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Technical-locomotor proficiency gaps in youth badminton beginners: serve, net-drop, smash, and footwork

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ABSTRACT

Technical competence is essential for long-term athlete development in badminton; however, the development of racket skills and court-movement abilities during the novice stage remains insufficiently examined. This study aimed to describe serve, net-drop, and smash accuracy, as well as footwork agility, and to examine their relationships with chronological age and sex. A descriptive quantitative, cross-sectional design was employed involving 23 novice athletes (16 boys and 7 girls) aged 11–15 years from a university-affiliated badminton academy in West Sumatra, Indonesia. Participants completed a standardized field-test battery consisting of a modified French-Scott-Fox serve accuracy test, net-drop and smash accuracy tests, and an 8-point footwork agility test. Data were analyzed using descriptive statistics, norm-referenced scoring, Spearman's rank correlation, and the Mann–Whitney U test. Mean serve accuracy was 45.4% (SD = 22.3), while net-drop and smash accuracy scores were 21.52 (SD = 8.55) and 18.74 (SD = 9.66), respectively. Mean footwork time was 18.14 s (SD = 3.33), with 69.6% of athletes classified in the very slowest normative category. Racket skills demonstrated moderate-to-high intercorrelations (ρ = 0.60–0.69, $p < 0.01$), whereas footwork was significantly correlated only with smash accuracy (ρ = −0.49, $p = 0.018$). Boys outperformed girls across the four performance measures (p = 0.006–0.007; d = 1.10–1.19), despite no significant difference in age distribution ($p = 0.397$). Age showed moderate-to-strong associations with the measured skills ($|r|$ = 0.47–0.57, $p < 0.03$). These findings indicate that racket-handling and locomotor skills represent relatively distinct domains of early technical development. Therefore, novice training programmes should place greater emphasis on footwork and multidirectional agility while considering age- and sex-related differences when grouping athletes for training.

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Introduction

Badminton is one of the quickest racket sports in the whole world and consists of very short but very high-intensity ralleys combined with rapid multi-directional moves and explosive striking (Phomsoupha & Laffaye, 2015), physical demands that are also reflected in the sport's elite injury-epidemiology literature (Pardiwala et al., 2020). A top performance in competition comes down to combining at least two totally different ability clusters those racket-handling skills that are responsible for stroke precision and strength serve, net drop, smash and locomotor capabilities that define speed and efficiency at which a player gets there to the shuttlecock just before executing those strokes of a good shot (Kuntze et al., 2010; Lam et al. 2020).

The international sport science guidance for long-term athlete development (LTAD) identifies the pre-adolescent stage as a key phase in motor-skill development which means that basic technical patterns should be set up before the sport-specific workload is increased (Balyi & Hamilton, 2004; Lloyd & Oliver, 2012). The question of whether indeed these two ability clusters racket skill and locomotion parallel progression takes place during this critical period is almost negligible as talent-development assessments in badminton predominantly report the individual technical skill rather than as a joint performance profile.

Footwork is widely regarded as one of the most influential physical factors in badminton player success, as it affects balance and time to hit a shuttlecock in a controlled way. Consistent with this view, biomechanical studies of the badminton lunge (Malwanage et al., 2022), a common movement that is the base of footwork on the court, indicate that unskilled players contact the ground longer, have smaller foot angles in the stroke, and are less effective in their joint-loading strategies compared to skilled players (Lam et al., 2018). Musculoskeletal modelling further shows that lunge mechanics generate substantial joint-contact loads that scale with movement deceleration demands (Chen et al., 2020). It is also the fact that lunges are very physical elements of the badminton game where the hips, knee, and ankles are subjected to large forces (Kuntze et al., 2010; Hu et al., 2015). Since changing the direction of motion as well as lunges form the majority of all court actions (Valldecabres et al., 2020), a poor-footwork player is likely to become a limiting factor even when they have otherwise good strokes. Also, a hand-eye coordination that is very advanced with poor footwork could result in a development road block which is not acknowledged at an early stage. However, whether footwork actually holds this primacy relative to racket skills, rather than simply being one of several co-equal contributors, has not been directly tested in youth beginners, which is the specific gap this study addresses.

Little is known about the changes of badminton-specific footwork as youth individuals train, though some studies are coming out. In a study with adolescent, competitive players, a balance-training programme was integrated for eight weeks within regular training, leading to a decrease of 19, 36% of push-off time (the interval between foot contact and take-off during a stroke) on several stroke types, whereas a control group that continued with ordinary training alone didn't show any better performance (Malwanage et al., 2022). These results support the fact that deficits in footwork can be effectively addressed by the right exercise that the person needs, meaning they don't have to continue in vain. Therefore, it is very practical to catch these shortcomings at an early stage because they can get worse as the tactical complexity increases.

A second avenue of research deals with growth and development of children. For as much as chronological age gives only a very rough idea of the degree of biological maturity of a child the different performance levels of mixed-age cohorts starting the sport, as you can find, for example, at community or university-linked academies, could be a good indicator of their growth stage rather than of the amount of training they have done. Sex-related differences in fundamental motor skill proficiency have been similarly well-dosed from the general child-development literature: a recent systematic review and meta-analysis of children aged 3, 6 years has shown that boys displayed greater proficiency object-control skills, and the difference increased with age (Zheng et al., 2022). If a similar trend were observable in racket-and-locomotion proficiency among older beginner groups and if it were equally observable for racket skills and footwork, it has not been clearly shown in the case of badminton.

