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RESEARCH ARTICLE

Exploring the Impact of Shuttlecock Feeder-Based Training on Biomechanical Characteristics in Para-badminton Athletes

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Abstract
Purpose: The study intended to investigate the impacts of four weeks of shuttlecock feeder machine-based training with biomechanical parameters on the playing ability of para-badminton players. **Methods:** Para-badminton sports classes, six wheelchair players (WH1) in the first classification and ten wheelchair players (WH2) in the second classification, together with a total of sixteen beginner badminton players from the Coimbatore region in Tamil Nadu State, were the subjects of this study. The experimental group (EG; n = 8) and the control group (CG; n = 8) were the two equal groups in which the subjects were randomly allocated. Kinovea software-based assessment on the angle of contact - pre and post-contact phase through Y1 Sports Camera was utilized. Following the pretest, the trainer administered four weeks of intervention to the experimental group, and meanwhile, a mid-test was conducted. A post-test was executed for the experimental group after a one-week intervention through a Badminton Robot V – 328 (Badminton Shuttlecock Feeder Machine). The data gathered for the control and experimental groups on the specified criterion variables, namely playing ability, pre and post-shuttlecock contact angle, and prior, during, and after data, were subjected to statistical analysis of Repeated measures ANOVA. **Findings:** There was a progressive improvement in both playing ability and biomechanical variables after the pre-test, during ($p < 0.01$) and post ($p < 0.01$) intervention. **Conclusion:** The results indicated that the badminton shuttlecock feeder-based intervention promotes playing ability among Para-badminton players.

Keywords
Para-Badminton, Shuttlecock Feeder Machine, WH1 Sport Class Wheelchair Players, Biomechanical Parameters

INTRODUCTION

A new form of badminton acclimated to physically disabled athletes is para-badminton. Similar rules as conventional badminton with tailored changes to accommodate the specially abled players. This sport gained recognition as a contesting sport for athletes with functional limitations or mobility changes to the opportunity to demonstrate their skills and engage in top-tier competition. Like Pullela Gopichand, who is the prototype of Indian badminton, Gaurav Khanna has heaved para-badminton out of obscurity and into the limelight and is credited for a steep rise for Indian para-badminton to a podium finish by making a clean-sweep by procuring medals at international levels. One of the world's most recognized paralympic sports involving rackets is para-badminton. Para-badminton is a specific badminton variation designed for athletes with disabilities in which they can compete (Purnama & Doewes, 2022). Parasports entail being "parallel to able-bodied sports or events involving sport" (Ungerer, 2018). Every individual with a disability engages in sporting activities on limitations imposed by their physical or mental impairment (Aitchison et al., 2022). All paralympic sports establish a functional classification system for physical disabilities

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(Katkat & Doğanel, 2024; Ungerer, 2018; Webborn, 2012; Tweedy, 2011). This system places para-athletes in certain sporting classes according to functional capabilities and particular evaluations (Purnama & Doewes, 2022). The classification system intends to ensure that paralyzed individuals succeed in sports despite their disability, which depends on certain tests to qualify disabled athletes into specific categories (Tweedy, 2011; Beckman, 2017). This system warrants fairness in competition by considering functional skills (Ungerer, 2018). There are six sporting classes governed by the Badminton World Federation (BWF), an apex body of Para-badminton: "WH1 and WH2 for wheelchair users, SL3, SL4, and SU5 for ambulant players, and SH6 for short stature" (BWF, 2024). Those categories of limitations are eligible for para-badminton participation: "decreased muscle strength, decreased range of motion, athetosis, hypertonia, ataxia, limb deficiency, differences in limb length, and short stature". The classification systems are designed to ensure fairness in competition and to allow the entry of para-athletes with various forms of disability in sports (Ungerer, 2018; Webborn, 2012; Tweedy, 2011).

Examination of the training method applying biomechanical principles is crucial for assisting athletes in reaching the pinnacle of technical proficiency. It can offer essential concepts for resolving specific issues during technique improvement and explain the cause-and-effect relationship between distinct phases of motor movement (Fernandez-Fernandez, 2009). Understanding that the systemic unity at every level of motor movement determines the outcome of an action is made possible by biomechanics principles (De Oliveira Mota Ribeiro, 2020). Accordingly, Steininger et al. (2021) claimed that because of the game's requirements, which include a smaller playing field, quick sports, rapid movement volume, and shuttlecock strikes, para-badminton players needed to develop stroke skills. Thus, this research aims to clarify the biomechanics of the playing ability of wheelchair Para-badminton players.

