	**Week 1,2**	**Upper Limb: -** • Wall push Exercise • Isometric Hold • Static Arm Hold • Plank **Lower limb: -** • Standing upright position for both limb. • Single leg stance for both lower limbs.	Firm surface then soft surface. Open your eyes then close them. Rocker or wobble board or Minitrampoline	15 sec. 3 repetitions.
Dynamic	**Week 3, 4**	**Upper limb**: • Medicine Ball against the wall. • Wall dribbling. • Tossing a soft weight	Open eyes then closed	3 sets of 7 repetitions.
		Lower Limb: - • A**gility Ladder drills: -** Laterally shuffle hop, skip, through the leader. • **Hurdle mobility: -** Walk over a low hurdle lifting knee high. • Forward stepping lunge exercise for both lower limbs. • T-band kicks exercise (weight bearing for both lower limbs).		
Functional	**Week 4, 6**	**Upper limb: -** • Wall Slide with ball • Wrist Extension with weight • Push • Pull • Press-up	Open eyes then closed Both against and away from a wall	20 meters
		Lower limb: - • **Walking Exercise: -** Both toe and heel skipping are performed with the toes pointed straight forward, then outward and inward. • **Squatting Exercises: -** For both lower extremities • **Step**	Sitting position then from standing position on both legs between parallel bars while keeping eyes open followed by eye closure.	3 sets of 7 repetition

Phase	Duration	Exercise	Progressed By	Frequency
		• Lunge with TheraBand • Exercises for balance on a rocker and wobble board: - 1. Anteroposterior rocking movement on the rocker board. 2. Mediolateral rocking movement on the rocker board.		

Table 2
Motor Control Exercise (MCE)+ conventional badminton training.

Sr. No.	Exercise	1–3 Week	4–6 Week
1	Reverse Bridge	2 Set * 8 times	2set * 10times
2	Side curl	8sets *8 repetition	2sets * 10 repetitions
3	Hamstring curl	8 set * 8 repetitions	2 set * 10 repetitions
4	Roll away	2 sets * 8 times	2 sets * 10 times
5	Reverse plank	2 sets (pelvic fall)	4 sets (pelvic fall)
6	Hundreds	3 sets * 10 times	3 sets * 12 times
7	Pendulum	2 sets	3 sets
8	Hip circle	3 sets * 10 times	3 sets * 12 times

Table 3
Socio-demographic characteristics and mean pre-intervention score of all variables, as well as f and p values of ANOVA (baseline data).

Variables	Control	Motor Control Exercise	Sensorimotor Training	F[2]	p-value[2]
Gender of participant	M = 12.00 (42.86%); F = 16.00 (57.14%)	M = 10.00 (35.71%) M = 18.00 (64.29%)	M = 15.00 (53.57%) F = 13.00 (46.43%)	1.8	0.4
Height in meters	1.68 ± 0.18	1.73 ± 0.17	1.68 ± 0.23	0.5	0.6
Weight in kilograms	65.39 (± 8.53)	65.22 (± 9.95)	66.96 (± 9.40)	0.3	0.7
Body Mass Index (kg/m□)	22.27 (± 3.09)	22.68 (± 3.28)	21.62 (± 3.00)	0.8	0.4
Age in years	19.54 (± 2.76)	20.43 (± 3.14)	20.71 (± 2.55)	1.4	0.2
Experience in years	3.82 (± 1.47)	4.32 (± 2.02)	3.50 (± 2.44)	1	0.4
Average Smash Velocity (Pre-test)	78.29 (± 5.38)	81.43 (± 4.96)	80.19 (± 4.16)	2.6	0.086
Average Accuracy (Pre-test)	19.59 (± 3.48)	18.26 (± 2.52)	18.28 (± 3.50)	1.5	0.2
Balance - Left Composite Score (Pre-test)	77.23 (± 10.04)	77.80 (± 11.15)	78.37 (± 8.47)	0.1	> 0.9
Balance - Right Composite Score (Pre-test)	79.58 (± 9.74)	83.19 (± 11.98)	83.15 (± 10.61)	1.1	0.3
1n (%)					
2. Pearson's chi-squared test; one-way analysis of means (not assuming equal variances)					

Outcomes

Between-group comparison of mean change (post-pre intervention)

The analysis of mean change scores after the intervention period reveals that there were significant differences between groups for all the performance variables that were measured. In the case of Average Smash Velocity (ASV), the Motor Control Program, as well as the Sensorimotor Training groups, had significantly greater mean changes as compared to the control group, the Motor Control Program having the largest mean change. The significant F-statistic ($p < 0.001$) indicates that the differences in training effects leading to the structured intervention protocols are considerable.