Local literature has separately described each of the four techniques considered in this study. Serve proficiency is said to rely on arm-muscle explosive power and eye–hand coordination (Nasri et al. 2019); smash accuracy is linked to joint effort from arm and leg power, timing, and coordination (Edmizal et al. 2022; Asnaldi 2020); footwork is a result of reactive leg power and agility training such as ladder drills and shuttle-and-zigzag runs (Nando & Wulandari 2018; Mirfan et al. 2020; Edmizal et al. 2020); net-play control is fine motor regulation of net play that separates the technique from the coarse power of smash. The lack of attention in the literature, both in Indonesia and internationally, to treat these four techniques as correlated and interdependent components within a single group explains the research method employed in this paper.

Three main gaps are identified in this article. First, there is a knowledge gap. The available description of technique that is typical of beginners in their first year of taking lessons focuses on each skill independently. So, for instance, when the beginner has excellent racket work, we cannot tell if the player also has developed excellent footwork skills, and vice versa. Coaches have not given much consideration to how they should distribute their time in practice for different strokes and movement. Lastly, this is also a methodological gap, and it refers to the case where even though the beginner athletes may range widely in time in years, they are still treated as the same homogenously in one group. As a result, such sex- or age-related patterns may not be fully captured or revealed in the data.

Actually, pointing out these discrepancies is very helpful, not only for academic purposes but also for practical ones. Since programmes such as those ones under scrutiny in our paper only have limited training periods it stands to reason that a trainer who cannot pinpoint the area(s) of technical weakness he/she has with the trainee will be unable to use the very hours most efficiently. Since poor footwork seems both to lend itself for improvement through training (Malwanage et al., 2022) and to be the basic mechanical foundation upon which other stroke skills depend (Kuntze et al., 2010), the earliest possible identification through correlation of the dissociation between the skills of the hand as opposed to the foot will help in a very material way in deciding how to order an introductory programme.

This study's novelty does not lie in its data-collecting tools which are field tests already well-established and used in Indonesian coaching-science study contexts but in the way it analyses the data. The findings are not just presented simply as four separate results, rather: (a) The study re-classifies each technical skill according to what is already known, as the standard of the technique, and arithmetics confirm it; (b) It explores the relationships between the four technical skills in a quantitative way, employing rank-based statistics suitable for small, non-normally distributed samples; (c) It examines whether age and sex are the factors behind the seen variation of the technical skills. This new approach will be used solely on the first group testing records (without changes in any scores, sample size, or the measurements themselves).

This research was designed with three operationalized objectives: (1) to quantify serve, net-drop, smash, and footwork technical proficiencies in a group of beginner youth badminton players using statistical analysis and corrected norm; (2) to examine the correlation between the four techniques as well as between each technique and chronological age; and (3) to compare technique proficiencies between boys and girls in the whole group. Here, "parallel progression" is operationalized as a statistically significant Spearman correlation between a racket-skill measure and the footwork measure within this beginner cohort, and footwork is mainly related to lower limb power and coordination through pathways different from the eye-hand and racket-control pathways of the racket skills (serve, net drop, smash) (Kuntze et al., 2010; Lam et al., 2020). Hence, footwork was thought likely to be less correlated with the racket-skills group than those racket skills are with each other, and simultaneously age and sex were considered to affect performance in all four techniques since there was quite a wide age range and sex related differences in motor-skill development were reported (Zheng et al., 2022).

Method

Design

For this investigation, a single beginner group with a cross-sectional, descriptive-quantitative approach was used to determine their basic technical skills. It's important to note that the group did not receive any intervention and there were no between-group comparisons other than sex and age. The sex and age-related analyses reported in Section 3 were planned a priori as exploratory, secondary analyses of the single testing occasion rather than as a separate study phase; no new data collection followed the primary technical-proficiency assessment, so the design remains a single cross-sectional dataset analysed for both descriptive and correlational purposes.

Participants

Twenty-three athletes (16 male, 7 female) who are students at a badminton academy attached to a university in West Sumatra, Indonesia took part in the sport. Every eligible athlete was tested (this is called total sampling); no participant was left out. The sample size was therefore fixed by the total population of eligible beginners enrolled at the academy at the time of testing rather than by an a priori power calculation; this constraint, and the resulting statistical power for the correlational and group comparisons reported in Section 3, is addressed explicitly in the Limitations. The ages of the participants ranged from 7 to 16 years old ($M = 10.78$, $SD = 2.33$). All participants were classified by the academy as beginner-level athletes with no competitive tournament history above local school level. Since the sample covers a large range of chronological ages, the cohort cannot be seen as a homogeneous maturation group; this point is made again in Section 3.4 and in Section 5.

Testing Procedures

The testing took place over two consecutive days, at the academy's indoor hall. Each athlete completed all four field tests within a single session on one of the two days. After a standardised warm-up, tests were carried out for every athlete in the fixed sequence of serve accuracy, net-drop accuracy, smash accuracy, and

footwork agility, with a standardised 3–5 minute rest interval between tests to limit fatigue effects on later tests in the sequence.

Serve accuracy
A modified French-Scott-Fox serve target test was employed. A graduated target zone was marked on a thread stretched parallel to and above the net. The player then served to the target eight times from behind the service line. The scores 1-5 assigned to the landing zones were added for the eight serves, and the total (maximum 40) was kept as the serve score. This zone-scoring format follows the serve-accuracy protocol previously reported for Indonesian collegiate badminton players (Suardi & Donie, 2018), from which construct validity for this instrument is inferred; no independent reliability re-testing was performed within the present sample, which is acknowledged as a limitation.