The analysis of match elements and performance success indicators in traditional badminton is becoming increasingly popular in the realm of sports performance (Chiminazzo, 2018). Collecting data on the number of strokes taken during games is valuable in developing training prescription parameters tailored to individual performances (Fernandez-Fernandez, 2009). Real-time matches through video analysis allow for extracting objectively analyzed information, which produces helpful feedback for coaches and players to enhance their performance (Phomsoupha, 2015). Very few studies in Para-badminton have applied the optimization of techniques, scientific evaluation of training, and match scouting in a real-time environment. Due to technological innovation, its application has grown day by day, and its impact on sports is inevitable. Virtual reality and robotics are a few of them that are applied in sports to enhance the potential of athletes. Badminton Robot: V – 328 (Badminton Shuttlecock Feeder Machine) is a device designed to automatically feed shuttlecocks in various trajectories, including high lobs, flat shots, and angled shots, with a predetermined angle of release, velocity, and frequency per minute, simulating real-game scenarios. In Para-badminton, such feeder machines and assistive technology-based research are possible means to add a quantum of knowledge to Para-badminton discipline and provide helpful feedback for coaches and players to enhance their performance (Phomsoupha, 2015).

Figure 1 interprets Clarivate Analytics on Web of Science, Science Direct, and Scopus global information providers emphasize that only 26 articles were published globally on Para-badminton from 2006 to 2024; only two articles were related to the biomechanical area of study. Purnama and Doewes (2022) analyzed several biomechanical factors of the badminton forehand smash in standing classification disabled players, including the angles of the elbow, shoulder, arm, hip, knee, torso, and ankle, as well as angular speed, shuttlecock speed and kinetic energy, force, and power.

The research participant, Suryo Nugroho, an international Indonesian Para-badminton player, provided insights into the physical capabilities and performance of para-badminton players with standing upper classification (SU5). Strapasson et al. (2021) attempted to compare and characterize the technical and temporal aspects of classes WH1 and WH2.

During the first round of the 2018 Brazil Para-badminton Championship, twenty-three men's singles matches from the WH1 and WH2 classes were recorded and evaluated. In terms of points, more significant victories in WH1 resulted from the net lift and service. The shots that culminated in winning points that occurred most frequently were drop-shot and clear (WH1) and net-shot and drop-shot (WH2). A research gap has not yet revealed the biomechanical components of wheelchair para-badminton. This investigation intends to examine the training with an assistance badminton shuttlecock feeder that instils significant changes in acquiring playing abilities based on biomechanical characteristics.

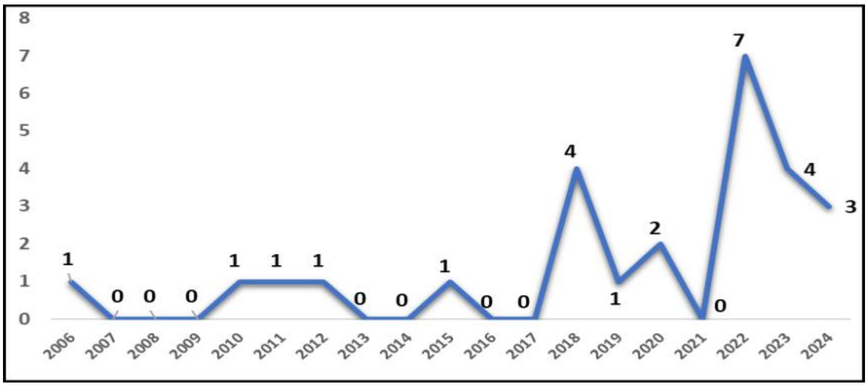

Figure 1. Year-wise distribution of articles on Para-badminton

Reviewing studies from 2006 to 2024 framed the research questions listed below. Based on the study's objectives, the research questions were framed as How does shuttlecock feeder-based training influence the biomechanics of stroke execution in Para-badminton athletes? and what significant technical advancements in the playing over time on biomechanical parameters? What advantage can be derived by using badminton shuttlecock feeder machines in propelling the performance of the specially abled population? Investigate the transferability of feeder machine advantages to Real Game Situations.

Objectives of the study

The following objectives were framed as;

The primary objective focused on the evaluation of effect size due to the Shuttlecock feeder-based training on playing ability among novice Para-badminton athletes over a period of time.

