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Pre-to-Post Changes in Planned Change-of-Direction and Sprint Performance Following Eight Weeks of Adaptive Footwork Training in SL3 and SL4 Para-Badminton Athletes: A Preliminary Single-Group Study



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ABSTRACT

Objective: Evidence on structured footwork training in standing lower-limb para-badminton athletes remains limited, particularly across SL3 and SL4 classifications. This preliminary exploratory study examined pre-to-post changes in planned change-of-direction and sprint performance following an eight-week adaptive footwork training programme and explored whether response patterns differed between SL3 and SL4 athletes.

Methods and Materials: Sixteen provincial-level para-badminton athletes (SL3, n = 8; SL4, n = 8) completed a single-group pretest–posttest intervention consisting of 24 sessions over eight weeks (three sessions/week). Planned change-of-direction performance was assessed using the T-test and linear sprint performance using the 20-m sprint test. Paired-samples t-tests, Cohen's dz, percentage change, and 2 × 2 mixed-design ANOVA (Time × Sport Classification) were used.

Findings: T-test completion time decreased from 16.06 ± 0.52 to 15.50 ± 0.50 s (3.53%; p < 0.001; dz = 3.63), while 20-m sprint time decreased from 6.07 ± 0.70 to 5.54 ± 0.51 s (8.69%; p < 0.001; dz = 1.76). The Time × Classification interaction was not significant for T-test performance (p = 0.292) but was significant for sprint performance (p = 0.004), with a larger reduction in SL3 than SL4 athletes. Training adherence was high (95.50 ± 3.54%).

Conclusion: Lower post-intervention T-test and sprint times were observed following the programme, with a preliminary classification-related sprint pattern. Because of the single-group design, small sample, and exploratory subgroup analyses, these findings should not be interpreted as definitive evidence of causal intervention efficacy.

Keywords: Para-Badminton; Footwork Training; Agility; Sprint Speed; SL3; SL4; Disability Sport

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1. Introduction

Badminton is characterized by repeated short-duration, high-intensity efforts interspersed with brief recovery periods, requiring players to accelerate, decelerate, lunge, and change direction repeatedly while maintaining postural control. International match analyses indicate that the temporal and movement demands of badminton vary according to playing category and competitive context, emphasizing the importance of sport-specific physical preparation (1-3). In addition to rapid locomotor actions, successful court coverage frequently requires athletes to perceive the movement of the shuttle and opponent and subsequently select an appropriate movement response. Accordingly, agility is commonly defined as a rapid whole-body movement involving a change in velocity or direction in response to an external stimulus (4). This perceptual and decision-making component distinguishes reactive agility from pre-planned change-of-direction performance.

Evidence from able-bodied badminton players suggests that structured physical and footwork-oriented training can be associated with improvements in several components relevant to court movement (5). Footwork-specific training has been reported to enhance movement performance, while balance, plyometric, ladder-drill, hurdle-drill, shadow, and speed-agility-quickness interventions have produced improvements in sprinting, multidirectional movement, reaction time, lower-limb power, balance, and related performance outcomes (6-9). However, the terminology used to describe these outcomes requires careful distinction. Although the T-test has frequently been used in the literature as an “agility” assessment and has demonstrated good reliability for multidirectional movement performance (10), its movement sequence is predetermined and does not include an externally generated stimulus or an in-test decision-making requirement. Therefore, within the framework proposed by Sheppard and Young (2006), the T-test is more appropriately interpreted as an assessment of planned change-of-direction performance rather than reactive agility (4).

These considerations may be particularly relevant in para-badminton, where impairment-related constraints can influence movement strategies and physical performance. Para-badminton includes wheelchair and standing sport classes, with SL3 and SL4 representing standing lower-limb classifications that differ in the functional impact of impairment (11, 12). Previous studies have shown that physical and technical characteristics differ across para-

badminton classifications and that impairment type, body composition, practice experience, and functional characteristics may be associated with performance outcomes (13-16). Sprinting capacity is also relevant for athletes with lower-limb impairments because reduced force-generating capacity and balance limitations may affect acceleration and court coverage (17-19). Consequently, training programs for standing para-badminton athletes may need to accommodate impairment-related movement constraints while preserving the speed and multidirectional demands of the sport (20).

Despite the continued development of para-badminton, intervention research examining structured court-based training in standing lower-limb athletes remains limited. Existing studies have predominantly focused on athlete profiling, classification, match characteristics, acute physiological responses, and the development of adapted testing or training approaches (21, 22). Although adapted physical activity and structured training have demonstrated potential benefits in populations with lower-limb impairments (23, 24), limited evidence is available regarding longitudinal, badminton-specific footwork interventions in SL3 and SL4 athletes. Furthermore, it remains unclear whether pre-to-post changes in planned change-of-direction and sprint performance show similar patterns across these two classifications. Because factors such as baseline performance, impairment characteristics, and previous training exposure may differ between classifications, any class-related differences observed in a small intervention study should initially be regarded as exploratory rather than as evidence of a specific physiological or functional mechanism.

Accordingly, the present study was designed as a preliminary exploratory intervention study to examine pre-to-post changes in planned change-of-direction performance, assessed using the T-test, and 20-m sprint performance following participation in an eight-week adaptive footwork training program among standing lower para-badminton athletes classified as SL3 or SL4. Training adherence was also documented as an indicator of the practical feasibility of implementing the program in this population. A secondary exploratory objective was to determine whether the magnitude of pre-to-post change differed between SL3 and SL4 athletes. Given the single-group pretest-posttest design and the absence of a control condition, the study was intended to characterize performance changes observed after participation in the intervention rather than to establish definitive causal

efficacy. It was hypothesized that lower T-test and 20-m sprint completion times would be observed after the eight-week training period, while classification-related differences were treated as exploratory and hypothesis-generating.

2. Methods and Materials

2.1 Study Design

This study was conducted as a preliminary exploratory intervention study using a single-group pretest-posttest design to characterize changes in planned change-of-direction and sprint performance following participation in an eight-week adaptive footwork training program among standing lower-limb para-badminton athletes. The study comprised baseline assessment, an eight-week intervention period, and post-intervention assessment.