Net-drop accuracy
Athletes' drop shots were tested. Athletes dropped 10 balls into a marked target area close to the net, the net score reflected the 10-attempt total. 5 drops were forehands and 5 backhands. The closest net line was a target. No score was given to shuttles which crossed above the marked height threshold, while points were rewarded to shuttles close to the target line. As with the serve test, this zoned-target format follows established coaching-science protocols for net-play assessment used in prior Indonesian badminton studies; formal reliability coefficients (e.g., Cronbach's alpha, ICC) were not computed for this administration, a gap addressed in the Limitations.

Smash accuracy
The protocol used by Edmizal et al. (2022), who reported acceptable validity and reliability coefficients for this smash-accuracy instrument, was followed. The athletes were subjected to 10 fed shuttles (5 each hand side) and performed a smash shot towards the target. The scoring area is the five-zone area on the court. If the ball landed either out of court or did not hit the target, zero point was awarded. Smash score was taken as the total of ten attempts.

Footwork agility
The athletes had to start from one place and then pass through the eight markers in a certain order on the court, hitting each one with the racket only, and the one who could do that quickly and precisely would come first. A person was there just to measure the time with a stopwatch. The faster the court movement, the better the performance; the time taken in the court movement was the footwork scoring measure. This eight-point movement-time format follows agility/footwork testing protocols previously used with Indonesian university badminton players (Nando & Wulandari, 2018; Mirfan et al., 2020); as with the other three instruments, no independent reliability re-testing (e.g., test-retest or inter-rater ICC) was conducted for the present sample, which is addressed in the Limitations.

Data Analysis
Raw scores of all 23 athletes (Appendix, original thesis dataset) were entered again and recalculated for independent verification purposes in the present study. Mean, standard deviation, minimum, maximum, coefficient of variation, skewness, and kurtosis were the measures of descriptive statistics of each technique. Normative category bands corresponded to the categories actually observed for the instruments. Classification percentages were recalculated as (frequency / 23) × 100 to address and eliminate an error in the original data (Section 3.1). The Shapiro, Wilk test was used to assess the degree of linearity of a single variable dataset. Due to the limitation of the size of the sample, non-normality in the distribution of most variables, and the nature of the normative bands as ordinal categories, Spearman ranking correlations were used to measure the relationship between the four techniques and also between each technique and the variable age; Mann, Whitney U tests (with the correlation of rank-biserial and Cohen's d for effect-size estimates) were employed to make boys and girls comparisons. All statistical testing tasks were done using Python (SciPy 1.17; NumPy 2.4; pandas 3.0). The level of statistical significance was $\alpha = .05$, two-tailed. No a priori power analysis was conducted given the fixed, total-sampled cohort ($N = 23$); a post hoc sensitivity check indicates this sample size affords roughly 80% power to detect correlations of $|\rho| \geq 0.55$ at $\alpha = .05$, meaning weaker true associations (as observed between footwork and serve or net drop) could reflect genuine null or near-null relationships or simply insufficient power to detect them, a distinction the current design cannot resolve.

Ethical Considerations
Due to minors being part of the participants, this article presents athlete data with de-identified codes (P01, P23) instead of names. Being in tune with the standard research protocols involving minors, publishing entails the availability of documented ethical approval from the institution and the parent/s guardian's

informed consent. In addition, it is the duty of the authors who are submitting this article to the respective journal(s), not only to ensure and cite the related approval and consent documentation before submission but also to adhere to what is stated in the Declaration of Helsinki.

Results and Discussions

Sample and Descriptive Profile

In the end, the sample size consisted of 23 athletes (16 boys, 7 girls; age 10.78 ± 2.33 years, range 7, 16). Descriptive statistics based on the four technical measures, after having recalculated from the original test scores, are displayed in Table 1.

Table 1. Descriptive Statistics for the Four Technical Measures (N = 23)

Variable	M	SD	Min	Max	CV (%)	Skewness
Serve (points, max 40)	18.17	8.94	4	33	49.2	−0.07
Net drop (points, max 40)	21.52	8.55	11	43	39.7	0.98
Smash (points, max 50)	18.74	9.66	5	35	51.6	0.06
Footwork (seconds)	18.14	3.33	12.22	24.58	18.4	0.41

Note. N = 23. CV = coefficient of variation. Positive skewness for net drop reflects a concentration of scores in the lower half of the scale.

A large range of variability in coefficients of variations between 39.7 and 51.6% for serve, net drop, and smash suggests a lot of variation among racket-skill levels in this novice group. Following the commonly applied sport-science heuristic that a coefficient of variation above roughly 30% indicates high relative dispersion, all three racket-skill CVs fall well within the high-variability range, whereas footwork does not. Meanwhile, footwork times showed much less variability (coefficients of variation = 18.4%).

Normative Classification

Recomputation of frequency distributions occurred by comparing the different norms of the instruments. The original paper included a table presenting service categories. These percentages added up only to 42% instead of 100%. The mistake could be located to the division by a wrong denominator. The revised percent figures (number of frequencies / 23 × 100) can be seen in Figure 2 and wherever else such data has been presented. Note that the base frequencies were not altered as a result, which means the data set remains the same.