The secondary objectives include designing and developing drills related to increasing the propulsive ability of the wheelchair along with handling the badminton racket with biomechanical characteristics such as the angle of pre and post-shuttlecock contacts.

MATERIALS AND METHODS

Study Participants

According to the guidelines provided by the World Badminton Federation (BWF) for Para-badminton sports classes, six wheelchair players (WH1) in the first classification and ten wheelchair players (WH2) in the second classification, together with a total of sixteen 25-33 age ranged beginner male badminton players from the Coimbatore region in Tamil Nadu State, were the subjects of this study. In the experimental group (EG; n = 8) and the control group (CG; n = 8), the subjects were randomly allocated into two equal groups. Prior to the experiment, the subjects were instructed about the badminton rules and regulations. All selected subjects were novices in wheelchair handling and wheelchair propulsion. Table 1 shows the sports classes of selected subjects.

Table 1. Sport classes of selected subjects

Classification	Description	Number of Subjects	
		Experimental Group (n = 8)	Control Group (n = 8)
Wheelchair 1 (WH 1)	"Players in this class require a wheelchair to play badminton. Players in this Sport Class usually have impairment in both lower limbs and trunk function" (Source: BWF, 2024).	3	3
Wheelchair 2 (WH 2)	"A player in this class could have impairment in one or both lower limbs and minimal or no impairment of the trunk. Players are required to play on a wheelchair" (Source: BWF, 2024).	5	5

Ethical Information

The Avinshilingam Institutional Human Ethics Committee approved this study (Ref: IHEC/22-23/PE-02). Furthermore, the participants gave written informed consent before commencing the study. After providing informed consent, the voluntary form included research details, risks, benefits, confidentiality and participant rights. The research followed ethical significance by delivering participants' declaration in the design, procedures and confidentiality measures regarding participants' rights and well-being.

Research Tool

Badminton Robot: V – 328 (Shuttlecock Feeder Machine) was utilized in this study. Each corner of the badminton singles court was marked with four arcs with 20 centimetres of radius and numbered 1,2,3,4 and 5. In the marked half-court, the shuttlecock feeder machine was placed. The shuttle feeder machine was loaded with 20 shuttlecocks, each of 4 champers, and 60 shuttles were fired at 5 meters per second. For short serve, the machine was set at a height of 5 feet with an angle of 15 degrees. The machine was set at the same height for deep serve but with an angle of 45 degrees. The first cock would be a right corner short serve, the second cock would be a left extreme deep serve, the third cock would be a left corner short serve, and the fourth cock would be a right extreme deep serve to the Para-badminton player, as shown in Figure 2. Subsequently, this cycle repeats up to 60 shuttlecocks (comprised of three trials; for each 20 shuttlecocks, the player is supposed to play). The players were expected to propel the wheelchair to play the shuttlecock against the machine and try to place the cock in the marked area numbered 1,2,3,4 and 5 of any four corners of the court. For 60 shuttlecocks, which had all been around 5 minutes of play and a consecutive series of three shuttlecocks, the test would be terminated if the player did not respond. No restriction was made to secure the points by which the player can execute badminton strokes such as drop shots, smashing, high clear and flick shots. Out of three trials, the best one will be selected as the score. The calibration of the feeder machine has been checked and ensured before the test was administered.