At baseline, participants completed the T-test as an assessment of planned change-of-direction performance and the 20-m sprint test as an assessment of linear sprint performance. Participants subsequently completed the adaptive footwork program three times per week for eight weeks (24 prescribed sessions). The same performance assessments were repeated after the intervention using procedures consistent with those employed at baseline.

Because no non-intervention or active control group was included, the study was intended to provide preliminary information regarding performance changes observed following participation in the intervention and its practical feasibility rather than to establish definitive causal efficacy of the training program.

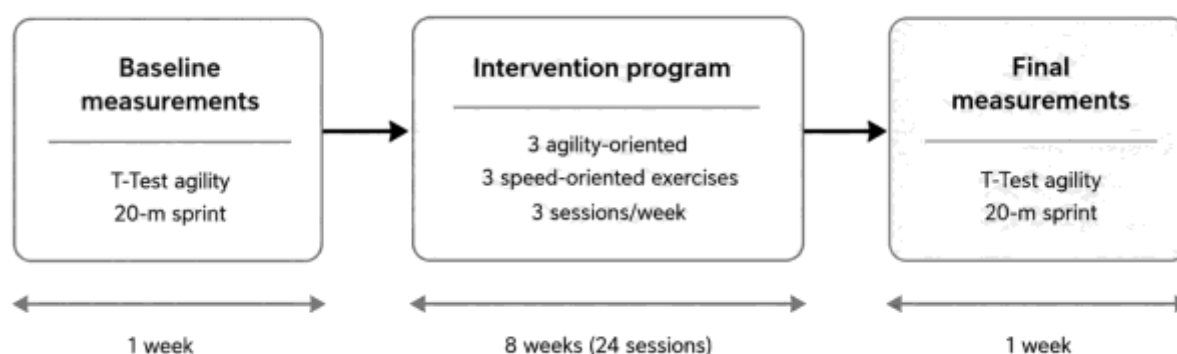


Figure 1. Study design and intervention timeline

2.2 Participants and Sample Size Considerations

Sixteen standing lower-limb para-badminton athletes participated in the study (SL3, $n = 8$; SL4, $n = 8$). All participants were competitive provincial-level para-badminton athletes representing the National Paralympic Committee of Indonesia (NPCI), Special Region of Yogyakarta (DIY), and were actively involved in provincial para-badminton training and competition. Participant characteristics recorded for descriptive purposes included age, sex, training age, dominant hand, sport classification, impairment side, intervention attendance, and number of completed intervention sessions. Training age represented the duration of systematic para-badminton training before study participation.

The eligible athlete population within the SL3 and SL4 classifications was limited. Accordingly, the study was designed as a preliminary exploratory investigation rather

than an adequately powered confirmatory efficacy trial, and no a priori sample-size calculation was used to establish a definitive efficacy sample. The available sample of 16 athletes was used to provide preliminary estimates of pre-to-post performance change, program adherence, and potential classification-related response patterns; SL3-SL4 comparisons were therefore treated as exploratory and hypothesis-generating.

Participants had previous exposure to conventional para-badminton conditioning activities, including resistance-band exercises, technical footwork drills, stroke practice, and other routine badminton exercises. General physical conditioning also included periodic aerobic exercise, such as an approximately 6-km running session conducted monthly. The athletes had not undertaken a separate formalized strength and conditioning program beyond these routine activities. Detailed historical training loads, previous national or international competition participation, and

habitual weekly badminton training duration outside the study intervention were not systematically recorded.

Participants were required to be physically capable of completing the planned change-of-direction assessment, 20-m sprint assessment, and adaptive footwork training procedures and to participate in both baseline and post-intervention assessments. Athletes unable to complete the required testing or intervention procedures because of injury, health-related limitations, or other circumstances preventing completion were to be excluded from the final analysis. All 16 participants completed both assessments and were retained in the final analysis.

2.3 Experimental Procedure

Baseline and post-intervention assessments were conducted under comparable conditions, including the same indoor badminton court environment, testing surface, equipment, test order, instructions, and recovery procedures. Before each assessment, participants completed a standardized 10-15-min warm-up consisting of light jogging, dynamic lower-limb stretching, lateral shuffling, forward and backward movement, and two to three submaximal acceleration trials. Participants then completed the T-test and 20-m sprint assessments, with adequate recovery between trials and tests to minimize acute fatigue.

2.4 Adaptive Footwork Training Intervention

Participants completed an eight-week adaptive footwork training program consisting of three scheduled sessions per week for a total of 24 prescribed sessions. Each scheduled session lasted 180 min (3 h), including exercise execution, prescribed recovery, coaching instruction, waiting periods, and athlete rotation across six exercise models. Approximately 30 min of scheduled station time was allocated to each exercise model. The prescribed scheduled intervention exposure was therefore 540 min (9 h) per week and 72 h across the eight-week period; the 180-min session

duration did not represent 180 min of continuous high-intensity exercise.

The program comprised three predominantly pre-planned multidirectional/change-of-direction exercises (six-point shadow footwork, four-point X-pattern shadow footwork, and three-point explosive net approach) and three exercises incorporating an externally generated coach cue and reactive movement component (reactive three-direction ring sprint, reactive three-direction centre-court sprint, and reactive backward-smash-to-net lob sprint). This distinction was maintained because planned change-of-direction performance and reactive agility are related but conceptually different movement qualities.

2.5 Training Organization and Progression

Training used four badminton courts divided into eight half-court working areas. One athlete occupied each half-court during an exercise bout; with 16 participants, approximately half performed concurrently while the remaining athletes waited for or prepared for their subsequent turn. Exercise initiation and timing were coordinated by coach whistle signals, and athletes rotated through the available working areas so that all participants completed the prescribed exposure. The same general organization was applied across participants to maintain consistency of instruction, spatial arrangement, and coach-directed cueing (25).

The intervention progressed from familiarization and technical execution toward greater exercise volume, reduced recovery, timed execution, variation in movement sequence, and more demanding coach cues. Exercises were generally performed at near-maximal or maximal effort; between-set recovery was approximately 90 s for most exercises and 2-3 min for the technically complex backward-smash-to-net lob exercise. Exercise-specific dosage and progression are summarized in Table 1.