Table 2. Corrected Frequency Distribution of Serve-Accuracy Classification (N = 23)

Interval	f	% (corrected)	Category
81–100	1	4.3	Very Good
61–80	6	26.1	Good
41–60	7	30.4	Moderate
21–40	3	13.0	Poor
0–20	6	26.1	Very Poor
Total	23	100.0	

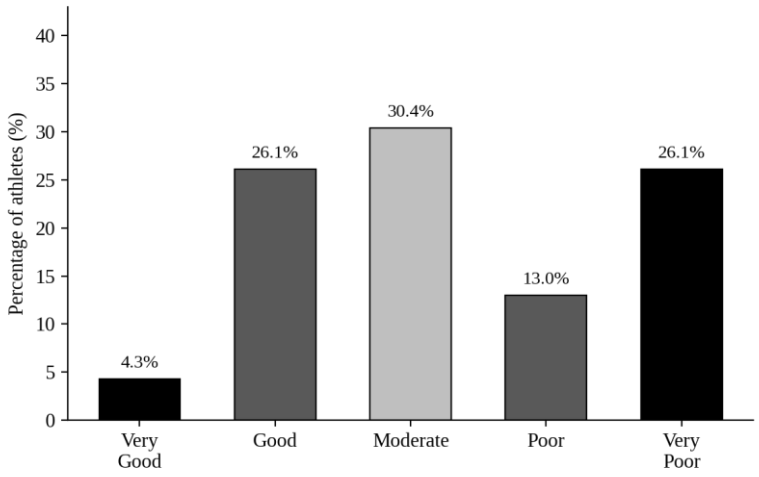

Figure 1. Distribution of serve-accuracy classification (N = 23). Source: original test data, this study.

Table 3. Frequency Distribution of Net-Drop Classification (N = 23)

Interval	f	%	Category
31–40	3	13.0	Very Good
21–30	8	34.8	Good
11–20	12	52.2	Moderate
0–10	0	0.0	Poor
Total	23	100.0	

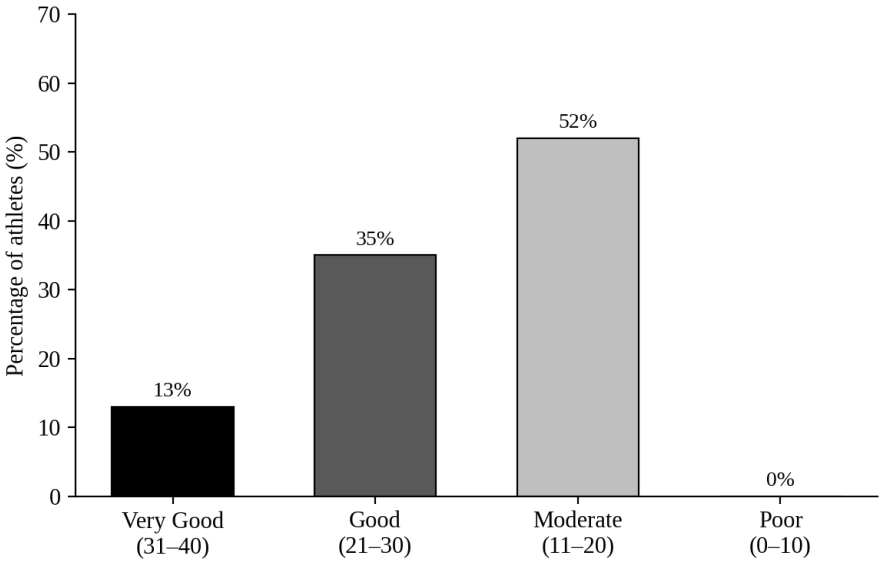

Figure 2. Distribution of net-drop classification (N = 23). Source: original test data, this study.

Table 4. Frequency Distribution of Smash-Accuracy Classification (N = 23)

Interval	f	%	Category
> 33	2	8.7	Very Good
24–32	7	30.4	Good
14–23	5	21.7	Moderate
4–13	9	39.1	Poor
< 4	0	0.0	Very Poor
Total	23	100.0	

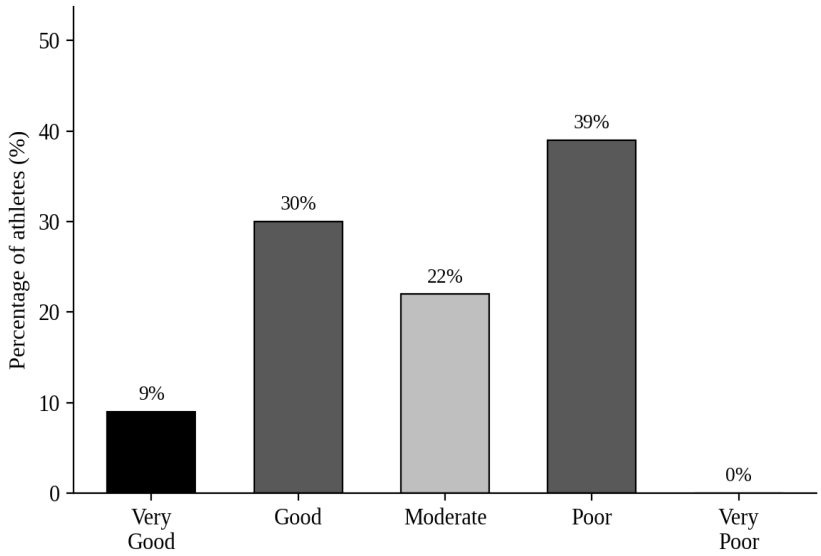

Figure 3. Distribution of smash-accuracy classification (N = 23). Source: original test data, this study.

