Statistical Analysis of Badminton Three-Zone Lunge: Training versus Singles

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***Abstract*—Proper footwork with good lunge motion skills is an important element for high performance in badminton. Various researchers reported on the kinematic parameters to optimize lunge performance. However, there is a limited study on the difference in lunge performance during training and in singles. This research aims to study the lunge motion between the university and national level players in training compared to singles at three-zone lunge: Left-Forward (LF), Center-Forward (CF), and Right-Forward (RF). Video captures of experiments between six university-level players and a Malaysian national-level player on lunge training and singles simulation were considered. The badminton performance metrics were the step forward and perform time of lunging. The paired sample t-test and one-way Analysis of Variance (ANOVA) statistical analysis were used to evaluate the within-group (comparing same players' level) and the between-group approach (comparing different players' level) on 95% confidence level ($p < 0.05$). Findings showed that the university players' lunge training has no effect in the singles at RF zone, while the national players showed more consistent performances in three-zone lunges during training; as good as it does in the singles.**

***Index Terms*—Badminton; Data Analysis; Lunge Performance; Video Analysis**

I. INTRODUCTION

Badminton is one of the most popular racket sports [1] contested in tournaments and for recreational leisure activity [2]. The fundamental aspects of the game are the mastery of effective footwork and lunging along with the accuracy in anticipating the opponent's shot. Improper technique in badminton results in poor game performances and injury risks on the knee and shoulders. Badminton's performance is usually judged based on stable footwork and lunge posture aside from the scoring system. Similar to other racket sports like tennis or squash, badminton game requires quick directional changes, rapid arm movements and a wide variety of postural positions [3].

Past research on badminton biomechanics was to improve the athletes' performance and to reduce the risk of sports injury [4-11]. Previous works did not consider the possibility of lunge performance deviation in actual games from training condition. No study has compared the players' performances in a controlled experiment during training with the actual games.

This study bridges the knowledge gap by comparing the lunge performance of the university and national level badminton players in three-zone lunge: left-forward (LF), center-forward (CF), and right-forward (RF) for simulation training and in singles. The goal is mainly to assess the players' performances in singles considering the possibility of deviation from the training zones. We hypothesized that there is no significant difference between the university and national level players. Six university players were tasked to perform lunges at LF, CF, and RF zones and play spontaneously in the badminton singles. For benchmarking, badminton lunge training video and singles tournament of a Malaysian national-level player were retrieved from the public domain database. The lunging step forward and perform time at LF, CF, and RF were statistically assessed on mean differences for the within-group (university/national), and between the group analysis (training/singles).

This paper is organized into eight sections. Section II presents the state-of-the-art review of badminton game research. Section III discusses the study methodology. Section IV and V further explain the experimental setup and design as well as the data analysis respectively. Section VI and Section VII present the results and discussion. Finally, the concluding remark is presented in Section VIII.

II. LITERATURE REVIEW

Earlier works in badminton game were mostly related to players' kinematics such as the velocity, acceleration of players and shuttlecock and the kinetics context such as the ground reaction force. For instance, Sasaki et al. [4] and Nagano et al. [5] studied the trunk acceleration properties.

Abas et al. [12] investigated kinematics parameters including the racket head, shoulder, joint and shuttlecock velocity in badminton games. Recent works encompassed beyond sports sciences discipline to include the clinical biomechanics, nutrition, psychology, and data analysis perspectives. More reported works were on the experimental basis [6-10] while others involved simulation works [13-14].

Badminton game was favorably analyzed from the data analysis standpoints [4-5]. Atar [6] investigated the statistically significant and insignificant differences observed for the static and dynamic balance parameters respectively between the tennis and badminton players. Yu [15] studied the statistically significant difference between badminton amateurs and athletes in footwork ground reaction force.

Low et al. [16] investigated the developmental factors of Malaysian elite youth badminton players on the players' accumulated hours spent in structured and unstructured badminton practice via statistical analysis.