Table 1. Exercise-specific dosage and progression

Component	Exercise / scheduled station	Sets x repetitions	Prescribed volume per session	Recovery and intensity	Progression
Pre-planned COD 1	Six-point shadow footwork 30 min	3-4 sets x 1 six-point circuit	3-4 circuits	30 s between circuits; ~90 s between sets; near-maximal (~RPE 8/10)	Weeks 1-2: 3 relatively self-paced sets; Weeks 3-5: progression to 4 sets and greater coach direction; Weeks 6-8: timed execution
Pre-planned COD 2	Four-point shadow footwork (X-pattern) 30 min	3-4 sets x 8 repetitions	24-32 repetitions	20-30 s between repetitions; ~90 s between sets; near-maximal (~RPE 8/10)	Set volume increased to 4 sets from approximately Week 3; inter-repetition recovery progressively reduced

Pre-planned COD 3	Three-point explosive net approach 30 min	3-4 sets x 3 repetitions	9-12 repetitions	Jog/walk-back between repetitions; ~90 s between sets; maximal effort	Early phase: standardized left-centre- right sequence; later phase: greater variation/randomization of target order
Reactive movement 1	Reactive three- direction ring sprint 30 min	3-4 sets x 6 coach-cued repetitions	18-24 repetitions	Running-in-place between cues; ~90 s between sets; maximal effort	Weeks 1-2: longer cue intervals; Weeks 3-8: progressively shorter cue intervals and stricter movement execution
Reactive movement 2	Reactive three- direction centre- court sprint 30 min	3-4 sets x 6 coach-cued repetitions	18-24 repetitions	Running-in-place between cues; ~90 s between sets; maximal effort	Same cue-based progression as Reactive Movement 1, performed from a centre- court starting position
Reactive movement 3	Reactive backward-smash- to-net lob sprint 30 min	3 sets x 4-6 coach-cued repetitions	12-18 repetitions	Running-in-place between cues; 2-3 min between sets; maximal/near-maximal footwork, controlled lob execution	Weeks 1-2: technique and lob accuracy; Weeks 3-5: increased repetition volume; Weeks 6-8: progressively shortened cue intervals

Note. COD = change of direction; RPE = rating of perceived exertion. The 30-min value represents scheduled station time and includes exercise execution, prescribed recovery, instruction, waiting, and athlete rotation. Exercise-specific volume is reported separately because the operational definition of one repetition differed across exercises.

2.6 Exercise-Specific Movement Descriptions

For the pre-planned exercises, participants moved from a central or designated starting position toward fixed court targets. The six-point shadow-footwork exercise required

movement to six court locations and return to base; the four-point X-pattern exercise required diagonal movement to near-net and rear-court targets; and the explosive net-approach exercise required rapid movement toward one of three fixed net-line targets followed by controlled recovery.

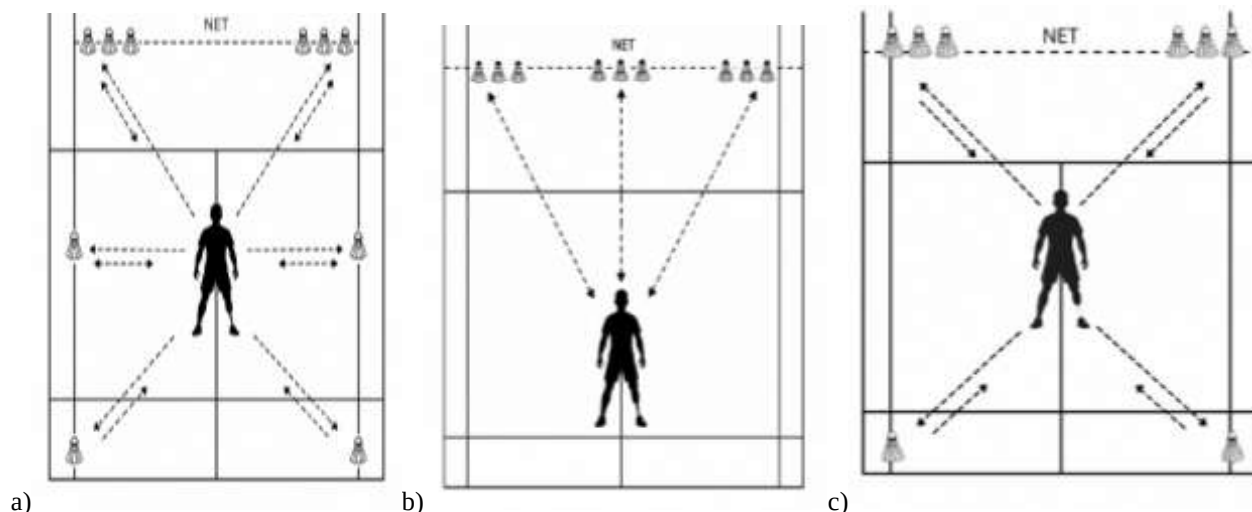


Figure 2. Pre-planned change-of-direction exercises: (a) six-point shadow footwork, (b) four-point shadow footwork (X-pattern), and (c) three-point explosive net approach.

For the coach-cued reactive exercises, participants began in a ready or running-in-place position and responded to an unpredictable directional signal from the coach. The ring sprint and centre-court sprint required rapid movement toward one of three possible targets followed by return to the

starting position. The backward-smash-to-net lob sprint combined an unpredictable left/right cue with diagonal rear-court movement, a shadow overhead smash, rapid forward movement, and a controlled lob before return to the starting position.