Table 5. Frequency Distribution of Footwork Classification (N = 23)

Interval (s)	f	%	Category
< 13.90	1	4.3	Very Good
13.90–14.76	3	13.0	Good
14.76–15.63	1	4.3	Moderate
15.63–16.49	2	8.7	Poor
> 16.49	16	69.6	Very Poor
Total	23	100.0	

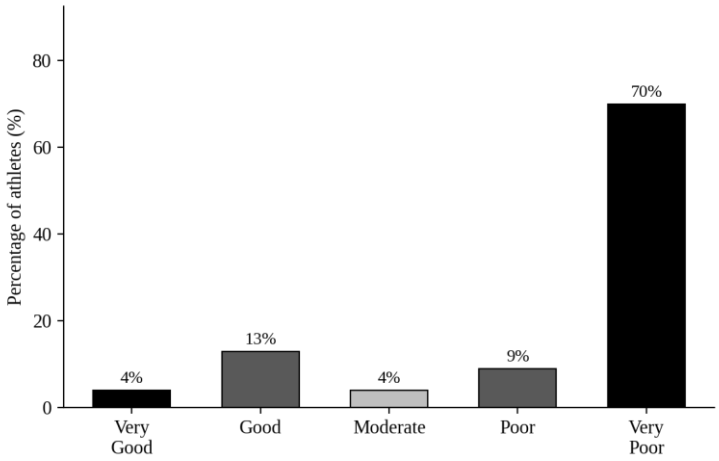

Figure 4. Distribution of footwork classification (N = 23). Source: original test data, this study.

After the mean scores for each technique are compared to one another (Table 6), a comparison of the interpretation of modal-categories in different ways will be seen if it is considered that the source thesis differs in one out of four categories. p> Serve accuracy (M=18.17/40, 45.4% of the maximum score) is interpreted as Moderate, not as Good; the net drop, whose accuracy is M=21.52, is regarded as Good, not as Moderate; and footwork with M = 18.14 seconds belongs to the Very Poor category, not to the Poor category. Smash categorisation as being Moderate and the norm for smash have both been based upon this sample's mean and its standard deviation so it is the latter norm only that is treated here as merely descriptive but not as a benchmarker against a criterion (Section 5.5).

Table 6. Corrected Modal Classification Compared with the Source Thesis

Technique	Sample M	Norm-band position	Corrected category
Serve	18.17 / 40 (45.4%)	41–60 band	Moderate
Net drop	21.52	21–30 band	Good
Smash	18.74	M ± 0.5 SD band	Moderate
Footwork	18.14 s	>16.49 s band	Very Poor

Correlational Structure Among Techniques

The Spearman rank correlations for the combination of the four methods can be found in Table 7. For racket skills which are: serving, net drop, and smash, there was a moderately to highly relationship (ρ =0.60.69, all p <0.01). Footwork was significantly correlated with smash (ρ =0.49, p =0.018, faster time means higher smash score) however; footwork wasnâ€™t correlated with serving (ρ =0.33, p =0.127) or net drop (ρ =0.33, p =0.121).

Table 7. Spearman Rank Correlations Among the Four Techniques

Pair	ρ	p
Serve–Net drop	0.64	<.01
Serve–Smash	0.60	<.01
Net drop–Smash	0.69	<.001
Serve–Footwork	−0.33	0.127
Net drop–Footwork	−0.33	0.121
Smash–Footwork	−0.49	0.018

Note. Footwork is scored in seconds (lower = better); negative correlations with footwork therefore indicate that better racket-skill scores are associated with faster (better) footwork times.

Age and Sex

Chronological age significantly influenced the performance of all four techniques as shown in Table 8: the older athletes generally got higher scores in serving, net-drop, and smashing, and had shorter (i.e., faster) footwork times. Chronological age explains 22-33% variation in technical performance (r^2 of each technique).

Table 8. Correlation Between Chronological Age and Each Technique

Technique	r (age)	p	r^2
Serve	0.55	0.006	0.31
Net drop	0.57	0.004	0.33
Smash	0.58	.0004	0.33
Footwork	−0.47	.0023	0.22

Boys (total 16) beat girls (total 7) on all four methods and differences in achievement were big (d = 1.10, 1.56), even though both genders were of nearly the same age. The boys' average age was 11.06 years (±2.62) and the girls' average age was 10.14 (±1.46)(U = 69.0, p =0.397).

Table 9. Sex Comparison on the Four Techniques

Technique	Boys M ± SD	Girls M ± SD	U	p	d
Serve	20.88 ± 8.79	12.00 ± 6.00	89.5	0.027	1.10
Net drop	24.12 ± 8.97	15.57 ± 2.76	91.0	0.021	1.11
Smash	22.50 ± 8.80	10.14 ± 4.98	97.5	0.006	1.56
Footwork (s)	16.95 ± 2.37	20.86 ± 3.78	22.0	0.025	−1.37