Average Accuracy (AAC) showed a similar trend where the motor control exercise was able to achieve the greatest improvement, the sensorimotor training group came second, and the control group made only slight improvements. The ANOVA conducted to compare the accuracy changes between groups was significant ($p = 0.012$),

improve smash performance, accuracy, and postural balance.

Pairwise (post hoc) comparison of mean change (post-pre)

Table 5 indicating the neuromuscular intervention targeted to the problem brought about larger enhancements in accuracy than routine training.

Table 5
Mean change comparison by group (post hoc ANOVA).

Variable	Comparison	MD (p)	95% CI
ASV	Motor Control Exercise-Control	9.71 (< 0.001)	3.99, 15.43
	Sensorimotor Training-Control	4.66 (0.133)	-1.06, 10.39
	Sensorimotor Training: Motor Control Exercise	-5.05 (0.095)	-10.77, 0.68
AAC	Motor Control Exercise—Control	3.09 (0.008)	0.68, 5.51
	Sensorimotor Training-Control	1.37 (0.372)	-1.05, 3.78
	Sensorimotor Training-Motor Control Exercise	-1.73 (0.208)	-4.14, 0.69
BAL-L	Motor Control Exercise-Control	12.06 (0.005)	3.07, 21.04
	Sensorimotor Training-Control	-8.47 (0.069)	-17.45, 0.52
	Sensorimotor Training-Motor Control Exercise	-20.52 (< 0.001)	-29.51, -11.54
BAL-R	Motor Control Exercise-Control	12.95 (0.002)	4.06, 21.83
	Sensorimotor Training-Control	4.46 (0.458)	-4.43, 13.34
	Sensorimotor Training-Motor Control Exercise	-8.49 (0.064)	-17.38, 0.40

The motor control exercise has also led to the greatest improvement in the Balance-Left Composite Score (BAL-L), exceeding the control and sensorimotor training groups. The sensorimotor training group demonstrated only slight changes, while the control group showed moderate gains. The significant group effect ($p < 0.001$) indicates that the most substantial increase in the stability of the left side of the body resulted from the motor-control-based regimen.

All groups showed improvement after the intervention in the Balance-Right Composite Score (BAL-R); however, the Motor Control Program was able to produce substantially larger gains than both the Control and Sensorimotor Training groups. The ANOVA result ($p = 0.003$) indicates that the difference between groups is significant and is in line with the greatest effectiveness of the targeted training approach in enhancing right-side balance performance.

Overall, Table 4 reveals that two experimental intervention strategies yielded greater performance improvements than the control condition, with the motor control exercise showing the most consistent and substantial improvements across all measured outcomes. These findings contribute to understanding how efficiently structured motor-control-oriented training can shows the post hoc comparisons provide additional details about the specific group differences that contributed to the significant omnibus ANOVA results. In the case of average smash velocity (ASV), the motor control exercise was able to increase the performance level significantly more than the control group, with a mean difference of 9.71 units ($p < 0.001$). The sensorimotor training group, however, did not significantly outperform the control group. The comparison between the two intervention groups revealed a favourable trend towards the Motor Control Exercise, for which the difference was very close to statistical significance.