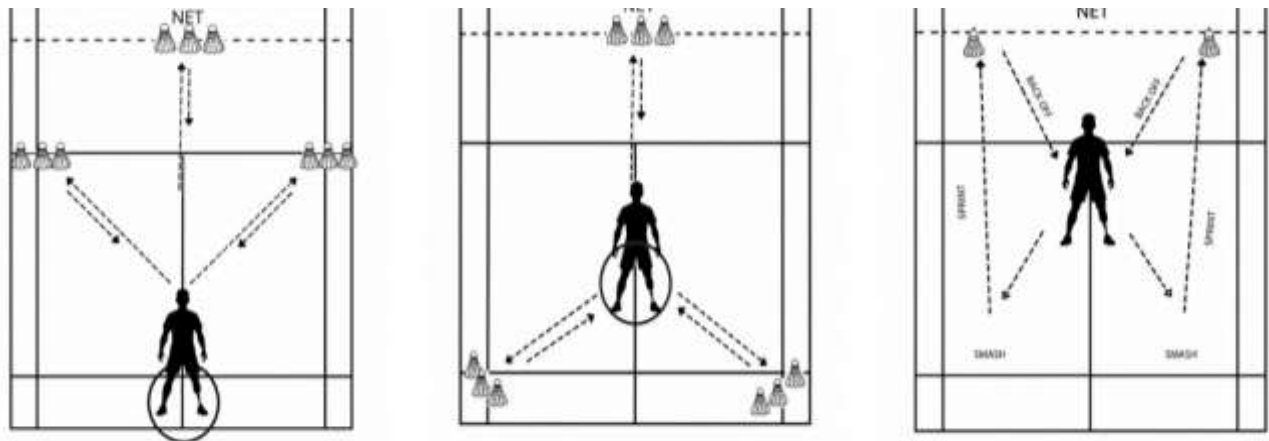


Figure 3. Coach-cued reactive exercises: (a) reactive three-direction ring sprint, (b) reactive three-direction center-court sprint, and (c) reactive backward-smash-to-net lob sprint.

2.7 Concurrent Training and Training Adherence

Athletes continued to train within the same general para-badminton environment at NPCI DIY. Routine activities included resistance-band exercises for the lower and upper limbs, conventional badminton drills, stroke practice, and other sport-specific technical exercises. Resistance-band exercises were delivered using the same general training format across athletes, and periodic general conditioning included an approximately 6-km running session once per month. Individual external training load outside the prescribed intervention was not objectively quantified using session RPE, heart rate, or other formal monitoring systems; therefore, equivalence of individual external training exposure cannot be confirmed.

Attendance was recorded throughout the eight-week intervention. For each participant, completed sessions were documented relative to the 24 prescribed sessions, and training attendance was calculated as: attendance (%) = (sessions completed / 24) × 100. All participants completed the baseline and post-intervention assessments. Reasons for missed intervention sessions were documented and included family-related commitments, bereavement following the death of a relative, and preparation for external competition such as the Kapolri Cup. Attendance was treated as an indicator of intervention feasibility rather than as a primary performance outcome.

2.8 Outcome Measures

The primary outcomes were planned change-of-direction performance and linear sprint performance, assessed using

the T-test and 20-m sprint test, respectively. Both outcomes were recorded as completion time in seconds, with lower values representing better performance. The T-test was explicitly operationalized as a measure of planned change-of-direction performance rather than reactive agility because its movement sequence was predetermined and did not require perception of an unpredictable external stimulus or an in-test decision-making response.

2.8.1 T-Test Change-of-Direction Assessment

Participants began behind cone A. Following the start signal, they sprinted 9.14 m forward to cone B, shuffled 4.57 m laterally to cone C, changed direction and shuffled across to cone D, returned laterally to cone B, and then moved backward to the starting position at cone A. Completion time was recorded using a digital stopwatch. Each participant completed two trials separated by 3 min of recovery, and the faster trial was retained for analysis. The same test configuration, surface, equipment, instructions, timing procedures, and scoring criteria were maintained at baseline and post-intervention.

2.8.2 20-m Sprint Assessment

Participants completed a 20-m sprint from a standardized standing position behind the starting line on an indoor badminton court and were instructed to cover the distance as rapidly as possible. Sprint completion time was recorded using a digital stopwatch. Two trials were performed with 3 min of recovery between trials, and the faster time was retained for analysis. The same procedures, equipment, court

surface, instructions, and scoring criteria were maintained at baseline and post-intervention.

2.9 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean $\pm$ standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Baseline-to-post-intervention difference scores were calculated as baseline minus post-intervention values; because both outcomes were completion-time measures, positive difference scores represented lower post-intervention times and therefore better performance.

Given the small sample size, distributional assumptions were not evaluated solely by formal hypothesis testing. Normality of paired difference scores for T-test change-of-direction performance and 20-m sprint performance was assessed using the Shapiro-Wilk test together with visual inspection of histograms, normal Q-Q plots, and boxplots. Paired-samples t-tests were used for the primary overall baseline-to-post-intervention comparisons. Mean paired differences, 95% confidence intervals (CIs), t statistics, degrees of freedom, and two-tailed p values were reported. Within-participant effect sizes were expressed as Cohen's d_z , calculated as the mean paired difference divided by the SD of the paired differences, and were interpreted as standardized descriptions of within-participant change rather than as estimates of causal intervention efficacy. Percentage change was calculated descriptively from group-level means as $[(\text{baseline mean} - \text{post-intervention mean}) / \text{baseline mean}] \times 100$ and was reported for the overall sample and separately for SL3 and SL4 athletes.

As a secondary exploratory analysis, differences in pre-to-post response patterns between SL3 and SL4 athletes were examined using a 2 x 2 mixed-design analysis of variance (ANOVA), with Time (baseline and post-intervention) as the within-subject factor and Sport Classification (SL3 and SL4) as the between-subject factor. The principal exploratory effect was the Time x Sport Classification interaction. Homogeneity of variance was assessed using Levene's test; because the within-subject factor contained only two time points, no sphericity correction was required. Interaction effect sizes were expressed as partial eta squared η^2 .

No additional baseline-adjusted between-class model was performed because the classification-specific comparisons

were secondary and exploratory, with only eight athletes in each classification. The principal comparison of pre-to-post response patterns between SL3 and SL4 was therefore based on the Time x Sport Classification interaction. Paired-samples t-tests were additionally conducted within SL3 and SL4 to descriptively characterize pre-to-post changes; these analyses were exploratory and were not interpreted as independent evidence of class-specific causal training effects.