The footwork skills are imperative to effectively execute a shot and return to the base position in preparation for the next shot. The importance of lunging skills was notable as the lunge motion accounts for 15% of all movement in the singles game [11]. Substantial research works had put emphasis on

footwork skills as well as specific lunge motion at different corners of the badminton court.

Previous works investigated lunging on one (right-forward) [7], three (left, front, and right-forward) [8] and four (left-forward, right-forward, left-backward, and right-backward) [9] directions. Lin et al. [10] found that the 3-step forward footwork was significantly faster than the 2-step footwork movement in step forward duration time and perform time.

Mei et al. [7] reported a significant difference ($p < 0.05$) in lower extremity kinematics and foot loading stance during landing between the elite and recreational players for the right-forward lunging steps. Hu et al. [8] showed higher plantar load over the left-forward and right-forward lunge as compared to the front-forward lunge. Hong et al. [9] reported a higher ground reaction force generated during foot loading in the left-forward lunge, indicating the critical maneuver for biomechanics skills.

From the basis of lunging performance, the main concern was in the kinetics parameters such as the ground reaction force to address injury risks. However, the existing studies had mainly focused on the controlled experimental environment without considering the possibility of performance deviation between the experimental (training condition) and the actual game.

III. Methodology

There were two case studies involving the experimentally captured data and the public domain videos on badminton training and singles. The lunge motion videos at three identified zones, LF, CF, and RF as detailed in Section IV from both cases studies were extracted. Adobe Photoshop CS6 software was used to extract images frame-by-frame from the video files. The step forward time and perform time from the lunge movement were evaluated by the frame rate.

Potential missing values and outliers identified through boxplots were removed. Data normality was screened with Shapiro-Wilk test and visual inspection on Q-Q plot.

Different statistical tests (paired sample t-test, ANOVA and Welch's ANOVA) were applied to assess the comparison of means within-group (university and national players) and between-group (university versus national players). The statistical analysis was conducted with IBM SPSS Statistics V22.0. The research framework is depicted in Figure 1.

IV. Experimental Design

A. *Case Study 1*

The badminton training and singles were experimentally captured in a badminton court of Azman Hashim USM Sports Arena, Universiti Sains Malaysia (USM) Main Campus on 22 June 2017. Six right-handed university level badminton players (3 males, 3 females, 22.67±1.51 years old, 1.68±0.08 m, 58.96±9.29 kg) representing USM with at least five years' experience in badminton game were included in the study. Prior permission was obtained from the Sports and Recreation Center, USM. All players were informed about the experimental procedures and were asked to provide their consents to participate in the experiment.

The players undergo lunge motion training and singles game simulation. The experiments were conducted in two sessions of the day, i.e. training (in the morning) and singles (in the afternoon). The recording system consisted of five cameras; 4K Ultra HD Sports Camera, Nikon D7000, Nikon D3100, Samsung S7 Edge camera and Xiaomi Mi3 camera to record the lunge motions from different angles.