Table 4
Comparison of mean change (post-intervention-preintervention) among groups (ANOVA)

	Mean ± SD	95% CI	F value	p-value
ASV				
Control	5.66 ± 6.78	3.03, 8.29	8.21	**< 0.001**
Motor Control Exercise	15.37 ± 9.42	11.71, 19.02		
Sensorimotor Training	10.32 ± 10.33	6.32, 14.32		
AAC				
Control	1.70 ± 4.00	0.15, 3.25	4.7	**0.012**
Motor Control Exercise	4.79 ± 3.24	3.54, 6.05		
Sensorimotor Training	3.07 ± 4.06	1.49, 4.64		
BAL-L				
Control	11.06 ± 16.99	4.47, 17.65	15.02	**< 0.001**
Motor Control Exercise	23.11 ± 14.10	17.65, 28.58		
Sensorimotor Training	2.59 ± 10.38	-1.43, 6.61		
BAL-R				
Control	3.63 ± 12.71	-1.29, 8.56	6.24	**0.003**
Motor Control Exercise	16.58 ± 12.71	11.65, 21.51		
Sensorimotor Training	8.09 ± 16.09	1.85, 14.33		

For the Average Accuracy (AAC) condition, the motor control exercise was again the one that indicated a significantly greater extent of improvement in comparison with the control group ($p = 0.008$). Both sensorimotor training-control and sensorimotor training-motor control program comparisons were not significant. This provides a rationale that accuracy improvements corresponding to sensorimotor training were less substantial and thereby not different from either of the comparator groups.

The changes in Balance – Left Composite Score (BAL-L) were even more evident. The motor control exercise was able to make a significant breakthrough in the performance of the left-sided postural stability of the participants as compared to the control group ($p = 0.005$). Although the sensorimotor training group showed a tendency to have lower improvements compared to the control group, this difference was very close to significance. The significant disadvantage of the Sensorimotor Training group relative to the Motor Control Exercise ($p < 0.001$) further indicates the superior effectiveness of motor-control-oriented training for left-sided balance.

Balance – Right Composite Score (BAL-R) also demonstrated similar trends. The motor control exercise resulted in considerably larger improvement than the control group ($p = 0.002$), however the sensorimotor training group showed no significant difference from the control group. The contrast between the two intervention groups suggested a meaningful, though not statistically significant, advantage for the Motor Control Exercise

Within-group change across Pre, Post, and Follow-up (repeated measures ANOVA)

In Table 6, the repeated-measures analysis demonstrated that the groups differed in their temporal change patterns, with the motor control exercise showing the most pronounced and consistent positive changes over time.

Table 6
Comparison of the three groups' means at pre-intervention, post-intervention, and follow-up (repeated ANOVA).

Variable	Group	Pre	Post	Follow	F	p	ES
AAC	Control	19.59 ± 3.48	21.29 ± 1.38	21.07 ± 3.93	2.511	0.091	0.057
	Motor Control Exercise	18.26 ± 2.52	23.06 ± 2.67	23.76 ± 2.43	42.932	< .001	0.490
	Sensorimotor Training	18.28 ± 3.50	21.35 ± 1.74	20.62 ± 2.36	11.034	< .001	0.203
BAL-L	Control	77.23 ± 10.04	88.28 ± 11.80	79.15 ± 11.25	7.289	0.002	0.165
	Motor Control Exercise	77.80 ± 11.15	100.92 ± 7.68	86.91 ± 7.32	43.469	< .001	0.543
	Sensorimotor Training	78.37 ± 8.47	80.96 ± 8.34	79.58 ± 9.60	0.673	0.514	0.015
BAL-R	Control	79.58 ± 9.74	83.21 ± 9.62	79.88 ± 13.02	1.302	0.28	0.023
	Motor Control Exercise	83.19 ± 11.98	99.77 ± 5.59	102.82 ± 11.10	35.683	< .001	0.437
	Sensorimotor Training	83.15 ± 10.61	91.24 ± 10.48	85.44 ± 6.96	5.290	0.008	0.118
ASV	Control	78.29 ± 5.38	83.94 ± 5.11	81.53 ± 3.46	10.514	< .001	0.200
	Motor Control Exercise	81.43 ± 4.96	96.79 ± 8.19	91.24 ± 5.37	40.725	< .001	0.510
	Sensorimotor Training	80.19 ± 4.16	90.51 ± 9.01	90.41 ± 2.72	27.940	< .001	0.408

Regarding Average Accuracy (AAC), a very pronounced and statistically significant effect was observed in the Motor Control Program, with the increase from pre- to post-intervention largely maintained at follow-up, as shown by a large effect size (ES = 0.490). The Sensorimotor Training group also exhibited significant improvement, but to a smaller degree (ES = 0.203), while the control group's changes were not statistically significant.