The potential issue of multiple testing was considered. Because the two overall performance outcomes represented the principal study outcomes and classification-specific analyses were secondary and exploratory, no formal multiplicity correction was applied. Secondary p values were interpreted cautiously together with effect estimates, 95% CIs, the magnitude and direction of observed changes, and the exploratory nature of the analyses. Statistical significance was set at a two-tailed $p < 0.05$ and was not interpreted as definitive evidence that the intervention caused the observed performance changes.

3. Results

3.1 Participant Characteristics and Training Adherence

A total of 16 standing lower-limb para-badminton athletes completed the study and were included in the final analysis. All participants completed both baseline and post-intervention assessments, and no missing data were identified for the primary performance outcomes. The participants had a mean age of 24.44 ± 4.63 years, ranging from 19 to 32 years, and a mean training age of 19.19 ± 4.75 months, ranging from 12 to 28 months. Ten participants (62.5%) were male and six (37.5%) were female.

The sample was equally distributed between the SL3 and SL4 sport classifications, with eight participants (50.0%) in each classification. Thirteen participants (81.3%) were right-hand dominant and three (18.8%) were left-hand dominant. Regarding impairment side, six participants (37.5%) had right-sided impairment, six (37.5%) had left-sided impairment, and four (25.0%) had bilateral impairment.

Training adherence was high. Participants completed an average of 22.88 ± 0.89 of the 24 prescribed intervention sessions, with individual participation ranging from 22 to 24 sessions. The reported mean training attendance was $95.50 \pm 3.54\%$. Reasons for missed intervention sessions were recorded and included family-related commitments, bereavement, and preparation for external competitive

events. All participants nevertheless completed the baseline and post-intervention performance assessments.

Table 2. Participant characteristics and training adherence (n = 16)

Variable	Value
Age, years	24.44 ± 4.63
Training age, months	19.19 ± 4.75
Male, n (%)	10 (62.5)
Female, n (%)	6 (37.5)
SL3, n (%)	8 (50.0)
SL4, n (%)	8 (50.0)
Right-hand dominant, n (%)	13 (81.3)
Left-hand dominant, n (%)	3 (18.8)
Right-sided impairment, n (%)	6 (37.5)
Left-sided impairment, n (%)	6 (37.5)
Bilateral impairment, n (%)	4 (25.0)
Sessions completed, n	22.88 ± 0.89
Training attendance, %	95.50 ± 3.54

Note. Continuous variables are presented as mean ± standard deviation (SD), whereas categorical variables are presented as frequency and percentage, n (%). Training age represents the duration of systematic para-badminton training before study participation. The intervention comprised 24 prescribed sessions conducted three times per week over eight weeks.

3.2 Assessment of Statistical Assumptions

Because of the relatively small sample size, the distribution of paired difference scores was evaluated using both formal and graphical procedures. The Shapiro–Wilk test indicated no statistically significant departure from normality for T-test change-of-direction difference scores ($W = 0.958$, $p = 0.633$). Similarly, 20-m sprint difference scores showed no statistically significant departure from normality ($W = 0.901$, $p = 0.084$).

Visual inspection of histograms, normal Q–Q plots, and boxplots was also performed. The observed values generally followed the expected distributional pattern, and no apparent extreme observations were identified that would preclude the use of parametric paired analyses. Accordingly, paired-samples t-tests were retained for the overall baseline-to-post-intervention comparisons.

3.3 Pre-to-Post Change in T-Test Change-of-Direction Performance

T-test completion time was lower at the post-intervention assessment than at baseline. Mean completion time changed from 16.06 ± 0.52 s at baseline to 15.50 ± 0.50 s following the eight-week intervention period. The mean paired difference, calculated as baseline minus post-intervention completion time, was 0.57 s, with a standard deviation of the paired differences of 0.16 s and a standard error of 0.04 s. The corresponding 95% confidence interval ranged from 0.48 to 0.65 s.

The paired-samples t-test identified a statistically significant pre-to-post difference:

$t(15) = 14.54$, $p < 0.001$, 95% CI [0.48, 0.65].

The standardized within-participant effect size was:

Cohen's $d_z = 3.63$.

Based on the reported analysis, T-test completion time was approximately 3.53% lower at post-intervention assessment. The Cohen's d_z value describes the standardized magnitude of the observed within-participant change relative to the variability of paired difference scores. Given the single-group design and small sample, it should be interpreted as a descriptive estimate of pre-to-post change rather than as evidence of causal intervention efficacy.

3.4 Pre-to-Post Change in 20-m Sprint Performance

Mean 20-m sprint completion time was also lower at post-intervention assessment than at baseline, changing from 6.07 ± 0.70 s to 5.54 ± 0.51 s. The mean paired difference was 0.53 s, with a standard deviation of the paired differences of 0.30 s and a standard error of 0.08 s. The corresponding 95% confidence interval ranged from 0.37 to 0.69 s.

The paired-samples t-test indicated a statistically significant pre-to-post difference:

$t(15) = 7.03$, $p < 0.001$, 95% CI [0.37, 0.69].

The standardized within-participant effect size was:

Cohen's $d_z = 1.76$.

Based on the reported analysis, 20-m sprint completion time was approximately 8.69% lower at post-intervention assessment. As with the T-test outcome, this standardized effect size characterizes the magnitude of the observed

within-participant change and should not be interpreted independently as evidence that the intervention caused the observed performance change.

3.5 Overall Pre-to-Post Changes in Performance

The primary performance outcomes are summarized in Table 3. Lower post-intervention completion times were observed for both T-test change-of-direction performance and 20-m sprint performance. The 95% confidence intervals

for both paired mean differences excluded zero, and both baseline-to-post-intervention comparisons were statistically significant.

The standardized within-participant effect sizes were $d_z = 3.63$ for T-test change-of-direction performance and $d_z = 1.76$ for 20-m sprint performance. These values characterize the standardized magnitude and consistency of the observed within-participant changes and should not be interpreted as direct estimates of intervention efficacy.