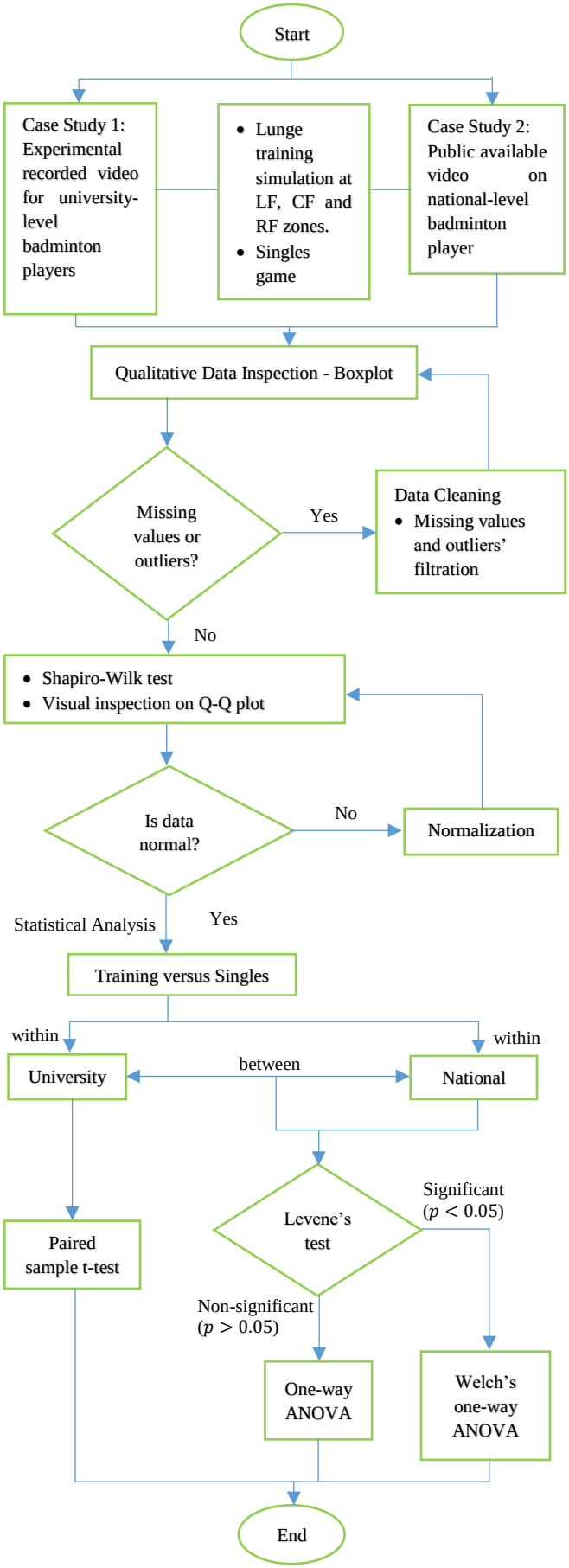


Figure 1: Research framework

In training, three equal sizes lunge zones (1.2×1.2 m) were marked on the badminton court, identified as left-forward (LF), center-forward (CF), and right-forward (RF) zones. Figure 2 shows the experimental setup with lunge zones and back zones representing the starting positions. Shuttlecocks were consistently thrown/hit to each lunge zones for three times from the opposite half court. The University players were required to perform lunges from the start position (left back zone for CF and RF, right back zone for LF and to strike the shuttlecock received at the lunge zones position across the net (Figure 2). Upon striking, players were required to return to the start position. The lunge for each zone was performed for three repetitions before proceeding to the next zone. In badminton singles, one set of the standard scoring system of 21 points game was captured. The natural spontaneous lunge motions were studied in the singles without specific restrictions given.

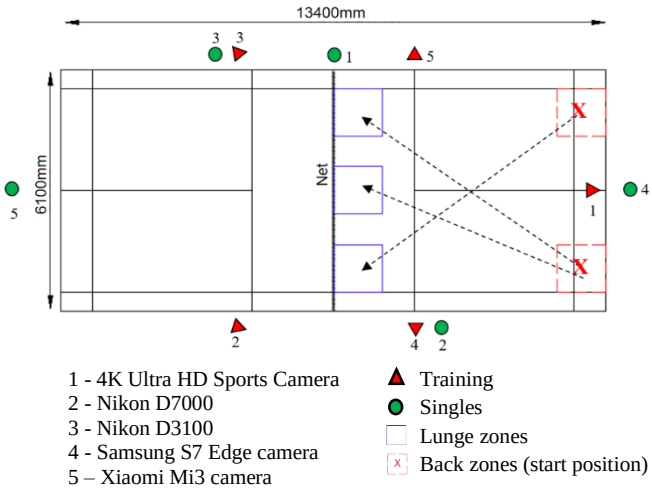


Figure 2: Experimental setup illustration

B. Case Study 2

The second case study was acquired from the public domain databases of the badminton footwork training [17] and singles recorded during the 2017 Hong Kong Super Series tournament [18]. The purpose is to set a benchmark database to compare with the experimental data analyses for verification purpose.