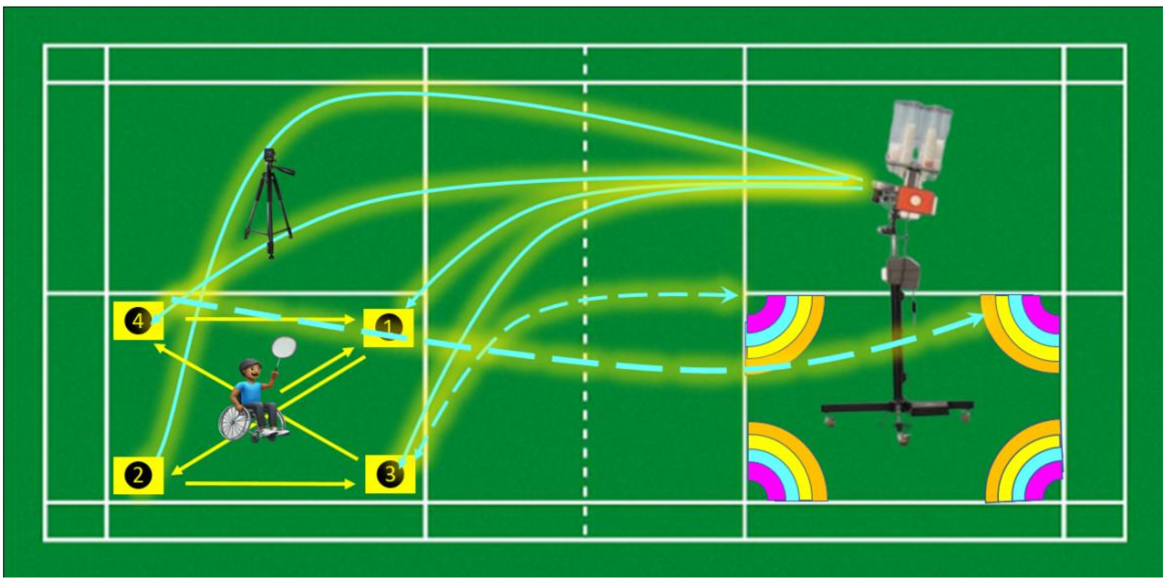

Figure 2. Badminton robot: V-328 (Shuttlecock Feeder Machine) and the expected moves of Para-Badminton Wheelchair Player

Training Phases

In wheelchair badminton, both offensive and defensive players must perform forward and backward propulsion successively to contact the shuttle. With these views, the French Short Serve test is modified into a combination of clear, drop, smash, block, lift, and push skills toward the opponents' court-targeted corner areas, as shown in Figure 3. The researchers executed the examination on a standard wooden badminton court. This study consists of three phases, namely the pre-test phase, where the selected subjects from the experiment group and control group players underwent 20 shuttle services towards the opponent court towards the four corners, each consisting of a marking 5, 4, 3, 2, and 1-point area within the stationary position (without propulsion). Each area has 20 shuttles and a maximum of (20 * 5) 100 points made by the tester. The pre-test completed by all the selected samples before the intervention obtained a total score of 100 points. In each stage, the camera with 90 frames per second (Y1 Sports Camera) has been placed perpendicular to the plane of action (adjacent to the badminton racket handling side of the player) 12 feet at 1.20 meters high from the ground level.

The dominant side of the hand had placed three reflective markers (Wrist, Elbow, and shoulder joint) with a diameter of 15 mm. Assess the angle between the wrist, elbow, and shoulder joints before shuttle contact and after the contact phase. The Kinovea open-source software extracted biomechanical parameters from the recorded film trips.

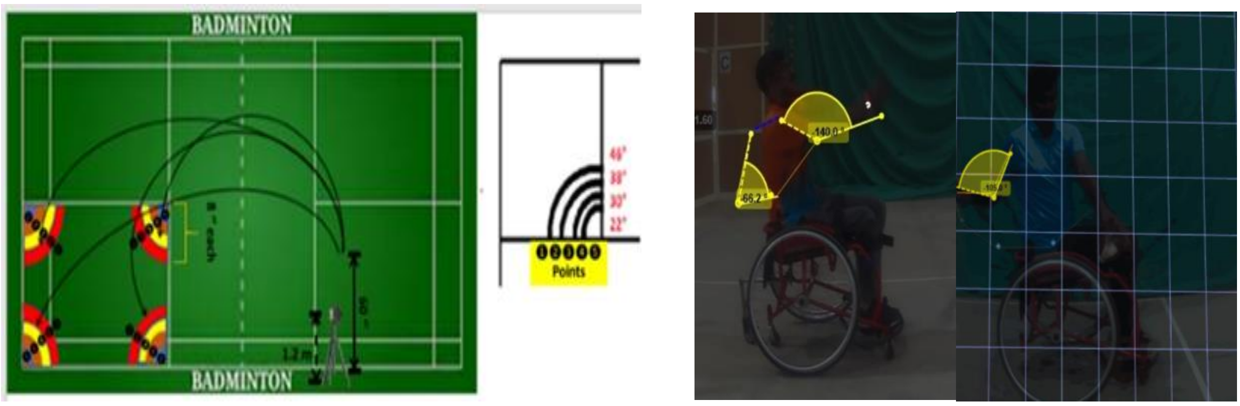

Figure 3. Playing ability assessment & camera placement and kinovea software output on pre - post shuttlecock contact angle