Balance – Left Composite Score (BAL-L): Both the Control and Motor Control Exercise groups displayed significant time effects; however, the extent of the improvement was substantially greater in the Motor Control Program (ES = 0.543). In fact, the Sensorimotor Training group did not show any significant changes over the three time points, thus suggesting that this intervention had little effect on left-side balance enhancement.

The same pattern was observed in Balance – Right Composite Score (BAL-R), where the Motor Control Programme had a very notable improvement from baseline to post-intervention, and the gains were maintained at follow-up (ES = 0.437). The sensorimotor training group had smaller but statistically significant changes (ES = 0.118), while the control group showed no meaningful progression over time.

For Average Smash Velocity (ASV), all groups were able to show statistically significant improvement, but again, the extent of the changes differed greatly between the interventions. The motor control exercise made the largest improvements (ES = 0.510), followed by the sensorimotor training group (ES = 0.408) and then the

control group (ES = 0.200). The results suggest the presence of a dose–response relationship, with the most significant improvements in striking velocity arising from the carefully planned motor-control–oriented training.

Multiple comparisons within each group (post hoc of repeated measures)

Post hoc comparisons using repeated measures ANOVA revealed differential effects of the interventions across variables and time points. Concerning AAC, the Motor Control Exercise significantly raised the scores from pre- to post-intervention (MD = 4.79, p < .001, 95% CI [-6.048, -3.538]) as well as from pre- to follow-up (MD = 5.50, p < .001, 95% CI [-6.789, -4.214]). Similarly, the sensorimotor training group also showed significant improvements at both time points (pre/post: MD = 3.07, p < .001, 95% CI [-4.641, -1.489]; pre/follow: MD = 2.33, p = .004, 95% CI [-3.841, -0.827]). The control group showed a small but significant improvement only from pre- to post-intervention (MD = 1.70, p = .033, 95% CI [-3.25, -0.149]). There were no significant differences between post-intervention and follow-up in any group, indicating that the immediate gains were retained.

Significant changes from pre- to post-intervention were detected in BAL-L for both the control (MD = 11.06, p = .002, 95% CI [-17.645, -4.469]) and motor control exercise groups (MD = 23.11, p < .001, 95% CI [-28.579, -17.647]). Moreover, the Motor Control Exercise group exhibited a follow-up sustained improvement (pre/follow: MD = 9.10, p = .003, 95% CI [-14.914, -3.292]). However, the Sensorimotor Training group did not manifest any significant changes at the different time points. The comparison between post-intervention and follow-up revealed a significant decrease in the Control (MD = -9.13, p = .009, 95% CI [2.504, 15.756]) and Motor Control Exercise groups (MD = -14.01, p < .001, 95% CI [10.12, 17.9]), indicating that some of the improvements had been lost.

The Motor Control Exercise group showed significant changes from pre- to post-intervention (MD = 16.58, p < .001, 95% CI [-21.51, -11.652]) and pre- to follow-up (MD = 19.64, p < .001, 95% CI [-25.627, -13.648]) for BAL-R, whereas the Sensorimotor Training group's changes from pre- to post-intervention were moderate (MD = 8.09, p = .013, 95% CI [-14.329, -1.851]), and post- to follow-up decline was also moderate (MD = -5.80, p = .025, 95% CI [0.786, 10.817]). The control group could not demonstrate statistically significant changes across time points.