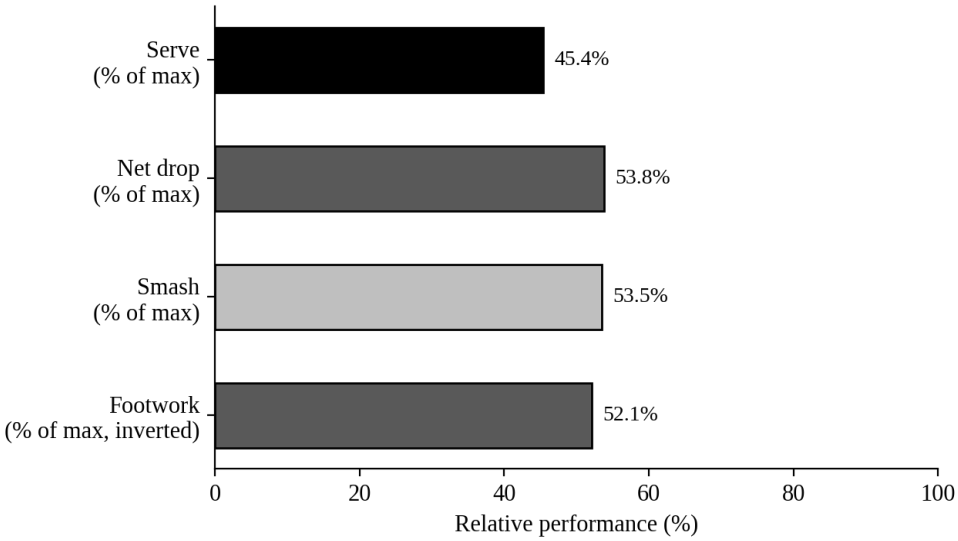

Figure 5. Relative performance profile across the four technical domains, expressed as a percentage of each instrument's own scale (footwork inverted so higher = better).
Source: original test data, this study.

When taken altogether, the findings from the descriptive statistical analysis, the correlation studies, and the comparison of results all seem to suggest the same pattern: racket skills are the most coherent cluster and the one with the strongest intercorrelations, footwork appears to be somewhat dissociated from it and overall footwork is the least effective skill domain, and gender differences at all ages are big and very consistent across all four techniques.

After profiling serve and net-drop skills, smash, and footwork in a group of 23 young beginner badminton players, the research analyzed these skills' relationships with each other, sex and maturity. Three major results support the discussion: (1) Racket skills constitute a moderately-to-strongly intercorrelated cluster while footwork was dissociated from the cluster; (2) in comparison, footwork was the weakest-performing domain where more than two-thirds of the athletes were in the lowest normative band; and (3) sex differences were very large among the four domains independent of age. Each is discussed in turn below, alongside its practical and academic implications. Because empirical work on badminton beginners specifically remains scarce, the sections below situate these results primarily against the local coaching-science literature (e.g., Nasri et al., 2019; Edmizal et al., 2022; Nando & Wulandari, 2018) and the broader biomechanics and motor-

development literature (e.g., Kuntze et al., 2010; Lam et al., 2018, 2020; Zheng et al., 2022; Hrysomallis, 2011), while acknowledging that a larger comparative base specific to youth badminton is still needed.

Serve Accuracy

Serve Accuracy on average was 45.4% of the maximum score. When the sample mean was compared to the instruments' own categorical table the class was placed in the moderate normative band, this is a change from the good classification previously mentioned for this type of dataset. A value of 49.2% for the coefficient of variation shows that this average moderate level hides the big differences at a personal level: a few athletes approached the very good band while an equal number went to the very poor one. Serve Skill in badminton is tied together with local coaching science publications, to eye, hand coordination and explosive power of the arm-muscles (Nasri et al., 2019), both of these continue to develop up to the age-range in our study. Anatomical and biomechanical analyses of the badminton serve motion similarly point to sequential shoulder-wrist coordination as the primary determinant of placement accuracy (Wijaksana, 2018). The moderate correlation between age and serve score in our data ($r = 0.55$, $p = 0.006$), thus, can be quite reasonably considered as consistent. In badminton, serve is the only stroke that can be done without direct interaction between player and opponent. So it is the stroke that can best be practiced in a closed-skill, high-repetition drilling situation. The wide variation that was noted here suggests that volume of practice alone might not result in equal outcomes for this cohort and drills differentiated by level of current skill, as opposed to uniform group instruction, could be more effective for getting the best out of each student.

Net-Drop Accuracy

The average net drop score was 21.52 out of 40. In terms of classification this cohort falls in the "Good" band which was a correction from initially reported "Moderate". Net play from the mechanical point of view differs to a smash. Whereas force generation is a key factor in the smash, regulation of racket swing amplitude together with racket-face angle are more important in net drop. Small force variations result in the shuttle being struck too high, which in turn leads to an attack from the opponent. The moderate-to-strong correlation found here between net drop and smash scores ($\rho = 0.69$, $p < .001$) and between net drop and serve scores ($\rho = 0.64$, $p < .01$) further supports the idea that, for this beginner cohort, net play is more of general racket skill than a specialised one. It seems likely that factors like grip control, a good awareness of racket-face and a history of practice may explain the shared elements rather than it being a skill unique to net play due to fine-motor specialisation. The pattern observed here would naturally change with continued training since elite players demonstrate more separation between touch-based net skills and power-based rear-court skills (Phomsoupha & Laffaye, 2015); the present group of players' beginner level seems a plausible reason for not having such a differentiation here.

Smash Accuracy

Smash accuracy averaged 18.74 out of 50, putting it just in the Moderate category under the normalization used here. But the normalization had itself been determined by this very data, the mean score plus-minus 0.5 SD defining the Moderate band of the norm. That makes the standard categories only partly reliable, a sample's center of gravity tends to be in the middle of a segment whose center of gravity is the same. The classification is in reality a description of the sample's internal distribution, not a benchmark against a standard elite/population norm. Considering raw variation separately, however, smash showed the highest, not the lowest, dispersion among the four measures: its coefficient of variation was 51.6%, the highest of the four techniques, which indicates that smash proficiency is the skill most unevenly distributed in this sample. The way in which smash accuracy is determined is through the coordinated force transfer of the trunk, shoulder, and wrist, which often has been described in biomechanical terms as X-factor or whip-like movement in highly skilled players (Zhang et al., 2016). That sequence itself is what most of the time requires a significant training history to fully internalize. The strong positive relation between age and smashing ($r = 0.58$, $p = 0.004$) in the data suggests this is a developmental story. The strong connection between smash and net drop ($\rho = 0.69$) is a further indication that a general racket-proficiency factor is the common basis at this stage, rather than specialisation of any one technique.

