***International Journal of Sports Physiology and Performance*, 2025, 20, 1265-1270**
https://doi.org/10.1123/ijspp.2024-0267

Human Kinetics
ORIGINAL INVESTIGATION

Energy Cost of Badminton Footwork: A Novel Experimental Approach

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Purpose: Despite the increasing body of literature on badminton, no data exist concerning the energy cost of badminton movement, known as "footwork." This study introduces a novel experimental approach to assessing the energy cost of footwork by applying established metabolic measurement techniques to badminton-specific movement patterns for the first time. In addition, it aims to verify whether differences exist between 2 different movement combinations. ***Methods:*** Seven male and 7 female badminton athletes (age 19 [4] y; body mass 64.9 [8.4] kg; height 1.72 [0.08] m; $\dot{V}O_2$peak 55.5 [10.3] $mL \cdot kg^{-1} \cdot min^{-1}$) completed 2 sets of 12 repetitions of 4 all-out preplanned footwork exercises with 30 seconds of passive recovery, using 2 types of steps (side step and running step). During exercises, respiratory data, blood lactate concentration, and net energy cost (C_{netFW}, $J \cdot kg^{-1} \cdot m^{-1}$) were determined, along with total exercise duration and average speed. ***Results:*** C_{netFW} was 19.59 (4.46) for side step and 20.38 (4.52) $J \cdot kg^{-1} \cdot m^{-1}$ for running step. No significant differences in metabolic data, total exercise duration, or average speed were observed ($P < .05$). C_{netFW} data showed a positive linear correlation between energy cost and footwork speed ($r = .62$; $r^2 = .39$; $P = .0009$). ***Conclusions:*** C_{netFW} increases with speed, but there is no significant difference between the 2 types of footwork. Players and coaches can choose the most appropriate step combinations based on individual characteristics and specific game requirements.

Keywords: racket sports, racquet sports, on-court activity, locomotion, physiological assessment, metabolic demand

Badminton is an intermittent racket sport in which short bouts of intense activity are followed by passive recovery.[1] Badminton players are required to perform very specific skills and movement patterns during the game, including split step, shuffle, cross-step, run, lunges, jumps, and landing with frequent acceleration, deceleration, and changes of direction performed on a small court. Players employ various combinations of these movement patterns to execute specific actions, aiming to reach the shuttlecock and cover the playing court efficiently. The complexity of badminton players' movement is generally denominated "footwork." Nowadays, badminton has been investigated focusing mainly on match demands including temporal structures and notational analysis[2–6] and physiological response during the game such as oxygen uptake, heart rate, energy expenditure, and blood lactate response.[4,6–11] In addition, biomechanical investigations have been conducted in order to analyze kinetics and kinematics of player's movements and strokes.[12–15] However, to the best of our knowledge, no existing data address the specific energy cost of footwork and movements in badminton. Badminton performance relies on multiple interconnected physiological, technical–tactical, and cognitive factors, all contributing to competitive success. The sport's intermittent, high-intensity nature demands a combination of cardiovascular endurance, explosive power, agility, and rapid decision making, which are particularly crucial for elite performance.[1] Research indicates that badminton is physiologically demanding, with specific movement patterns contributing to the overall energy expenditure during match play.[1,6,10] Understanding these physiological aspects, particularly the energy cost associated with different footwork techniques, could provide valuable insights into key performance determinants in competitive badminton. This knowledge may directly impact training methodology, tactical decision making, and injury prevention strategies. From a training perspective, quantifying the metabolic demands of specific movement patterns enables coaches to design conditioning programs that replicate the physiological requirements of competitive play. Tactically, players who understand the energy cost of various movement techniques can make more informed decisions during matches, potentially conserving energy during prolonged rallies and improving efficiency during critical points. Furthermore, understanding the biomechanical and metabolic demands of badminton footwork has important implications for injury prevention. The repetitive loading patterns during specific badminton movements are associated with overuse injuries, particularly in the lower extremities.[12] By optimizing movement efficiency based on energy cost data, coaches can potentially reduce injury risk while simultaneously improving performance, reinforcing the connection between metabolic efficiency and injury prevention strategies. Finally, assessing the energy cost can be important for optimizing nutritional strategies that support an athlete's general health and training needs.

Recently, some authors have developed specific testing procedures/protocols to quantify the energy cost of shuttle running (sprint < 20 m) in intermittent sports played on small size courts.[16–19] These authors have demonstrated that it is feasible to calculate the

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metabolic demand of shuttle running from oxygen uptake, respiratory exchange ratio, and blood lactate values. In this way and with the application of the equivalent slope concept,[20,21] the metabolic demand of several team sports (eg, soccer) was defined. Similar to these sports, badminton is characterized by continuous changes of direction and intermittent short bouts of high intensity. Therefore, it is advisable to expand testing procedures to include the assessment of metabolic demand during badminton practice.