The video data collected involved a Malaysian professional badminton singles player at the national level (male, 35 years old, 1.72 m, 68 kg). The specific player was selected for his excellent worldwide record in the singles tournaments, therefore, he is the best badminton performance baseline model for this study. The data retrieval was in accordance with the similar lunge simulation training and singles as designed in Case Study 1. In the footwork training video [17], the camera was placed outside the court behind the player for recording the lunge motion. In [18], the top view of the whole court during the badminton match was captured. The lunge motions at LF, CF, and RF zones matching the experimental design of Case Study 1 were retrieved.

V. DATA ANALYSIS

The video processing began with extracting the relevant features of lunge motions performed at LF, CF, and RF zones from the case studies. The video segments were transformed into discrete image sequences using the Adobe Photoshop CS6 at 29.97 fps following the US National Television Systems Committee (NTSC) standard for each video segment. This frame rate was considered sufficient to view an image sequence containing a player's lunge posture changes smoothly at continual time points to complete the video frame capturing. According to Thomas [19], the human eye requires a minimum of 24 fps rate for smooth-looking images though, at 30 fps, the videos appear more natural. Teeple et al. [20] had also used the standard of 29.97 fps to study the temporal accuracy of the human motion capture systems.

In this study, two temporal information was extracted from image sequences; step forward and perform time measured using frame-to-frame approach for university and national player during training and singles (averaged for the university players) lunge performance analysis. Table 1 describes the study attributes and its characteristics.

Table 1
Description of Study Attributes

Attribute	Description	Scale	Range
Lunge zone	Pre-identified square-sized (1.2×1.2 m) position where the shuttlecocks were delivered into from the opposite half court.	Nominal	{LF, CF, RF}
Players' level	Experimental treatment (by skill level in badminton game performance) on the different subject group in the same condition (either training or singles).	Nominal	{University, National}
Condition	Experimental treatment (by training or singles design) on the same subject group (either university or national level) for within-group analysis.	Nominal	{Training, Singles}
Step forward time	Time beginning from the ready position when a foot lifted off the ground until the moment the heel of the dominant foot touches the lunge zone (in seconds).	Numeric	[0.567, 1.802]
Perform time	The period of time when the player begins lifting one foot off the ground until the shuttlecock is stricken (in seconds).	Numeric	[0.667, 1.913]

The time parameters were statistically assessed on the mean differences of the step forward and perform time for the within-group (university/national) and between group analysis (training/singles). The respective experimental treatments were the condition {training, singles} and the players' level {university, national}. The main study hypothesis was that there is no significant difference between the university and national level players. Paired sample t-test was performed to establish the significant level of differences for the within university players: training versus singles.

On the other hand, one-way analysis of variance (ANOVA) was performed for the within national player: training versus singles and for between-group analysis: university versus national players. Three fundamental assumptions for ANOVA analysis were considered; independence of data, normality, and homogeneity of variance. The paired sample t-test was used to compare two sample data that are correlated (non-independence). On normality and homogeneity of variance checks, Shapiro-Wilk normality test and Levene's test were conducted. Welch's

ANOVA test was performed when the data violates the homogeneity of variance assumption ($p < 0.05$ on the Levene's test). All statistical analysis was conducted using IBM SPSS Statistics V22.0 tool, with the significance level of $p < 0.05$ for 95% confidence interval.

VI. RESULTS

Pearson correlation coefficients, r were computed between the step forward time and perform time for training and singles at three zones, LF, CF, and RF as shown in Table 2. Table 2 reports strong correlations ($r > 0.900$) for all training and singles at all zones except for the national player's training at RF zone indicating moderate correlation ($r = 0.576$).