After the pretest phase, only the experimental group exposed to 3 weeks (excluding Monday, six days per week) of target-based clear, drop, smash, block, lift and push skills in terms of drills were given. Every day, in the morning session, a one-hour training comprises strokes with a flat (offensive clear) and rising trajectory (defensive clear) towards the rear and back of the opponent's court. Along the drills, in the third week of the second phase, the experimental group was exposed to Badminton Robot V – 328 (Badminton Shuttlecock Feeder Machine) in a stationary position (without propulsion). The control group wasn't exposed to any special training. In the second phase, during the intervention, the same assessment of playing ability as done during pretest procedures was made for both the control (n = 8) and experiment (n = 8) groups. After the second phase, the experiment group exclusively experienced one week of intervention using the Badminton Robot V – 328 (Badminton Shuttlecock Feeder Machine), which exposed them to predetermined velocity and angle of release with propulsion. In contrast, the control group did not receive any specialized training. The sum of the 60 shuttles' placement in the marked area as 1, 2, 3, 4, and 5 on any corner as secured as their respective scores out of that marked area where the shuttlecock placed considered zero marks. Right after the intervention, the researcher administered the post-test assessments.

Table 2. Variables and test items

Pre-test (Before Intervention)		Mid-test (During Intervention)		Post-test (After Intervention)	
Playing Ability (100 points) Angle of pre-contact phase and post-contact phase		Playing Ability (100 points) Angle of pre-contact phase and post-contact phase		Playing Ability (100 points) Angle of pre-contact phase and post-contact phase	
EXG	CG	EXG	CG	EXG	CG
No Specific Training	No Specific Training	1st Two Weeks – Drills and 3rd Week – V 328 – without propulsion	No Specific Training	Fourth Week – V 328 – with propulsion	No Specific Training

Statistical Analysis

In experimental and control groups, sixteen Para-badminton players underwent pre-, mid, and all the selected variables, the descriptive statistics of mean and standard deviation are computed before, during, and after the interventions. The repeated measures Analysis of Variance (ANOVA) with Partial Eta Squared evaluated the effect size of different times of pre-mid-post interventions on playing ability and the pre-and post-shuttlecock contact angle. Estimated marginal means were analysed by plotting a line graph. IBM SPSS version-29 was utilized for all the statistical computations for all cases, setting the significance level at 0.05.

post-tests on playing ability with and without shuttlecock feeder machine intervention, as shown in Table 2. For

RESULTS

Table 3 presents descriptive statistics indicating the mean and standard deviation values of playing ability out of 100 points before, during, and after the intervention. It shows that the control group remains constant, whereas the experiment group gradually progressed to a maximum of 78 out of 100 points from 51 points.

Table 3. Descriptive statistics of playing ability

Variable	Group	Mean	Std. Deviation (±)
Playing Ability before	Experiment	50.88	4.993
	Control	48.06	4.403
Playing Ability during	Experiment	71.25	3.379
	Control	50.60	4.057
Playing Ability after	Experiment	78.36	6.567
	Control	50.73	2.885

Table 4 displays the results of a repeated measures ANOVA that assessed the mean difference in playing ability before, during, and after the intervention over a period. The result of the ANOVA indicated that a significant time effect, Wilk's Lambda = 49.36; F (1,14) = 112.5; $p < 0.01$, Ƞ2 = 0.89, yield significant evidence that the shuttlecock feeder-based training influences the playing ability of Para-badminton athletes. Figure 4 duplicated the Estimated Marginal Means of Playing Ability that acknowledged the positive impact of training on playing ability.

Table 4. Repeated measures ANOVA between subjects effects on playing ability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared ($Ƞ^2$)
Between	3482.1	1	3482.1	112.51	.000**	0.889
Within	433.3	14	30.948			

Significance = *$p < 0.05$; **$p < 0.01$

From Table 5, Descriptive statistics imply the mean and standard deviation values of the pre-contact angle before, during, and after the intervention. It clearly shows that the control group remains almost the same mean value. In contrast, the experiment group gradually decreased from a maximum of 120 degrees to 59 degrees on pre-contact of shuttlecock angle.