The aims of this study are (1) to present a novel experimental approach to determine the energy cost of badminton "footwork" and (2) to verify if any difference in energy cost exists between 2 different combinations of "footwork." We hypothesized that the methodological approach previously validated for shuttle running protocols would be valid for badminton footwork, allowing reliable measurement of energy cost in sport-specific conditions. In addition, we hypothesized that different footwork techniques would demonstrate different energy costs due to their distinct biomechanical characteristics.

Methods

Subjects

After receiving a full explanation of the purpose and objectives of the research and of the experimental procedures, 14 badminton players [7 males and 7 females; mean [SD]; age: 19 [4] y; body mass: 64.9 [8.4] kg; height: 1.72 [0.08] m; $\dot{V}O_2$peak: 55.5 [10.3] mL·kg^{-1}·min^{-1}) competing at national and international levels gave their informed consent to participate in the study. The parents or legal guardians of participants under 18 years signed the consent form. Participants were all part of Italian national team from 2 to 8 years, with an average weekly training of 25 hours. All participants were part of the same training group and managed by the same coaching staff, and they were tested during the same phase of the season. The rate of perceived exertion was recorded to ensure that participants were in comparable conditions, with no high-intensity sessions scheduled in the 48 hours prior to testing. The study conformed to the standards set by the Declaration of Helsinki, and the local institutional review board approved the procedures.

Design

The study employed an experimental, within-subject design to determine the energy cost of specific badminton footwork movements and to compare the energy expenditure between 2 different footwork techniques: running step (RS) and side step (SS).

Methodology

Before each experimental session, the participants were asked to abstain from stimulants in the 24 hours preceding the tests. They were also instructed to have a light meal before the test session and not to have engaged in intense physical exercise in the 48 hours prior to testing. Before the test, participants were familiarized with the instruments and procedures.

Footwork Exercise

Players were asked to perform sets of 12 repetitions of specific movements (footwork) with change of direction and using different combinations of steps. The exercise was composed by 2 shuttle movements (4 movements in total) performed at maximal speed, according to a preplanned sequence, from the center of the badminton court to the forward part of the badminton court (net; Figure 1). Players started from the point marked on the court representing the center, and they were asked to simulate a net stroke using the heel of the racket hand to pass a line marked on the right side, go back to the center, and repeat the movement on the left side. The exercise was concluded when players returned to the center. Players repeated the exercise 12 times with 30 seconds of passive recovery between repetitions. The total distance covered during each repetition was 10 m, for a total of 120 m for the whole exercise.

Players performed the exercise twice, with at least 24 hours of rest between sessions, in a random order, using 2 different techniques of movement: (1) RS and (2) SS. The RS included the approach to the net using a running pattern, and the SS included the approach to the net using a SS (also named a shuffle step). In both conditions, players reached the target at the net with a lunge and returned to the center using backward running.

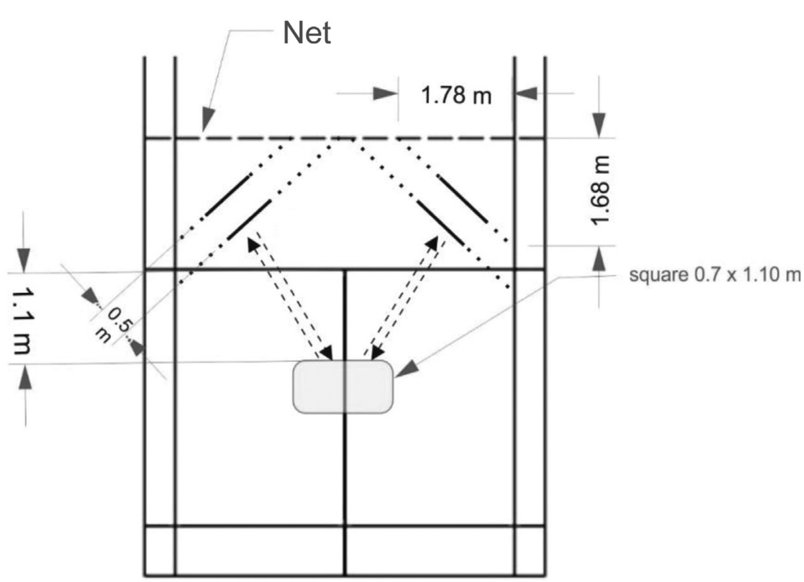

Figure 1 — Overview of the experimental setup for the footwork exercise. Adapted from Abián-Vicén et al.[34]

Exercise protocol was chosen on the basis of previous studies on the energy cost of shuttle running[17,18] and was designed to reflect game-specific movement patterns. Competitive badminton involves frequent short-distance, high-intensity movements with rapid directional changes, and repeated lunges (~15% of total game time), the majority of which occur diagonally.[22] This design ensures ecological validity for badminton-specific performance assessment.

