



Original Article

Progressive decrease in leg-power performance during a fatiguing badminton field test

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Abstract. [Purpose] This study aimed to evaluate the changes in leg-power generation that accompany competitive badminton, as simulated in a badminton field test (FT). [Participants and Methods] Fifteen male badminton players with 1–2 years of experience performed five repetitions of an FT involving rapid and randomly assigned shuttle-run movements between markers distributed around a badminton court. Repetitions were separated by a 1-minute rest period. Peak mechanical power, obtained from the serial vertical jump tests, was used to estimate fatigue and performance reduction. [Results] Decreases in distance and time were significantly different in each of the five FT repetitions while maintaining the same speed for the condition. The peak mechanical power and fatigue index significantly declined. The reduction in the peak mechanical power percentage (11.78–35.49%) was in the acceptable peak mechanical power range for each FT set. These results were confirmed by the significant increase in the participants' blood lactate concentration levels, the rating of perceived exertion, and heart rate. [Conclusion] Leg-power generation could gradually be decreased in badminton competition as indicated by a badminton field test.

Key words: Badminton field test, Peak mechanical power, Vertical jump

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INTRODUCTION

Limitations to maximal exercise can be both central and peripheral fatigue¹⁻³⁾. For periphery limitations, fatigue often occurs beyond the neuromuscular junction^{2, 4)}, and this type of fatigue is commonly associated with high-intensity, short-duration exercise, such as that occurs when participating in racquet sports. The literature review revealed that few studies have investigated the effects of fatigue on performance in racquet sports⁵⁻⁷⁾. In the present study, the experiment focused on the skeletal muscle fatigue that can occur in badminton players following repetitive, high-intensity exercise; specifically, it investigated reductions in peak quadriceps force generation during and following a badminton field simulation.

A primary difficulty of this type of research is the creation of opportunities to study fatigue under conditions that are reproducible and effective across a range of participants. While there are numerous laboratory-based tests of force generation and fatigue⁸⁻¹²⁾, they are sometimes seen to be lacking in content, face or ecological validity. It is very important that sport-specific movement patterns and speeds are used because, without such activities, the fatigue that has been induced is unlikely to reflect the fatigue that is encountered during an actual competition. Therefore, the present study used a sport-specific field test (FT) in the experiment¹³⁻¹⁵⁾ where the validity and reliability of that test were previously established¹⁶⁾.

Since badminton players rely heavily upon explosive movements, including sprinting, lunges, smash jumps, and rapid

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changes of direction^{17, 18}), most of which are driven by the legs, a primary source of neuromuscular fatigue would be predicted to occur within the lower limbs. To evaluate the progression of that type of fatigue, a vertical jump (VJ) test could replace laboratory-based measurements, since that type of test has been shown to provide both valid^{19, 20} and reliable data²¹. However, no study includes leg-power assessment in the badminton FT. Therefore, this study aims to develop a novel experimental protocol in which serial repetitions of a badminton FT with alternating VJ tests to assess progressive changes in the leg-power performance of badminton players.

PARTICIPANTS AND METHODS

Fifteen males, non-elite badminton players (age range: 18–25 years) were recruited from a tertiary student population at Gannan Normal University, China. The participants' mean \pm standard deviation (SD) for age, weight, height and body mass index were 20.2 ± 0.9 years, 63.2 ± 5.1 kg, 173.0 ± 4.1 cm and 20.9 ± 1.5 kg/m², respectively. All of them were the 5th level (from 9 levels) of the adult badminton. The mean \pm SD for the participants' experience with badminton training and competition was 1.3 ± 0.4 years. The required sample size was determined (power test), using data collected from a pilot investigation (N=10). Each participant provided a written informed consent prior to participating in the study, and the experiment proposal was approved by the Human Ethics Committees of Khon Kaen University (Thailand: HE602261) and Gannan Normal University (China: 2017001).

All the participants underwent a pre-activity screening and a physical fitness test. They also completed a health questionnaire and a physical activity questionnaire. Exclusion criteria included: joint or muscle dysfunction, heart disease, pulmonary disease, coronary artery disease, renal disease and diabetes, injury within the previous six months and smoking and alcohol consumption within the previous two weeks.

The badminton FT took place on half a badminton court. The participants began the FT at a centralised location from which rapid shuttle runs were randomly directed to each of eight fixed locations using orange traffic cones (left/right forecourt corner, left/right backcourt corner, left/right midcourt and fore/back midcourt) (Fig. 1).