All intervention groups had significant improvements from pre- to post-intervention as well as from pre- to follow-up (Control: MD = 5.66, p < .001, 95% CI [-8.285, -3.025]; Motor Control Exercise: MD = 15.37, p < .001, 95% CI [-19.019, -11.714]; Sensorimotor Training: MD = 10.32, p < .001, 95% CI [-14.324, -6.316]; Control: MD = 3.24, p = .012, 95% CI [-5.708, -0.779]; Motor Control Exercise: MD = 9.81, p < .001, 95% CI [-12.801, -6.818]; Sensorimotor Training: MD = 10.22, p < .001, 95% CI [-12.07, -8.375]). The comparison between post-intervention and follow-up showed a small yet significant loss in the motor control program group (MD = -5.56, p = .007, 95% CI [1.651, 9.463]), while in other groups the changes were not significant; thus, improvements in ASV performance can be deemed as sustained for the control and sensorimotor training groups in Table 7.

Table 7
Multiple comparisons at various levels of intervention (post-hoc analysis of repeated-measure ANOVA)

Variable		Control			Motor Control Exercise			Sensorimotor Training		
	Comparison	MD	p	95% CI	MD	p	95% CI	MD	p	95% CI
AAC	Pre / Post	1.70	0.033	-3.25 to -0.149	4.79	< .001	-6.048 to -3.538	3.07	< .001	-4.641 to -1.489
	Pre / Follow	1.48	0.096	-3.236 to 0.282	5.50	< .001	-6.789 to -4.214	2.33	0.004	-3.841 to -0.827
	Post / Follow	-0.22	0.797	-1.534 to 1.979	0.71	0.318	-2.136 to 0.719	-0.73	0.166	-0.324 to 1.787
BAL-L	Pre / Post	11.06	0.002	-17.645 to -4.469	23.11	< .001	-28.579 to -17.647	2.59	0.198	-6.614 to 1.435
	Pre / Follow	1.93	0.501	-7.723 to 3.869	9.10	0.003	-14.914 to -3.292	1.22	0.641	-6.509 to 4.077
	Post / Follow	-9.13	0.009	2.504 to 15.756	-14.01	< .001	10.12 to 17.9	-1.37	0.521	-2.96 to 5.707
BAL-R	Pre / Post	3.63	0.142	-8.563 to 1.293	16.58	< .001	-21.51 to -11.652	8.09	0.013	-14.329 to -1.851
	Pre / Follow	0.31	0.916	-6.178 to 5.567	19.64	< .001	-25.627 to -13.648	2.29	0.29	-6.643 to 2.065
	Post / Follow	-3.33	0.139	-1.156 to 7.814	3.06	0.16	-7.4 to 1.287	-5.80	0.025	0.786 to 10.817
ASV	Pre / Post	5.66	< .001	-8.285 to -3.025	15.37	< .001	-19.019 to -11.714	10.32	< .001	-14.324 to -6.316
	Pre / Follow	3.24	0.012	-5.708 to -0.779	9.81	< .001	-12.801 to -6.818	10.22	< .001	-12.07 to -8.375
	Post / Follow	-2.41	0.06	-0.11 to 4.933	-5.56	0.007	1.651 to 9.463	-0.10	0.955	-3.416 to 3.611

Discussion

The current study was done to determine the effectiveness of sensorimotor training (SMT) and motor control training (MCT) on smash velocity, smash accuracy, and balance of badminton players. These results suggest that 30 sessions of SMT and MCE over 6 weeks improved badminton performance compared with conventional training. However, MCE produced considerable improvement across average smash velocity, average accuracy, and balance. These findings are supported by statistically significant between-group differences and favorable within-group changes.

Baseline characteristics of the 3 groups were homogenous, with no statistically meaningful difference between groups in demographic variables, anthropometric characteristics, experience, smash velocity, smash accuracy, and balance composite scores before treatment. Participant adherence was acceptable, with 88% of

participants completing all 30 sessions. All randomized participants were included in the intention-to-treat analysis. These methodological features strengthen the internal validity of the trial.

The results of this study suggested that MCE is more effective than conventional badminton training for improving smash velocity, smash accuracy, and dynamic balance, and it was superior to SMT across the selected outcome measures. The greatest mean improvements were observed in the MCE group for average smash velocity, average accuracy, left balance composite score, and right balance composite score. Repeated measures analysis also showed that MCE produced the largest effect sizes across outcomes, supporting a stronger and more sustained training effect.