Table 3. Pre-to-post changes in T-test change-of-direction and 20-m sprint performance

Outcome	Baseline, Mean $\pm$ SD	Post-Intervention, Mean $\pm$ SD	Mean Change	95% CI	t (df)	p	Cohen's d_z
T-test change-of-direction performance (s)	16.06 $\pm$ 0.52	15.50 $\pm$ 0.50	0.57	0.48–0.65	14.54 (15)	<0.001	3.63
20-m sprint performance (s)	6.07 $\pm$ 0.70	5.54 $\pm$ 0.51	0.53	0.37–0.69	7.03 (15)	<0.001	1.76

Note. Mean change was calculated as baseline – post-intervention; therefore, positive values represent lower post-intervention completion times. Percentage changes were calculated descriptively in the study analysis. CI = confidence interval; SD = standard deviation; d_z = Cohen's d for paired observations.

Overall, performance improvements were observed following participation in the eight-week intervention, as reflected by lower post-intervention completion times for both outcomes. Given the single-group pretest–posttest design, these findings represent observed within-participant changes and should not be interpreted as definitive evidence that the adaptive footwork programme alone caused the changes.

3.6 Exploratory Comparison of Pre-to-Post Changes Between SL3 and SL4

Secondary exploratory analyses examined whether the magnitude of pre-to-post performance change differed between SL3 and SL4 athletes. Because only eight participants were included within each sport classification, all classification-specific analyses were considered exploratory and hypothesis-generating.

3.7 T-Test Change-of-Direction Performance

Among SL3 athletes, mean T-test completion time decreased from 16.01 $\pm$ 0.65 s at baseline to 15.40 $\pm$ 0.58 s at post-intervention assessment. The mean paired change was 0.61 s (95% CI [0.47, 0.75]), corresponding to an approximately 3.81% reduction in completion time. The within-class paired comparison was statistically significant, $t(7) = 10.23$, $p < 0.001$.

Among SL4 athletes, mean T-test completion time decreased from 16.12 $\pm$ 0.39 s at baseline to 15.59 $\pm$ 0.43 s at post-intervention assessment. The mean paired change

was 0.53 s (95% CI [0.41, 0.64]), corresponding to an approximately 3.29% reduction in completion time. The within-class paired comparison was statistically significant, $t(7) = 10.59$, $p < 0.001$.

The Time $\times$ Sport Classification interaction was not statistically significant:

$$\mathbf{F(1,14) = 1.20, p = 0.292, \eta^2 = 0.079.}$$

Thus, although lower post-intervention T-test completion times were observed within both classifications, the present data did not provide evidence that the magnitude of pre-to-post change differed between SL3 and SL4 athletes.

3.8 20-m Sprint Performance

Among SL3 athletes, mean 20-m sprint completion time decreased from 6.28 $\pm$ 0.62 s at baseline to 5.56 $\pm$ 0.46 s at post-intervention assessment. The mean paired change was 0.72 s (95% CI [0.50, 0.94]), corresponding to an approximately 11.46% reduction in sprint completion time. The within-class paired comparison was statistically significant, $t(7) = 7.76$, $p < 0.001$.

Among SL4 athletes, mean sprint completion time decreased from 5.85 $\pm$ 0.75 s at baseline to 5.52 $\pm$ 0.59 s at post-intervention assessment. The mean paired change was 0.33 s (95% CI [0.17, 0.49]), corresponding to an approximately 5.64% reduction in completion time. The within-class paired comparison was statistically significant, $t(7) = 4.93$, $p = 0.002$.

In contrast to the T-test outcome, the Time $\times$ Sport Classification interaction for 20-m sprint performance was statistically significant:

$$F(1,14) = 11.62, p = 0.004, \eta^2 = 0.454.$$

Within the present sample, the observed pre-to-post reduction in sprint completion time was larger in SL3 than in SL4 athletes. However, because this comparison was

secondary, involved only eight participants per classification, and was not supported by direct measurements of potential explanatory mechanisms, the finding should be regarded as preliminary and hypothesis-generating rather than as evidence of a definitive classification-specific training response.

Table 4. Exploratory comparison of pre-to-post changes between SL3 and SL4 athletes

Outcome	Class	Baseline Mean $\pm$ SD (s)	Post-intervention Mean $\pm$ SD (s)	Mean Change (s)	95% CI	Change (%)	t(7)	Within-Class p
T-test change-of-direction performance	SL3	16.01 $\pm$ 0.65	15.40 $\pm$ 0.58	0.61	0.47–0.75	3.81	10.23	<0.001
	SL4	16.12 $\pm$ 0.39	15.59 $\pm$ 0.43	0.53	0.41–0.64	3.29	10.59	<0.001
20-m sprint performance	SL3	6.28 $\pm$ 0.62	5.56 $\pm$ 0.46	0.72	0.50–0.94	11.46	7.76	<0.001
	SL4	5.85 $\pm$ 0.75	5.52 $\pm$ 0.59	0.33	0.17–0.49	5.64	4.93	0.002

Time $\times$ Sport Classification interactions:

T-test change-of-direction performance: $F(1,14) = 1.20, p = 0.292, \eta^2 = 0.079$.

20-m sprint performance: $F(1,14) = 11.62, p = 0.004, \eta^2 = 0.454$.

Note. Mean change was calculated as baseline – post-intervention; therefore, positive values represent lower post-intervention completion times. Percentage changes were calculated descriptively from the classification-specific values used in the analysis. Within-class paired comparisons and classification-specific analyses were exploratory. η^2 = partial eta squared; CI = confidence interval.

3.9 Consideration of Multiple Comparisons

The overall T-test change-of-direction and 20-m sprint analyses represented the principal performance outcomes of the study. Classification-specific comparisons were conducted as secondary exploratory analyses. No formal adjustment for multiple comparisons was applied to these exploratory subgroup analyses. Accordingly, their p values were interpreted cautiously and considered together with confidence intervals, effect estimates, the direction of observed changes, and the small number of participants within each classification. Statistically significant secondary findings were therefore not treated as confirmatory evidence of a definitive classification-specific difference in pre-to-post change.