At each location, the running direction was activated by the 8-light on the monitor in front of the net (ENLAN Footwork Auxiliary Trainer; Jinan Enlan Sports Co., Ltd., Tianjin, China), signifying that it had become the target (pacing indicated by an orange traffic cone) and that the test participants should move as rapidly as possible to touch the target, before rapidly returning to the starting position. This FT was a modified version of the procedure used by Chin et al.¹³), which was completed as five repetitions. Each set of the FT, the participants completed as many shuttle runs as possible until they decided to stop because of unbearable fatigue. Immediately after each set, a VJ test was performed. The rest period between the set was the same duration (1-minute recovery). Thus, while every participant experienced the same amount of fatigue, each of them took a different amount of time to feel fatigued. The running time in each set was recorded. However, every VJ was performed at the same point of fatigue. During each set of shuttle runs and at the end of each set, the participants' heart rate (HR) and rating of perceived exertion (RPE) were monitored and recorded.

Prior to beginning of the FT, the participants completed a standardised warm-up (trunk and leg stretching and jumping). During the five shuttle run repetitions, they also completed the VJ test, which consisted of six VJs (Fig. 2). Each VJ test consisted of three jumps, and the best score was recorded. The first VJ test was con-

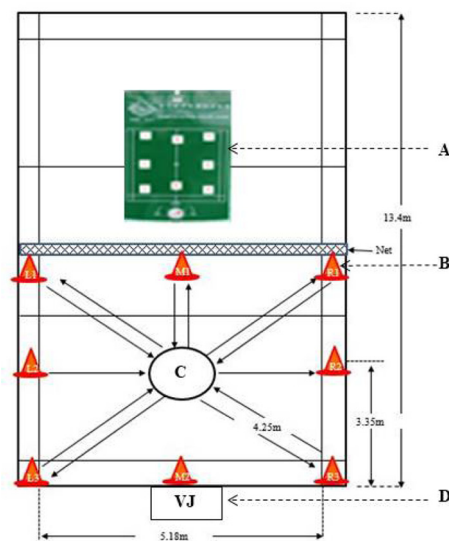


Fig. 1. The badminton field test with A: the badminton footwork auxiliary trainer; B: eight fixed locations (left/right forecourt corner, left/right backcourt corner, left/right midcourt and fore/back midcourt); C: starting position; D: vertical jump test point.

WU	FT1	R	FT2	R	FT3	R	FT4	R	FT5
VJ	VJ	RPE	VJ	RPE	VJ	RPE	VJ	RPE	VJ
BL	RPE	HR	RPE	HR	RPE	HR	RPE	HR	BL
RPE	HR		HR		HR		HR		RPE
HR			HR		HR		HR		HR

Fig. 2. The exercise-induced fatigue protocol. WU: warm-up; FT: modified field test; R: rest; VJ: vertical jump; BL: blood lactate; RPE: rating of perceived exertion; HR: heart rate.

ducted before the first shuttle run test each subsequent VJ test was conducted immediately after completion of each of the remaining test batteries (Fig. 2).

The test-retest reliability of the VJ test was determined prior to beginning the experiment (N=15; age: 20.2 years), with a resulting intraclass correlation coefficient (ICC) of 0.92 (95% CI 0.80–0.97, $p < 0.01$).

To evaluate the progression of fatigue, running performance, including total running distance, running time, movement speed and fatigue index (FI), were quantified. Running distance was derived from the total number of shuttles completed, along with the distance that each light was from the starting location. The running time was determined by the time it took to complete all the shuttles; each shuttle time was separately recorded, and the average running speed was determined from that data. The FI was computed for the running time in each shuttle run repetition (not including the rest or recovery time) using Equation 1, modified from previous studies^{22, 23}:

$$\text{Fatigue index} = \left(\frac{[\text{test-battery run time of FT2 (or FT3, FT4, FT5)}] - [\text{test-battery run time of FT1}]}{100 / [\text{test-battery run time of FT1}]} \right) \times 100 \quad (1)$$

The VJs were performed as maximal effort using the counter-movement technique with an arm swing^{11, 24}. The participants were instructed to keep both feet on the ground and to reach one arm as high as possible on a measuring scale mounted on a wall. They then placed both hands on their hips while bending their knees to a freely selected angle; they immediately attempted to jump as high as possible, touching the measuring scale on the wall. Their fingers were dipped into red ink, so this left a clear mark to record the height of the VJ, and to determine the vertical displacement. Peak power (PP) was calculated based on the method found in Sayers et al.²⁵; while that test was derived for a squat jump, it can be used with a counter-movement jump because the error of power estimation is $< 3\%$ ²⁵, as seen in Equation 2:

$$\text{Peak power} = (60.7 \times \text{jump height [cm]}) + (45.3 \times \text{body mass [kg]}) - 2,055 \text{ (W)} \quad (2)$$

The other parameter was the blood lactate (BL) concentration, which was measured from a fingertip blood sample (0.5 μL) using a portable blood lactic analyser (SensLab GmbH, Leipzig, Germany) before and after the FT. HR and RPE were monitored before and after each set of the FT battery tests. HR was measured with a polar watch and an HR sensor (S810i, Polar Electro Oy, Kempele, Finland). RPE was measured before and after each running set using a Borg scale ranging from 6 (no exertion) to 20 (maximal exertion). The Borg scale board was hung on the net in front of each participant, and he was asked to rate the RPE^{26, 27}.