A possible explanation for the superior effect of MCE is that the badminton smash performance depends on efficient production and transmission of force via the kinetic chain. A powerful smash requires coordinated sequencing from the trunk and lower limbs to the racquet and upper limbs.[28,29] Existing literature also highlighted the importance of trunk control, proximal stability, and intersegmental coordination for efficient movement quality and force transfer.[30,31] In badminton, upper limb explosive power and coordination and kinetic chain movement are also important contributors to smash performance.[6] Thus, motor control exercise may enhance force transmission, postural alignment, and body control during overhead stroke production, which explains why the MCE group showed improvement in velocity, accuracy, and balance.[32,33]

The current study also suggests that SMT is effective to some extent in badminton players, although its effects were smaller than those of MCE. SMT has not shown a significant retained effect at follow-up assessment. Sensorimotor training is intended to improve sensory-motor integration, proprioception, postural adjustments, and neuromuscular coordination through progressively challenging tasks. Romero-Franco (2012) reported that sensorimotor training can improve postural balance through more efficient integration and control of internal and external forces.[34] Ahmad et al. (2019) also stated that the main purpose of sensorimotor training is to improve somatosensory integration and proprioception, correct muscular imbalances, and develop fine motor patterns. These mechanisms may help to explain the observed improvements in the SMT group.[35]

The superiority of MCE is observed in the present study because MCE addresses both stability and controlled movement execution. Badminton performance does not depend only on balance but also on trunk stability, segmental control, and postural alignment. Swiss ball and Pilates-based motor control exercises provide an effective stimulus for improving deep trunk activation and postural recruitment.[36] Existing literature has suggested that exercises performed on unstable surfaces increase activation of trunk musculature and demand better control of the center of gravity, thereby enhancing postural stability and neuromuscular control, which supported our findings.[30,37,38]

There are some significant benefits to the study. It is a randomized controlled trial with 3 parallel groups, includes a control group, uses baseline comparability, and applies an intention-to-treat analysis. Outcomes were assessed at three different intervals: baseline (0 day), post-intervention (3rd week), and follow-up (10th week), to find the retention of training effects. In addition, the study evaluated badminton-specific outcomes such as smash velocity, smash accuracy, and dynamic balance, thereby providing a broader understanding of badminton-specific performance adaptation.

The limitation of the current study is that the “follow-up” period was of limited duration; thus, the long-term sustainability of observed effects remains uncertain. The study was not conducted in a controlled environment and was conducted in selected badminton academies in Haryana and Punjab; this would restrict the findings' application to athletes from different training settings.

Future studies should be conducted to evaluate the combined SMT and MCE protocol and the longitudinal effect. A standardized and effective training dosage should be designed. Further trials may also investigate whether these interventions produce similar benefits in elite players, players returning to sport, or athletes

from other overhead racket sports. In addition, biomechanical variables such as trunk kinematics, landing control, and stroke sequencing should be studied to explain the underlying mechanisms of performance improvements.

Conclusion

The conclusion of this study suggested that sensorimotor training (SMT) and motor control exercise (MCE) are effective in smash velocity, smash accuracy, and balance as compared to the control group of badminton players. However, MCE produced the most consistent improvements in smash velocity, accuracy, and dynamic balance compared to the SMT and Control groups. To improve their performance, badminton players use MCE into their regular training regimen in addition to traditional training.

Declarations

Conflict of interest declaration

NA

Ethical approval:

The study was conducted and approved by the Institutional Ethical Committee of Guru Jambeshwar University (on dated 29/12/2020 with letter no. Ref: A. Psy/20/8487) and registered with CTRI (CTRI/2021/03/031967).

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Author Contribution

Authors’ contributions: Nitin Kumar Indora contributed to the conception and design of the study, collected the data, performed the data analysis and interpretation, drafted and critically revised the manuscript, and approved the final version for publication. Manoj Malik contributed to the conception and design of the study, participated in data analysis and interpretation, critically revised the manuscript, and approved the final version for publication. Jaspreet Kaur contributed to the conception and design of the study, participated in data analysis and interpretation, critically revised the manuscript, and approved the final version for publication.