Table 5. Descriptive statistics on pre-contact angle over a period of time-before, during and after intervention

Variable	Group	Mean	Std. Deviation (±)
Pre-Contact angle before	Experiment	118.76	4.008
	Control	120.75	1.394
Pre-Contact angle during	Experiment	100.41	3.931
	Control	119.00	4.940
Pre-Contact angle after	Experiment	59.28	2.185
	Control	121.83	5.475

Table 6 displays the results of repeated measures ANOVA to assess the mean difference in pre-contact shuttlecock angle over time-before, during, and after the intervention. The result of the ANOVA indicated that a significant time effect, Wilk's Lambda = 197; $F(1,14) = 640.9$; $p < 0.01$, $\eta^2 = 0.97$, yield significant evidence that the shuttlecock feeder-based training influences the pre-contact angle of shuttlecock of Para-badminton athletes. Figure 4 duplicated the Estimated Marginal Means of the shuttlecock's pre-contact angle that acknowledged the intervention period's positive impact on the shuttlecock's pre-contact angle.

Table 6. Repeated measures ANOVA between subject's effects on pre-contact angle of shuttlecock

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared (η^2)
Between	9216.9	1	9216.9	640.9	.000**	.979
Within	201.4	14	14.4			

From Table 7, descriptive statistics imply the post-contact angle's mean and standard deviation values before, during, and after the intervention. It clearly shows that the control group remains almost the same mean value. In contrast, the experiment group gradually decreased from a maximum of 153 degrees to 139 degrees on the pre-contact of the shuttlecock angle. The analysis utilized repeated measures ANOVA to assess mean differences in post-contact shuttlecock angle over time, specifically before, during, and after the intervention.

Table 7. Descriptive statistics on a post-contact angle over a period of time – before, during and after intervention

Variables	Group	Mean	Std. Deviation **(±)**
Post Contact angle before	Experiment	153.85	5.287
	Control	160.49	5.965
Post Contact angle during	Experiment	149.44	3.881
	Control	158.52	5.941
Post Contact angle after	Experiment	139.57	2.061
	Control	161.15	4.450

From Table 8, the result of the ANOVA indicated that a significant time effect, Wilk's Lambda = 10; $F(1,14) = 96.3$; $p < 0.01$, $\eta^2 = 0.87$, yields significant evidence that the shuttlecock feeder-based training influences the post-contact angle of shuttlecock among Para-badminton athletes. Figure 4 duplicated the Estimated Marginal Means of the shuttlecock post-contact angles that acknowledged the intervention period's positive impact on the post-contact angle and the overall badminton playing ability

Table 8. Repeated measures ANOVA between subjects' effects on the post-contact angle of the shuttlecock

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared (η^2)
Between	1856.1	1	1856.13	96.32	.000**	.873
Within	269.8	14	19.27			

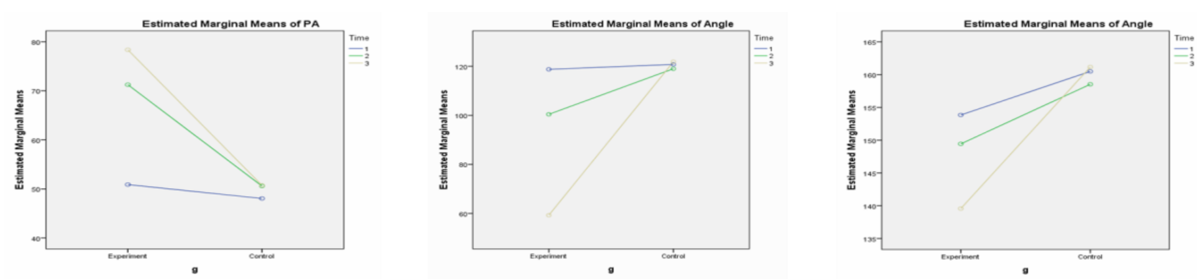

Figure 4. Estimated marginal means of playing ability, pre and post-contact angle of shuttlecock

DISCUSSION

The study investigated the effect of a shuttlecock feeder machine-based training over a period – before, during, and after intervention among two groups, namely the experimental group (EG; n = 8) and the control group (CG; n = 8) on playing ability and biomechanical characteristics. The researcher identified a positive impact on playing ability pre- and post-shuttlecock contact angle. More specifically, the strokes - clear, drop, smash, block, lift, and push increased the propulsion phase due to the shuttlecock feeder machine-based training among the experimental group rather than the control group. The Paralympics marked the debut of para-badminton. This sport is unique because it requires athletes to concentrate on wheelchair propulsion and racket handling (Alberca et al., 2022). Rice et al. (2010) conducted a laboratory-based evaluation of the biomechanics involved in manual wheelchair propulsion. The biomechanical feedback-based learning software is designed to utilize motor learning theory concepts to enable real-time random discontinuous visual display of crucial spatiotemporal and kinetic parameters. This study stressed, more specifically, the positive training effect on the propulsion method by lowering stroke cadence and raising the contact angle at the same time. The software-based assessment clearly provides the means to identify the crucial key factors responsible for success in para-badminton wheelchair sports.