Metabolic Measurements

Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), and respiratory exchange ratio (RER) were determined on a breath by-breath basis using a previously calibrated portable metabolic system (K5, Cosmed). Respiratory data were collected at rest during 10 minutes for baseline measurement and during exercise. Metabolic data collected during the last 2 minutes of exercise were averaged and used for further analysis. A typical example of $\dot{V}O_2$ during exercise is shown in Figure 2.

At rest and at 3, 5, and 7 minutes after the end of the exercise, a blood sample (0.3 μL) was taken from the ear lobe to measure blood lactate concentration ($[La^-]b$, mM). Blood samples were analyzed by means of a portable lactate analyzer (Lactate Pro, Arkray Inc). Net blood lactate accumulation ($[La^-]b_{NET}$) was calculated from the difference between the highest $[La^-]b$ value recorded at the end of the exercise and $[La^-]b$ at rest. The energy derived from anaerobic lactic energy sources was calculated by taking into account an energy equivalent of 3.3 $mL \cdot kg^{-1} \cdot mM^{-1}$.[23]

The net energy cost of badminton footwork (C_{netFW}) was calculated as $C_{netFW} = (EaerO_2 + ELab)/d$, where $EaerO_2$ ($mL \cdot kg^{-1}$) is the energy derived from aerobic energy sources calculated by multiplying $\dot{V}O_2NET$ ($\dot{V}O_2$ of the last 2 min of exercise minus $\dot{V}O_2$ at rest) for total exercise duration ($mL \cdot kg^{-1} \cdot min^{-1} \times min$), ELab ($mL \cdot kg^{-1}$) is the energy derived from anaerobic lactic energy sources calculated by multiplying $[La^-]b_{NET}$ for the energy equivalent ($mM \times mL \cdot kg^{-1} \cdot mM^{-1}$), and d is the total distance covered (120 m). C_{netFW} was finally expressed in $J \cdot kg^{-1} \cdot m^{-1}$ using an energy equivalent, which takes into account the RER: $\dot{V}O_{2NET} \times (4.94 \times RER + 16.04)\ J \cdot mLO_2^{-1}$.

Statistical Analysis

Data are reported as mean (SD). The energy cost between RS and SS was analyzed using a linear mixed-effects model implemented in SPSS (IBM SPSS Statistics for Windows, version 29.0.2.0). The model included fixed effects for the footwork technique with participants as a random factor, employing an unstructured covariance matrix. The restricted maximum likelihood method was used for parameter estimation, and the Satterthwaite approximation was applied to calculate degrees of freedom. The model fit was assessed using information criteria including −2 restricted log likelihood (128.68), Akaike information criterion (134.68), and Bayesian information criterion (138.34). In addition, a separate model was developed to examine the relationship between movement speed and energy cost, using the maximum likelihood method. Pearson correlation coefficient was also calculated to quantify the linear relationship between movement speed and energy cost, complementing the findings from the mixed model analysis. A P value of .05 or less was considered statistically significant. Effect sizes were calculated using Cohen d. Magnitude thresholds of <0.2, 0.2 to 0.60, 0.60 to 1.2, 1.2 to 2.0, 2.0 to 4.0, and >4.0 were considered trivial, small, moderate, large, very large, and extremely large, respectively.[24] Figures were prepared using GraphPad Prism.

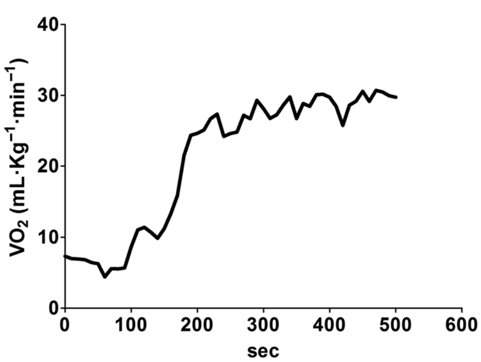

Figure 2 — Typical example of $\dot{V}O_2$ data during the footwork exercise. $\dot{V}O_2$ indicates oxygen uptake.

Results

Metabolic data, total exercise duration, and average speed of the 2 types of footwork are shown in Table 1. No significant differences in the energy cost were observed between footwork types (RS vs SS) based on linear mixed model analysis, $F_{1,12.12} = 0.612$, $P = .449$. The variance parameters indicated greater variability in the SS condition (21.24 [8.33]) compared with the RS condition (17.25 [6.90]), with a very high correlation between conditions ($r = .91$ [.05]), suggesting consistent individual differences across techniques. Data of C_{netFW} was grouped and analyzed as a function of speed (Figure 3). Figure 3 shows a positive linear correlation between energy cost and footwork speed ($r = .62$, *large*; $r^2 = .39$; $P = .0009$), described by the equation $C_{netFW} = -16.46 + 13.00 \times v$. The mixed model analysis of this relationship revealed a similar coefficient (13.78 [2.96] $J \cdot kg^{-1} \cdot m^{-1}$ per $m \cdot s^{-1}$ increase in speed; $P < .001$) and explained approximately 44.5% of the variance in energy cost. In Figure 3, the relationship between energy cost and 5 + 5-m shuttle running speed with a 180° change of direction, as reported by Zamparo et al,[17] was represented as a dashed line to show that the badminton footwork values align with the same equation.