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Figures

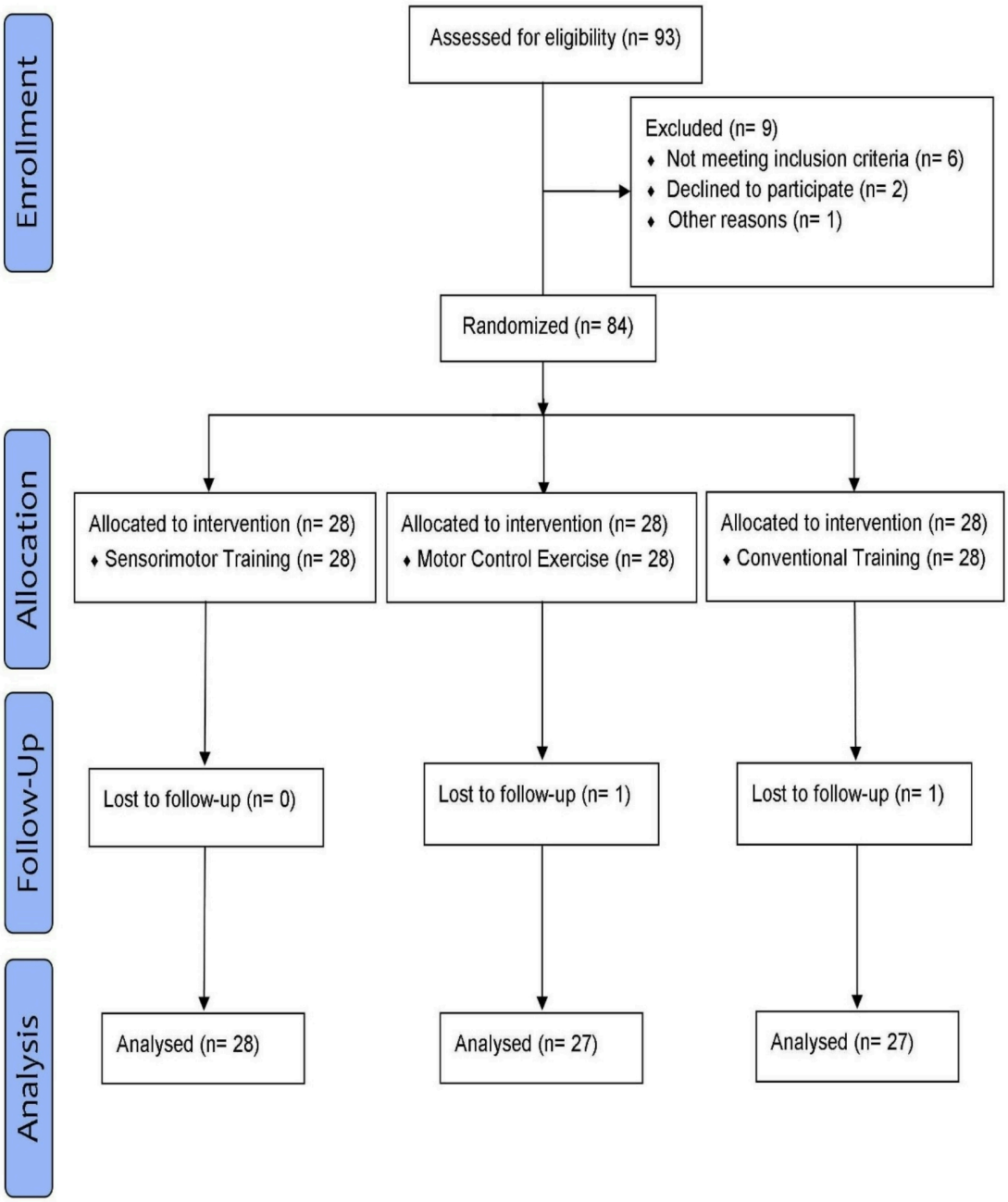


Figure 1

Consort Flow Diagram of study