All data were presented as mean \pm SD. Both the pre-test and post-test of VJ and RPE data were verified for normal distribution (Shapiro-Wilk test). Running and physical performance parameters which need to be examined only the differences among the sets of the FT (FT 1–5), one-way repeated measure of ANOVA was used however, RPE and HR which needed to be examined the differences between the Pre-Post-test among the FT1–5, two-way repeated measure of ANOVA with the Bonferroni post-hoc test was used. The level for statistical significance was set at $p < 0.05$. Analyses were performed using IBM® SPSS® Statistics version 23.0 (IBM Corp., 1 New Orchard Rd., Armonk, NY, USA).

RESULTS

Table 1 shows the results of all the parameters. For each running set, the participants could maintain the same speed (velocity). Both running distance time and FI progressively decreased in each of the post-test FT sets ($p < 0.001$); the results of running distance and time were found with significantly decrease from FT2 to FT5 in comparison to FT1. However, there were no significant differences in these parameters among the FT2 to FT5 results. The FI was drastically significantly increased for FT3 to FT5 in comparison to the FI for FT2. However, there were no significant differences among the results for these FT sets.

The averaged VJ height for the pre-test was 63.98 ± 5.04 cm; it was significantly decreased in each post-test FT set ($p < 0.001$); the Cohen's effect size was 5.64 (large effect size). When the VJ was calculated as the PP, the results also showed a progressive decrease after each FT set ($p < 0.01$). In terms of the percent of reduction, VJ% and PP% significantly increased in each FT set ($p < 0.01$). The levels of BL at the pre-test and post-test were 2.82 ± 1.12 mmol/L, and 16.07 ± 2.52 mmol/L respectively. Significant differences in BL were found before and after the FT (13.25; 95% CI 12.00 to 14.51, $p < 0.001$).

As seen in Table 2, the participants reported a significant increase in RPE from a score of 6 at the pre-test to a score ranging from 17 to 19 at the post-test for each of the running sets ($p < 0.01$). Similar results were reported for HR; there was a significant increase in HR from the pre-test to the post-test for each running set.

DISCUSSION

This study is the first to demonstrate that five repetitions of a badminton FT with an alternating VJ test can be used to assess the progressive decrease in leg PP with increasing BL concentrations and increasing FI in badminton players. Thus, the FT protocol, along with alternating VJs, could be used to assess progressive neuromuscular fatigue. The specific skills used in

Table 1. Running and physical performances of 5 sets of test battery using the badminton field test (FT)

Variables	Pre-test	FT1	FT2	FT 3	FT 4	FT 5
Running performances						
Distance (m)	NA	273.40 ± 85.99	204.09 ± 67.87*	198.30 ± 64.63*	181.94 ± 64.01*	192.05 ± 91.40*
Time (s)	NA	97.71 ± 29.74	74.18 ± 25.93*	71.12 ± 22.08*	65.73 ± 23.87*	69.57 ± 32.91*
Velocity (m/s)	NA	2.79 ± 0.22	2.79 ± 0.40	2.80 ± 0.43	2.79 ± 0.34	2.77 ± 0.53
Fatigue index (%)	NA	0	-22.55 ± 18.77*	-25.88 ± 13.12*	-31.92 ± 15.06*	-29.47 ± 18.67*
Physical performances						
Vertical jump (cm)	63.98 ± 5.04	54.80 ± 4.31*	50.27 ± 5.55*	44.87 ± 6.16*	42.13 ± 5.72*	36.60 ± 6.53*
Peak mechanical power (W)	4,693.22 ± 324.90	4,136.13 ± 248.80*	3,860.96 ± 307.14*	3,533.18 ± 382.23*	3,367.27 ± 370.84*	3,031.39 ± 392.12*
Percentage of reduction in Vertical jump (%)	0	14.29 ± 3.34	21.40 ± 5.72*	30.00 ± 6.07*	34.20 ± 6.32*	42.87 ± 8.07*
Percentage of reduction in PP (%)	0	11.78 ± 2.60	17.68 ± 4.39*	24.81 ± 4.80*	28.33 ± 5.23*	35.49 ± 6.46*
Blood lactate (mmol/L)	2.82 ± 1.12	NA	NA	NA	NA	16.07 ± 2.52*

*p<0.001, significant differences from pre-test or FT1. NA: not applicable. Fatigue index (minus means reduce from FT1 or increase fatigue). The data are shown as mean ± SD.