Footwork

Footwork ranked the least successful area relatively: 69.6% of the athletes ended up in the lowest band of the norms whereas 26.1% the serve, 0% the net drop, and 0% the smash, respectively in their lowest bands fell. Footwork is a physical ability that underlies the game of badminton. On-court mobility is a factor that determines if a player is able to physically reach the shuttle and maintain control of the racket with time, balance and precision to perform the required racket skill (Malwanage et al., 2022). This is consistent with broader sport-science evidence that balance ability itself predicts athletic performance across sports (Hrysomallis, 2011). Research on the biomechanics of badminton lunge which is a basic foot movement

reveals that unskilled players are more susceptible to a longer ground-contact period and a less efficient loading pattern at different body joint levels than skilled players (Lam et al., 2018; Kuntze et al., 2010), which supports the idea of relatively poor footwork performance of this beginner group. The good news is that the weakness in footwork is usually not irrecoverable: an eight-week balance-training exercise program embedded in the regular training reduced the badminton-related launch-off period by 19-36% in the experimental group of adolescent competitive players versus a no-intervention control group (Malwanage et al., 2022). Shadow-badminton, ladder-drill, and reactive-agility methods, on the other hand, have been linked to footwork development in Indonesian university players (Nando & Wulandari, 2018; Mirfan et al., 2020). Footwork does not seem to be connected very much with serving and net drop as shown by the small correlations in footwork-serve (ρ =0.33, not significant), net drop (ρ =0.33, not significant), and smash (ρ =0.49, p =0.018). This means in a way that at the early development stage, footwork is considered to be a major component of the overall performance and a separate factor to the racket skills in terms of the quality of movement. Having great racket skills does not necessarily bring along great court movements for such beginner level players. Inversely, poor racket techniques does not always mean that their court movements are inadequate as well.

Integrative Interpretation: A Technical–Locomotor Dissociation

When viewed overall, the four techniques at skill level provide the evidence behind the primary pattern the study had in mind: racket skills (serve, net drop, smash) form a coherent cluster, correlating with each other at ρ =0.60 ρ =0.69 whereas footwork is significantly detached correlating only with smash but to a smaller extend (ρ = -0.49). This separation coexists with a difference in the levels of performance racket skills grouping mostly in the Moderate-to-Good range while footwork being heavily clustered in the Very Poor range such a combined pattern might best be explained as a skill locomotor dissociation, rather than as a uniformly weak beginner technique. Two explanations can be made. First, badminton coaching in clubs and academies often focus on strokes' technique by using static or mildly served drills which improve racket competence without actually preparing for multidirectional, high-intensity movement patterns that footwork measures instrument (Kuntze et al., 2010; Valldecabres et al., 2020); if a large part of training time is given for repeating strokes, a hand leg discrepancy as the one we saw here can indeed be an expected consequence and not a surprising one. Second, the eight-minute test time format chosen to assess footwork is a whole-body coordination and conditioning factor which is absent from the racket skill tests that are mainly carried out from a stationary or lightly loaded base; a starter athlete can thus rack up massive racket repetition while very little locominator demand is captured by the footwork test, in proportion.

Sex Differences

The boys significantly outperformed the young girls across four technical areas by large margins with the difference being d = 1.10, 1.56 which did not arise due to any age difference between the sexes (p =0.397). This result is almost entirely in line with child development literature in general: A systematic review and meta-analysis of fundamental motor-skills proficiency in children aged 3, 6 years concluded girls have significantly smaller object-control skill set in comparison to boys, and the gap was growing as time passed (Zheng et al., 2022). Since object-control skills, catching, striking, and manipulating an implement, align more closely (from a conceptual standpoint) to badminton's racket-handling requirements rather than to its locomotor demands, the pattern of sex difference observed here (present across both racket skills and footwork, though numerically largest for smash) brings this general finding back to a sport-specific, slightly older demographic. There are, however, two things that one has to keep in mind when one interprets the above results. First, given the tiny number of girls (only 7) as against boys (16 who, on average, were younger as per an insignificant age comparison even so), we cannot fully rule out that some unmeasured factors such as one child's exposure to training/learning, motivation etc., may contribute, if anything, to a residual confounding, at least on this small a sample. For example, the girls might differ slightly from the boys even more than the boys from the girls in a way that a child's behavior depends on their parents' expectations and thus the way they raise their children is influenced by the child's gender (the so-called "gender schemas"). So it is entirely possible that differences in training habits between boys and girls (a boy's first day of formal training was earlier and a boy practices more often at a junior academy) that were not captured and represent a possible and/or alternative explanation to a purely developmental one; the authors cannot make a distinction between a maturational vs. a practice-exposure explanation, and most likely both are involved.