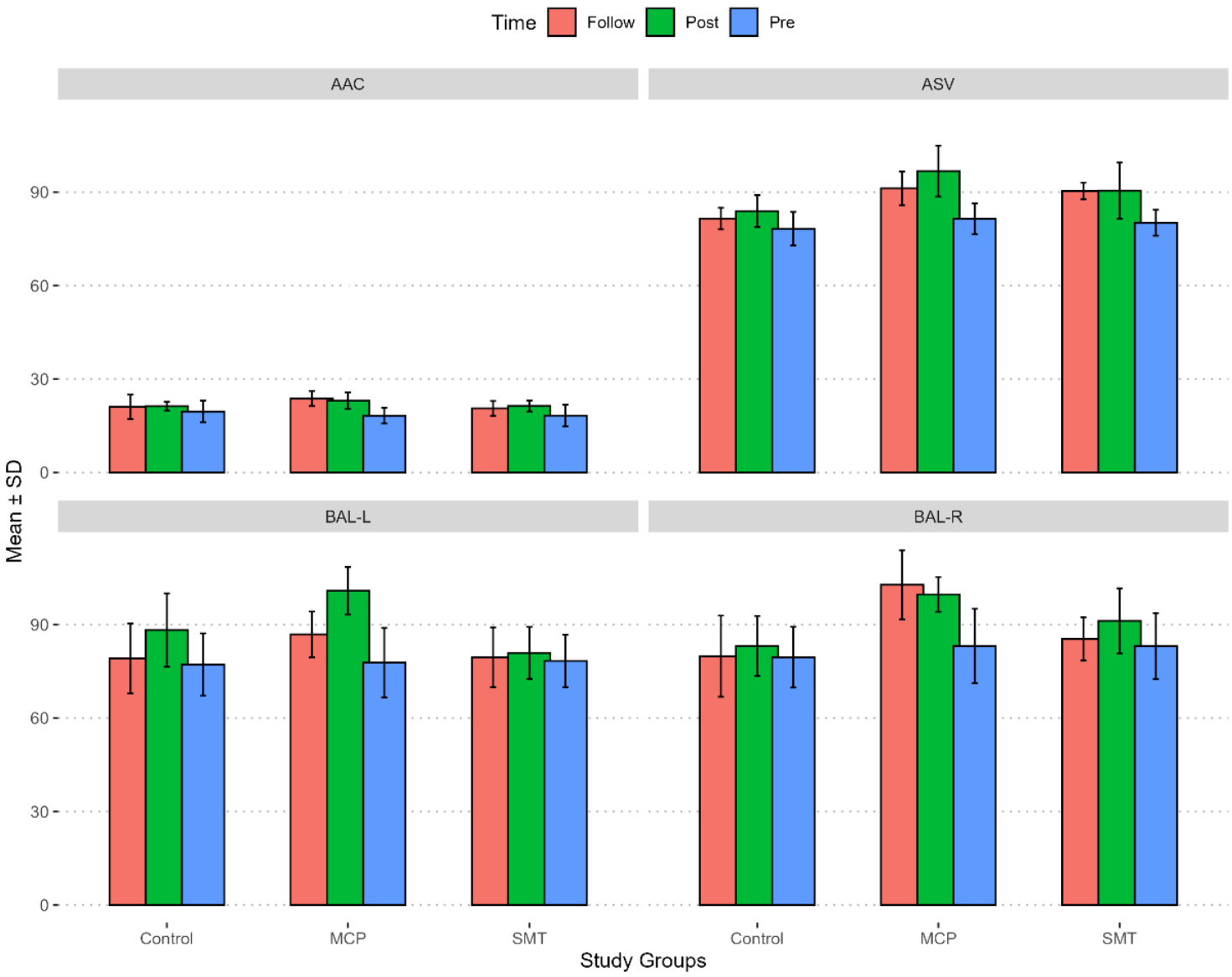


Figure 2

Mean Mean± SD of the four outcome measures for the three study groups.