Table 2. Rating of perceived exertion score (RPE) and heart rate (HR)

Variables		FT1	FT2	FT3	FT4	FT5
RPE (scores)	Pre	6.00 ± 0.00	12.2 ± 0.78	13.27 ± 0.70	14.13 ± 0.64	14.80 ± 0.77
	Post	15.53 ± 1.81*	16.80 ± 1.42*	17.27 ± 0.96*	18.00 ± 0.65*	18.67 ± 0.90*
HR (beats/min)	Pre	63.53 ± 3.76	104.93 ± 9.36	118.60 ± 9.58	127.27 ± 7.69	131.73 ± 6.99
	Post	172.13 ± 5.29*	173.93 ± 4.48*	174.40 ± 4.53*	177.8 ± 3.47*	178.00 ± 3.95*

*p<0.001, significant differences from pre-test. Pre: pre-test; Post: post-test; The data are shown as mean ± SD.

this FT protocol included essential components, such as sprinting, lunges, smash jumps and rapid changes of direction^{15, 18}), thereby enhancing on-court success when playing badminton.

A reduction in leg PP is a primary source of neuromuscular fatigue; therefore, the progressive decrease in the percentage of PP in the five FT sets, ranging from 11.78–35.49%. This reduction of PP range was accepted to be the range of achieved the fatigue state which is 20% to 50%^{28, 29}).

The present study's results confirm that VJs reflect the muscle contractile capability of lower-limb performance²⁴). Moreover, the VJ height can be calculated to be the PP, which reflects the muscle power in the lower limbs; thus, it can be used to assess and determine exercise-induced fatigue in a clinical practice³⁰). The fatigue indicated by the reduction of muscle PP may be explained by the disturbance of normal muscle function and activities, such as: 1) the stretch-shortening cycle fatigue model that causes disturbance in stretch-reflex activation^{31, 32}), 2) ionic disturbance ((Na⁺ and K⁺) resulting in a decrease in the M-wave amplitude, which is used as the index of neuromuscular transmission and action potential propagation in muscle fibre^{33, 34}) and 3) disturbance excitation contraction coupling that results from ionic imbalance, which causes a decrease in the amount of acetylcholine released at the neuromuscular junction and the amount of Ca²⁺ from the sarcoplasmic reticulum³⁵).

The study's finding of a lower PP or VJ was consistent with the reduction of running performance, such as distance and running time (reflecting the FI) while maintaining the same speed for each FT set. These findings may were in line with the results reported in previous studies, which showed the sensitivity of jump procedures in assessing muscular fatigue in team-sport athletes^{36–38}).

In terms of subjective or psychophysical indicators, this study's findings demonstrated that RPE significantly increased from 6 to 18 after each FT set. This finding is consistent with the results reported in a previous study, which showed that a change of RPE could be caused by a reduction in PP output³⁹). Increases in RPE reflect the participant's perceived experience of effort, strain, discomfort or fatigue⁴⁰). RPE has been widely used as a reliable and valid parameter to assess the early termination of bouts of exercise⁴¹). The generation of RPE is associated with the afferent information of peripheral systems from the cardiorespiratory, muscular and metabolic systems, which are transmitted to the brain⁴⁰). In terms of safety monitoring in the present study, HR also increased in the post-test for each FT set. However, these increases were less than 92% of HR_{max}, which is considered to be in the safety range⁴²). This result indicates that a modified FT is safe enough to perform.

Moreover, the FT protocol was classified to be a high-intensity test with a short resting break²⁸) based on the high RPE scores (17–19), the HR_{max} (75–90%) and the total running time of 15.00 ± 2.42 minutes (including all test-battery run times

and resting times). Such a high FT intensity may require energy that is provided by both anaerobic glycolytic and aerobic oxidative pathways; thus, the FT protocol in the present study recreated the same condition that would occur during a badminton game^{15, 43, 44}. These findings may also be confirmed by the increase in the BL concentration (up to 5.7 times), which always be associated with muscle fatigue. However, Zhang et al. noted that acidosis due to BL is probably not the cause of fatigue⁴⁵.

The present study had some limitations. The study population only included only male non-elite athletes. Thus a study that also included female athletes might have different results. We suggest that further studies are needed to confirm the leg power performance in female and elite athletes.

In conclusion, we found that leg-power generation could gradually be decreased in badminton competition as indicated by a badminton field test. We also suggested that a serial repetitive badminton-specific FT with an alternating VJ test could be used to assess progressive changes in leg power performance in badminton game.

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Conflicts of interest

The authors declare no conflict of interest.

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