Table 2
Correlation Coefficient Values between the Step Forward and Perform Time

Zone	University		National	
	Training	Singles	Training	Singles
LF	0.960 ($n = 6$)	0.945 ($n = 6$)	N/A ($n = 2$)	0.979 ($n = 5$)
CF	0.975 ($n = 6$)	0.927 ($n = 6$)	0.949 ($n = 10$)	0.925 ($n = 20$)
RF	0.902 ($n = 6$)	0.941 ($n = 6$)	0.576 ($n = 4$)	0.965 ($n = 10$)

(sample size, n)

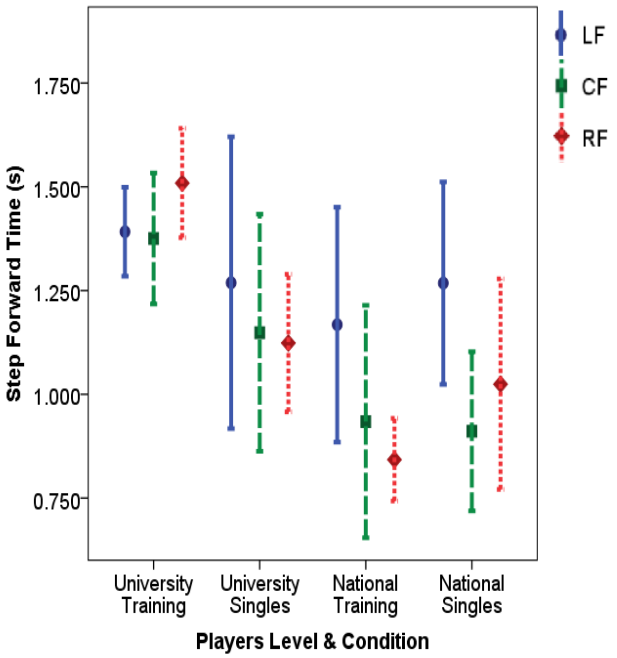
The data analyses results were subjected to statistical paired t-test and one-way ANOVA to establish the level of differences in the step forward and (perform time) at LF, CF, and RF zones for the within and between the university and national players during the training versus singles conditions. As observed in Figure 3, the lunge motions in university players during the training at three zones were mainly consistent, accompanied by little variations of standard deviation not exceeding 0.158 s (0.178 s). During the singles, the university players showed a greater variation in the step forward and perform time, greater standard deviations (0.352 s (0.367 s)) at LF zone compared to the training.

As for the national player, the lunge motions' variation for training versus singles were almost similar in terms of time parameters (difference in standard deviation not exceeding 0.088 s (0.091 s)), with an exception for a step forward time at RF zone (0.154 s difference in standard deviation).

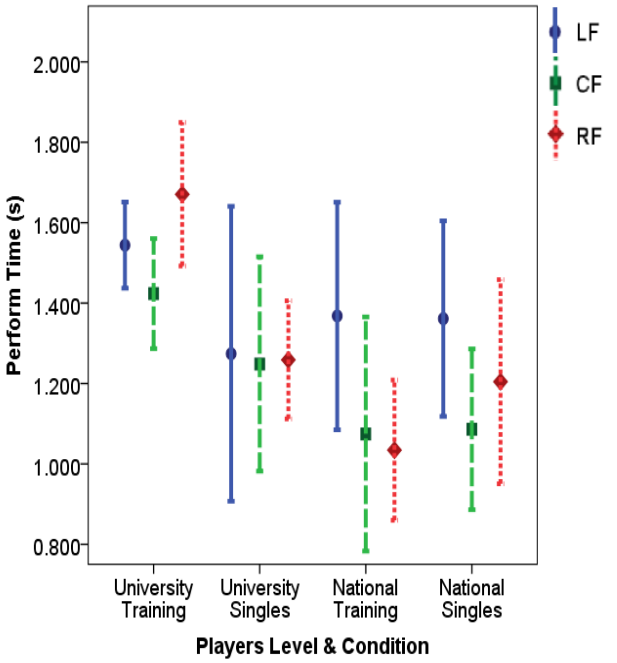
On statistical significances for university players, the training versus singles showed no significant differences in the step forward and perform time ($p > 0.05$) in all zones except for RF ($p = 0.011^{*}(0.010^{*}) < 0.05$) as indicated in Table 3. It can be deduced that the training session for RF zone does not give much impact on the actual game performance for the university players.