Practical Implications for Coaches

There are three main outcomes that result from these results. First, since footwork was the weakest area and at the same time footwork is the area shown elsewhere to be highly responsive to targeted, time-limited intervention (Malwanage et al., 2022), coaches working with similar beginner groups should think about giving priority to footwork and multidirectional agility sessions shadow badminton, ladder drills, reactive

cone drills instead of splitting the practice time equally among the four skills. This makes particularly good sense since the racket skills in this cohort were already correlated with one another and getting better together. Game-based formats adapted for this age group, such as structured shuttlecock-throwing games shown to improve stroke development in 10–12-year-old beginners (Kusumawati, 2017), may offer a way to combine general racket-control practice with the engagement needed to sustain young athletes' motivation. The next insight is the fact that all the different techniques of racket use were basically grouped together without showing specific differences for each technique, a training block focused solely on general racket control (grip, swing path, timing of stroke) should be able to bring about improvements in serve, net shot and smash at the same time in beginners. It would be the same as having each stroke treated as completely separate but practice-time efficiency would definitely favor combining and improving general racket control through this way of training. Lastly, the differences in ability and performance according to sex and age reported in this work raise questions about using the same set of criteria for group drills involving a mixed sex and age group without taking individual capability into account such a setup could leave some athletes under-challenged while others are over-challenged at the same time. It is therefore proposed that instead of a one-size-fits-all set of criteria for progression (pass/fail thresholds) individualized or tiered progression criteria should be used, which would better facilitate practice in a group with such a high degree of internal diversity (CV = 18-52% across techniques).

Academic Implications and Future Directions

On the matter of sport-science research, these results strongly point towards presenting beginner technical assessment reports by means of joint, correlated profiles instead of separate percentages. The reason lies in the fact it is the interrelations rather than the individual mean values that convey useful information on the distribution of training (or lack thereof) with respect to different skill areas. In the case of beginner-level badminton studies, the use of population-based standards instead of internally derived norms like the circular-smash classification as utilized in the present paper will definitely improve the comparability of studies done in different academies and countries.

Limitations

These findings are subject to several caveats. Firstly, as it is cross-sectional in nature and mainly descriptive, one will only get a picture of a correlation between the different skills and their possible age dependency but not any cause-effect relation. Besides, one will not see if and why footwork coaching really can help to obtain better rackets skill scores, because only the two factors' statistical relationship is revealed. Secondly, the chronological age range of subjects for the sample (N = 23) varied from 7, 16 years, and chronological age used throughout as a surrogate of developmental status because no independent measure of a biological maturation indicator as peak height velocity of age was collected, so the results on age should be taken into account with this reservation. Thirdly, the smash normative categories used to assess individual's athletic skill were based on the sample's own mean and standard deviation. This has two consequences: one, the athlete who is close to the category's boundary is more likely to be put in the higher or the lower one if the classification is based partly on the sample's statistics of smash only; two the classification does not reflect the athlete's skill level, only the relative differences in the sample in skill level. Besides, fourthly, only one testing session was arranged on two days in a row, no repeat test for each session or test-retest reliability check within the subjects. Single-occasion field testing is frequently used in exploratory coaching science studies but can be affected by variations due to fatigue, low motivation, or being a new to the protocol, more so than a multi-session design. Fifthly, there was a disparity in the size of the two groups used for comparing genders, (16 boys, 7 girls), the difference in the group sizes would impact the accuracy of the estimated effect sizes and our confidence in the conclusion of being able to control for the confounding influence of differing training history between the sexes at the unmeasured level. Sixthly, the whole cohort was the one academy only in one city, so, limitations in extending these findings beyond this population of novice players with different coaching, facilities, selection processes, etc., are considerable. And seventh, just one of the net-drop scores (43) was higher than the 40-point ceiling that the norms of the scale for classification were based on. This may have meant the result was a scoring-zone value that the test wasn't documented to capture at all, or the data got corrupted when it was entered into the database (a transcription error). Since no changes were made to the original scores themselves, the data was kept, but this case should be cross-checked against the original test protocol, if this dataset is planned to be used further, or a new test should be conducted before the dataset is used. Eighthly, formal reliability coefficients (e.g., Cronbach's alpha, test-retest or inter-rater ICC) were not computed for any of the four field instruments in the present sample; the instruments were adopted from precedent coaching-science protocols rather than independently validated here, which limits confidence in the precision of individual scores. Ninthly, the fixed total-sampled cohort (N = 23) was not preceded by an a priori power analysis, and unmeasured confounds such as prior practice volume, coaching

quality, and out-of-academy training exposure were not recorded; these could plausibly explain part of the observed age, sex, and skill-cluster patterns and should be measured directly in future work.

Conclusions

This study involved 23 adolescent novice badminton players and addressed the three objectives set out in the Introduction. In relation to Objectives 1 and 2, serve, net drop, and smash were moderately-to-strongly intercorrelated (ρ = 0.60–0.69), forming a coherent racket-skill cluster, whereas footwork was the weakest-performing domain and was only weakly-to-moderately correlated with the racket skills (strongest with smash, ρ = -0.49), indicating a measurable dissociation between racket-handling and locomotor proficiency at this developmental stage. In relation to Objective 3, boys outperformed girls on all four technical measures (d = 1.10–1.56), a difference that was not attributable to age, since the two sex groups did not differ significantly in age (p = 0.397). This dichotomy between technique and locomotor skills is an aspect that needs recognition in order to decide the best manner of allocating training time to these types of introductory sport programs: the lack of footwork and the ability to perform quick changes of direction at various angles seems to be the main limitation preventing these players from being ready for competitive play. However, prior interventional evidence indicates that such constraints are responsive to targeted, time-limited training, such as the eight-week balance-training programme shown to reduce badminton launch-off time by 19–36% in adolescent players (Malwanage et al., 2022), suggesting that a similarly structured, short-term footwork and multidirectional-agility block, rather than generic conditioning, is the more specific recommendation for beginner programmes.

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