Dellabiancia et al. (2013) investigated the upper body's 3-D kinematic properties and the electromyographic (EMG) signals of deltoid, biceps, triceps, and forearm muscles during wheelchair racing over a roller system. They revealed that the greater push time and angle concerning the propulsion of wheelchairs are more suitable only for endurance-based wheelchair athletes and not suitable for explosive and agile-based wheelchair sports (Chow et al., 2001). Since para wheelchair badminton is one of the agile sports where forward, lateral, and backward propulsion are involved. In terms of sports performance, analysis of match elements and performance success indicators are becoming prevalent in conventional badminton. The measurement of strokes made during games yields valuable data for creating training prescription parameters that are particular to performance (Barreira & Chiminazzo, 2020). Strong badminton skills are a prerequisite for winning, and the smash technique, the basis for many points, is the most thrilling part of badminton matches (Zhang et al., 2016). The lesser the angle during and after the shuttlecock contact, the greater the smash was, in accordance with the previous studies. This study concluded that reducing the error in unwanted movements, reducing the angle when contacting the shuttlecock, and increasing wheelchair propulsion once evoked the required mechanically advantaged counter moves against the opponent in wheelchair para-badminton.

The gadget used to feed the shuttlecock in badminton has been designed to replicate accurate strokes and increase accuracy (De Alwis, 2020). Mimicking the visual search behaviour of competitive match play accelerates the irregular feeding practice routines and improves skill learning and growth in wheelchair badminton players (Smith et al., 2022). Depending on the situation, players may use a combination of stroke angle and strength to perform clears (hitting the shuttlecock to the back of the opponent's court) or drives (fast, horizontal shots). These strokes require a balance to achieve the desired trajectory, which is highly influenced by assistive techno-based training (Chen & Chen, 2009). This study clearly emphasizes that body positioning, release angle, and limb coordination are interconnected elements that impact the overall performance of badminton strokes. The result of this research study relates to the same concept that systematic and repetitive training is essential for players to refine these aspects of their technique, leading to improved shot quality, consistency, and strategic execution on the badminton court (Li et al., 2017).

Conclusions

The badminton shuttlecock feeder-based training positively influenced the playing ability of novice wheelchair para-badminton athletes after the intervention. The pre-and post-shuttlecock contact, along with wheelchair handling and wheelchair propulsion, was also optimized to a greater extent. Shuttlecock feeder-based training using Badminton Robot: V – 328 (Badminton Shuttlecock Feeder Machine) effectively simulates athletes' playing ability and propulsion in Para-badminton. Investigations with large sample sizes on the profile of biomechanical characteristics of various strokes and playing techniques specific to wheelchair Para-badminton were still lacking at an elite level.

Analyzing international wheelchair Para-badminton tournaments requires actively assessing tactical aspects such as game strategies, shot selection, and on-court positioning in a real-time live environment while also considering defensive pressure.

Enhancing research and developing specialized equipment, including customized wheelchairs and racquets designed explicitly for the unique needs and biomechanics of wheelchair Para-badminton players, is recommended. The wheelchair is the most common limiting factor for participation in activities for Paralympic sports. Research should explicitly design wheelchairs for para table tennis to improve stability, mobility, and posture, addressing the sport's specific needs. Suggest researchers actively focus on enhancing stability, mobility, and posture in wheelchairs designed for para table tennis, addressing the sport's specific needs. Further, it is needed to explore the impact of customized equipment on player performance and injury prevention. Since Para-badminton is growing, investigation is essential on how wheelchair-specific factors influence game dynamics.

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Conflict of Interest

The authors declare that this article has no conflict of interest.

Ethics Statement

This research followed the ethical standard and received approval from the Avinshilingam Institutional Human Ethics Committee with registered numbered Ref: IHEC/22-23/PE-02.

Authors Contribution

Research Design, GN, SPR; Research Data Input, GN, SPR; Statistical Data Analysis, GN; Data Processing, GN; Manuscript Preparation, GN, SPR, MV, KK; Journal Literacy, GN, SPR, MV, KK. Each author has reviewed the final draft of the manuscript and given their approval.

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