Similar comparative statistical significances of differences performed were acquired within the national players, on the training versus singles. There were no statistically significant differences observed in step forward and perform time for all three zones ($p > 0.05$). Apparently, the national players' training session reflects similar performance in the singles.

As for the training mode between the university and national players, both the step forward and perform time were significantly different at CF and RF zones ($p = 0.003^{*}(0.016^{*}) < 0.05$) and ($p = 0.00003^{*}(0.0005^{*}) < 0.05$) respectively as shown in Table 3.



(a)



(b)

Figure 3: Error bar for (a) step forward and (b) perform time, mean ± standard deviation, ($\bar{x} \pm \sigma$)

Table 3
Statistical Significant Results: Comparison of Means between Group for Step Forward and (Perform Time)

	Singles		Zone	University		
	University	National		Training	Singles	
Training	0.453 (0.174) $r = 0.924$	0.655 (0.976) $r = 0.960$	LF	0.459 (0.537) $r = 0.982$	0.996 (0.660) $r = 0.943$	National
	0.233 (0.328) $r = 0.947$	0.790 (0.898) $r = 0.934$	CF	0.003* (0.016*) $r = 0.964$	0.026* (0.119) $r = 0.927$	
	0.011* (0.010*) $r = 0.966$	0.197 (0.247) $r = 0.931$	RF	0.00003* (0.0005*) $r = 0.960$	0.410 (0.642) $r = 0.956$	

*Significant at $p < 0.05^{*}$

In case of the singles, university versus national players showed a significant difference in a step forward time at CF ($p = 0.026^* < 0.05$), but lack of significant differences was shown for the perform time.

VII. Discussion

The study aimed at comparing the performance of university and national badminton players during training and in singles using tests of statistical significance. The performance indicators were the step forward and perform time evaluated from case study recorded videos.

The overall strong correlation reported between step forward and perform time attributes reflects that it may be possible to comprehensively assess either attribute itself to study statistical significances on players' performances in training and singles. The hypothesis which assumed that there is no significant difference in the between-group analysis (university versus national players) was rejected at CF and RF zones for training and at CF zone for singles. Nevertheless, within-group analysis for university players at the LF and CF zones and the national player in all zones (LF, CF, and RF), no significant difference was reported.

Literature had reported the correlation and statistical significances in badminton kinematics parameters instead of the step forward and perform time on three (left, front, and right-forward) [8] and four (left-forward, right-forward, left-backward, and right-backward) lunge directions [9]. Most studies have only focused on the controlled experimental design alone without considering the deviation of players' performances between the experimental and actual game. Bankosz et al. [21] assessed the simple reaction time of badminton players, which failed to reflect the actual performance time parameters during games.

This study has taken a step further towards assessing the players' performances in singles considering the possibility of deviations (significant differences) from the training condition. The paired sample t-test and one-way ANOVA differences in sample means were observed in training versus singles mainly for the within-group (university and national players) and between-group (university versus national players) (Table 3). The reason to employ within-group approach (comparing same players' level) was to verify if players' performance in training reflects the performance in the singles as further discussed in Section (VII. A). On the other hand, the between-group approach (comparing different players' level) was to investigate if there is a significant difference in performance by skill level (Section VII. B).