4. Discussion

The present preliminary exploratory study examined pre-to-post changes in planned change-of-direction performance and 20-m sprint performance following participation in an eight-week adaptive footwork training program among standing lower-limb para-badminton athletes classified as SL3 and SL4. Following the intervention period, T-test completion time was 3.53% lower than baseline and 20-m sprint completion time was 8.69% lower. Both pre-to-post differences were statistically significant and were accompanied by large standardized within-participant effect

sizes (Cohen's $d_z = 3.63$ for T-test change-of-direction performance and $d_z = 1.76$ for 20-m sprint performance) (26). High training adherence (95.50 $\pm$ 3.54%) suggested that the program could be implemented with good adherence within the present NPCI Special Region of Yogyakarta, training environment, although attendance alone should not be interpreted as comprehensive evidence of feasibility.

Exploratory classification-specific analyses showed no statistically significant difference in the magnitude of T-test change between SL3 and SL4 athletes. In contrast, a significant Time $\times$ Sport Classification interaction was observed for 20-m sprint performance, with a larger reduction in sprint completion time in SL3 than SL4 athletes. Given the single-group design, small overall sample, and only eight participants per classification, these findings should be interpreted as preliminary patterns of change rather than definitive evidence of intervention efficacy or class-specific training responsiveness.

4.1 Magnitude and Interpretation of Pre-to-Post Changes

The standardized within-participant effect sizes observed in the present study were considerably larger than effects commonly reported in controlled training studies. Meta-analytic evidence in healthy badminton players has reported a standardized mean difference of approximately -0.61 for agility-related outcomes following physical training (27), whereas a broader meta-analysis of speed, agility, and

quickness training reported small-to-moderate pooled effects for change-of-direction performance ($ES = 0.39$) and 20-m sprint performance ($ES = 0.49$) (28). These values should not, however, be directly compared with the present Cohen's d_z estimates. Cohen's d_z standardizes the paired pre-to-post difference by the variability of individual difference scores, whereas controlled studies typically report between-group standardized effects. The metrics are therefore conceptually and mathematically different and do not support a conclusion that the present intervention produced a substantially greater causal training effect.

The very large d_z of 3.63 for the T-test is especially important to interpret cautiously. A large d_z may arise when the mean pre-to-post change is relatively consistent across participants and the standard deviation of the individual change scores is small (29). Thus, d_z reflects both the magnitude and consistency of observed within-participant change; it does not indicate a 363% improvement and should not be interpreted as a direct estimate of intervention effectiveness (30). With only 16 athletes, effect-size estimates may also be unstable and sensitive to limited variability in change scores. Replication in larger samples is required before the magnitude of these estimates can be considered robust.

The absence of a non-intervention or active control group further limits causal interpretation. Repeated exposure to the same T-test and sprint procedures may have contributed to lower post-intervention completion times through familiarization, task-specific motor learning, or greater comfort with maximal-effort testing. This concern is particularly relevant to the T-test because its predetermined movement sequence can be learned with repeated exposure. Similar familiarization may have occurred for the sprint start and maximal-effort execution. In addition, regression toward the mean cannot be excluded in an uncontrolled pretest-posttest design. Baseline performance level may also have influenced the magnitude of change because the athletes had limited exposure to a formalized progressive footwork intervention of the type examined here. Collectively, these factors reinforce that the effect sizes should be regarded as descriptive estimates of within-participant change, not as estimates of the causal effect attributable solely to the adaptive footwork program.

4.2 Interpretation of Change-of-Direction and Sprint Outcomes

An important conceptual distinction concerns interpretation of the T-test. Although the T-test has

historically been described as an agility assessment and has demonstrated reliability for multidirectional movement performance (10), its movement sequence is predetermined and known before test initiation. Under the framework proposed by Sheppard and Young (2006), agility includes a perceptual and decision-making response to an external stimulus (31). The T-test does not include such an unpredictable stimulus during the timed trial and is therefore more appropriately interpreted as an assessment of planned change-of-direction performance rather than reactive agility (32).

This distinction is relevant because the intervention contained both closed and reactive movement elements. The shadow-footwork and predetermined movement exercises primarily challenged acceleration, deceleration, and planned directional changes, whereas the coach-cued exercises incorporated unpredictable directional information and a perceptual-response demand. Consequently, the lower post-intervention T-test time supports an observed improvement in planned multidirectional change-of-direction performance (5), but it does not establish that perceptual or decision-making agility improved (33). Future studies should therefore include both a planned change-of-direction test and an externally paced reactive agility assessment (31).

The lower post-intervention 20-m sprint time indicates faster linear sprint performance following the intervention period. This pattern is compatible with the repeated acceleration, high-intensity footwork, forward and backward movement, and coach-directed sprint actions included in the training program (34). Nevertheless, the sprint change cannot be attributed specifically to the adaptive footwork component (35). Participants continued routine para-badminton training, resistance-band work, technical drills, stroke practice, and periodic general conditioning, while individual external training load was not objectively quantified. The observed sprint change may therefore reflect the combined influence of the study intervention, concurrent sport training, test familiarization, and other uncontrolled factors.

4.3 Exploratory Differences Between SL3 and SL4

The classification-specific findings require particular caution because only eight athletes were included in each classification. For T-test change-of-direction performance, both SL3 and SL4 athletes showed lower post-intervention completion times, but the Time x Sport Classification interaction was not statistically significant. The present data

therefore do not provide evidence that the magnitude of planned change-of-direction change differed between classifications.

For the 20-m sprint, the reduction in completion time was larger in SL3 athletes (0.72 s) than in SL4 athletes (0.33 s), and the Time x Sport Classification interaction was statistically significant. One possible explanation is the difference in baseline performance: SL3 athletes had a descriptively slower baseline sprint time (6.28 s) than SL4 athletes (5.85 s), potentially leaving greater numerical room for improvement. However, no additional baseline-adjusted between-class model was performed, and the present study cannot determine the extent to which baseline performance contributed to the interaction.

Differences in functional impairment may also theoretically influence movement adaptation because SL3 and SL4 classifications reflect different levels of functional limitation, and classification-related differences in para-badminton performance have been reported previously (13, 14, 16, 36). However, lower-limb strength, balance, anthropometry, impairment severity, neuromuscular function, and other measures of functional capacity were not assessed as explanatory variables. Explanations based on impairment characteristics, greater adaptation potential in SL3 athletes, or a possible performance ceiling in SL4 athletes therefore remain hypotheses rather than demonstrated mechanisms.