A. Training versus Singles

Strong correlations between step forward and perform time ($r > 0.900$) were observed for both national and university players at all three zones in training versus singles as shown in Table 3. This explains that either the step forward and perform time is sufficiently representative to establish a test of statistical significant difference for the training versus singles. In fact, the perform time may be a better reflection on the players' ability to perform an effective shot (as quickly as possible) to return the shuttlecock successfully across the net.

Findings from Figure 3 showed that the step forward and perform time for university players were longer for the training compared to the singles at all three zones (by 9.7% (21.2%) at LF, by 19.8% (14.0%) at CF, by 34.3% (32.7%) at RF), but the difference was only found statistically significant at RF ($p = 0.011^*(0.010^*) < 0.05$) (Table 3). Comparing by lunge zones for the university training, the step forward and perform time at RF were the longest (1.509 s (1.671 s) as compared to LF (1.392 s (1.544 s)) and CF (1.375 s (1.424 s)) but showed shortest (1.124 s (1.259 s)) for the singles (Figure 3). This effect tallies the significant difference observed between training versus singles at RF.

On the other hand, there were no significant differences observed for the national players between step forward and perform time in all three zones ($p > 0.05$). An important finding is that the national players' training enhances competitive proficiency, as statistically shown and reflected in their singles.

B. University versus National

The main significant effects were only reflected in both the step forward and perform time between the university and national players' training at RF and CF zones, while only for the step forward time in the singles at CF zone. The strong correlation between step forward and perform time in training at CF ($r = 0.964$) and RF ($r = 0.960$) explained the consistency of the parameters in RF and CF for university versus national players (Table 3). As per expectations from the high correlation findings, the step forward or perform time shall yield similar statistical significant differences.

In training, the national and university players differ significantly ($p < 0.05^*$) for the step forward and perform time (Table 3). There were significant effects for the time attributes indicating national player lunged quicker than the university players at CF (by 32.1% (24.5%) shorter) and RF zones (by 44.2% (38.1%) shorter) (Figure 3). The national player engaged in a more structured and centralized training program with the Badminton Association of Malaysia (BAM) and the National Sports Institute of Malaysia as compared to the university players [16, 22-23].

In singles, statistical significant contradictions between step forward and perform time were observed at CF zone for national versus university players despite having a strong correlation ($r = 0.927$) (Table 3). From Figure 3, the differences in the step forward and perform time between national and university players were 0.238 s and 0.162 s respectively.

Apparently, in the singles, the national player showed a significantly much shorter step forward time ($p = 0.026^* < 0.05$) than university players, while no significant difference seen in the perform time ($p > 0.05$) as illustrated in Table 3 and Figure 3. An additional finding in [6] confirms that the national player is skillful in shuffling around the court corners (i.e. LF and RF in this study) therefore showing greater lunge motions for these zones. Unfortunately, there is no direct benchmark found from any previous work other than the national player's professional achievement alone to support the finding that the national player was superior (quicker) in lunging at CF zone as compared to the university players.

VIII. Conclusion

This paper investigated the lunge performance metrics: the step forward and perform time of university and national-level badminton players in three-zone lunge: LF, CF, and RF in training and in singles. The comparison of within-subject training versus singles aims to verify the possibility of performance deviation in the singles from training, which had yet to be addressed by previous studies. The between-subject

comparison aims to highlight the university players' weaknesses by three-zone lunge direction with reference to the national player's skills.

Our findings show: (1) For within-subject comparisons, the significant difference was reported for university players at RF zone. Meanwhile, no significant difference was observed for the national player in within-group comparison. (2) For between-subject comparisons, significant differences were reflected in step forward and perform time at CF and RF zones for training, and in the step forward time at CF for singles.

The findings shall serve as a highlight on the weaknesses of university players at certain lunge direction. At the same time, this provides a guideline to instruct university players for footwork training skills with reference to the national player's skills.

Further research could account for other kinematic and kinetic parameters like ground reaction force, body joint velocity, and acceleration focusing on the lower body extremity to consider the lunge posture performances.

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