The classification analyses were secondary and exploratory, and no formal adjustment for multiple testing was applied. Accordingly, the significant sprint interaction should not be treated as confirmatory evidence that SL3 athletes respond more favorably to adaptive footwork training than SL4 athletes. Rather, it identifies a potentially relevant classification-related pattern that warrants evaluation in larger, adequately powered controlled studies.

4.4 Practical Implications and Feasibility

From an applied perspective, the high training attendance observed in the present study suggests that the program could be delivered with good adherence within the participating NPCI DIY squad (11). The intervention combined planned change-of-direction drills with coach-cued reactive movements and progressively manipulated exercise volume, recovery, movement speed, and task complexity. This structured progression may provide coaches with one possible framework for organizing

multidirectional and sprint-oriented practice in standing lower-limb para-badminton athletes (20, 22, 37).

However, adherence should not be equated with comprehensive feasibility, and the findings should not yet be used to make definitive training prescriptions. In particular, the exploratory SL3-SL4 sprint difference does not justify assuming that SL3 athletes will consistently achieve larger gains than SL4 athletes. Individual responses should continue to be monitored rather than predicted solely from sport classification.

The prescribed exposure was also substantial: three scheduled sessions of approximately three hours per week. This duration included exercise execution, recovery, instruction, waiting periods, and athlete rotation rather than three continuous hours of high-intensity activity. Even so, implementation in other settings may depend on court availability, coaching staff, athlete recovery capacity, concurrent training demands, and impairment profile. The present adherence findings should therefore be interpreted as evidence of practical implementation within this specific training environment rather than proof that the same format is feasible across all para-badminton contexts.

4.5 Limitations and Future Directions

Several limitations should be considered. First, the absence of a non-intervention or active control group prevents the observed pre-to-post differences from being attributed unambiguously to the adaptive footwork program. Familiarization, task-specific motor learning, concurrent training, normal performance variation, and regression toward the mean cannot be separated from changes potentially associated with the intervention. Second, the total sample was small ($n = 16$), with only eight athletes in each classification, limiting the precision and generalizability of effect-size estimates and restricting interpretation of the exploratory SL3-SL4 analysis. Third, the classification analyses involved multiple secondary comparisons without formal multiplicity adjustment and should therefore remain hypothesis-generating.

Additional limitations relate to measurement and training exposure. The T-test assesses a predetermined change-of-direction sequence rather than reactive agility, so transfer to perceptual-cognitive decision-making cannot be determined. Potential mechanisms underlying the SL3-SL4 sprint pattern were not measured, including lower-limb strength, balance, anthropometry, impairment severity, neuromuscular characteristics, and functional capacity. Participants also

continued routine badminton and conditioning activities, while individual external training loads were not objectively quantified. Detailed information on historical competitive exposure and long-term training load was limited, and no follow-up assessment was conducted to determine whether the observed changes were retained after the intervention period.

Future studies should use randomized or controlled comparative designs, ideally with an active control group continuing standard para-badminton training. Larger multicentre samples, a priori sample-size calculations, and prespecified analysis plans would provide more precise effect estimates and more robust comparisons among classifications. Additional familiarization before baseline testing may reduce test-learning effects, while the inclusion of both planned change-of-direction and externally paced reactive agility assessments would better distinguish physical movement capacity from perceptual-cognitive agility (38). Mechanistic measures of strength, balance, anthropometry, impairment characteristics, neuromuscular function, and functional capacity should be incorporated when classification-related differences are investigated (9, 39). Concurrent badminton, rehabilitation, resistance, and conditioning loads should also be systematically quantified, and longer-term follow-up is needed to determine retention and transfer to match-relevant performance.

5. Conclusions

This preliminary exploratory study showed that standing lower-limb para-badminton athletes demonstrated lower T-test change-of-direction and 20-m sprint completion times after participation in an eight-week adaptive footwork training program. T-test completion time was 3.53% lower and 20-m sprint completion time was 8.69% lower at post-intervention assessment, accompanied by large standardized within-participant effect sizes. High training adherence also indicated that the program could be implemented with good adherence within the present NPCI DIY training environment.

Exploratory classification-specific analyses indicated no clear difference between SL3 and SL4 athletes in the magnitude of change in planned change-of-direction performance, whereas a larger reduction in 20-m sprint time was observed in SL3 than in SL4 athletes. However, this classification-related sprint pattern should be regarded as preliminary and hypothesis-generating because of the small subgroup sample, absence of a control group, and potential

influence of baseline performance and other uncontrolled factors.

Accordingly, the findings support the practical implementation of structured adaptive footwork training in this specific para-badminton setting but do not establish that the intervention itself caused the observed performance changes. Larger controlled studies with adequately powered classification-specific samples, objective monitoring of concurrent training loads, and both planned change-of-direction and reactive agility assessments are needed to confirm these preliminary findings and determine their broader applicability.

Authors' Contributions

Conceptualization, H.A.H. and S.N.; methodology, H.A.H., S.N., R.A.H., and F.I.; validation, S.N. and Z.A.R.; formal analysis, F.I. and I.K.; investigation, H.A.H., R.A.H., F.I., and I.K.; data curation, R.A.H. and I.K.; writing—original draft preparation, H.A.H.; writing—review and editing, S.N., Z.A.R., F.I., and R.A.H.; visualization, I.K.; supervision, S.N. and Z.A.R.; project administration, H.A.H. All authors have read and agreed to the published version of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study was conducted in accordance with ethical principles for research involving human participants. Ethical approval was obtained from the Research Ethics Committee of the Directorate of Research and Community Service, Universitas Negeri Yogyakarta, under approval number No. 255.17/DST/UN34.9/T/PT.01.04/2026 before the commencement of data collection. The study was declared ethically appropriate according to the seven WHO 2011 ethical standards and referred to the CIOMS 2016 guidelines. All participants were informed about the objectives, procedures, potential benefits, and possible risks associated with participation. Participation was voluntary, and written informed consent was obtained before testing and intervention procedures were initiated. Participant confidentiality and privacy were maintained throughout data collection, analysis, and reporting.

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