Discussion

The first aim of this study was to propose an experimental protocol to determine the energy cost of badminton-specific movements on

Table 1 Metabolic Data, Total Exercise Duration, and Average Speed of the 2 Types of Footwork

	RS	SS	Effect size
$\dot{V}O_2$, $mL \cdot kg^{-1} \cdot min^{-1}$	24.7 (4.5)	25.5 (5.0)	0.17 (trivial)
RER	0.84 (0.04)	0.84 (0.03)	0.00 (trivial)
$[La^-]b_{NET}$, mM	0.6 (0.3)	0.7 (0.3)	0.33 (small)
t_{tot}, s	373 (4)	372 (3)	0.28 (small)
v_{mean}, $m \cdot s^{-1}$	2.0 (0.4)	2.0 (0.5)	0.00 (trivial)
C_{netFW}, $J \cdot kg^{-1} \cdot m^{-1}$	19.59 (4.46)	20.38 (4.52)	0.18 (trivial)

Abbreviations: C_{netFW}, net energy cost; $[La^-]b_{NET}$, net blood lactate concentration at the end of exercise; RER, respiratory exchange ratio; RS, running step; SS, side step; t_{tot}, total exercise duration; v_{mean}, average speed; $\dot{V}O_2$, oxygen uptake. Note: Values are represented as mean (SD).

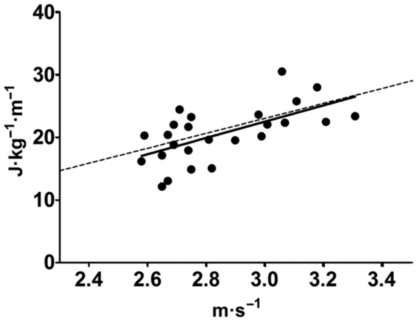

Figure 3 — Data of net energy cost as a function of speed. The solid line represents the positive linear correlation between the energy cost ($J{\cdot}kg^{-1}{\cdot}m^{-1}$) and footwork speed ($m{\cdot}s^{-1}$; $r = .62$; $r^2 = .39$; $P = .0009$). The dashed line represents the relationship between energy cost and 5 + 5-m shuttle-running speed from Zamparo et al.[17]

courts. Recently, the intermittent shuttle running test (eg, over distance of 5 + 5 m) performed at various speeds, with 30 seconds rest between repetitions and with a total duration of about 6 minutes have been presented. This type of protocol allows for almost complete resynthesis of creatine phosphate during recovery; thus it is sufficient to measure only aerobic and anaerobic lactic energy sources to estimate the metabolic energy expenditure.[17,18,25] Moreover, with a total exercise duration of about 6 minutes, a sort of steady state of oxygen consumption can be reached despite the intermittent nature of the effort, and it has been reported that nearly all of the needed energy derives from oxidative sources.[17]

The mean values of RER (about 0.85) and net blood lactate accumulation (<1 mM) shown in Table 1 indicate that the proposed exercise was essentially based on aerobic energy sources (considering also that during the recovery periods oxygen is consumed for phosphocreatine resynthesis) with anaerobic lactic source accounting for only 1.3%. Figure 2 also shows how oxygen consumption reached a steady state toward the end of the exercise. This confirms that the experimental protocol is adequate for calculating the energy cost (also) of badminton footwork.

The second aim of the study was to verify if there were differences in energy cost between 2 typical combinations of badminton movements. Mainly in single events (men's singles and women's singles), players can use RSs or SSs, among others, to approach the 2 sides of net from the middle court, and typically they come back using backward steps. Our data show that there is no significant difference in average speed (2.0 [0.4] and 2.0 [0.5] $m \cdot s^{-1}$ for RS and SS, respectively) or energy cost (19.59 [4.46] and 20.38 [4.52] $J\,kg^{-1}\,m^{-1}$ for RS and SS, respectively) between the 2 types of badminton footwork. The estimated effect size for the difference in energy cost was trivial ($d = 0.18$), suggesting that, from a practical perspective, the choice of either approach could be as metabolically demanding as the other with similar court performance. Particularly noteworthy was the high correlation ($r = .91$) between individual energy costs in the 2 techniques, indicating that approximately 83% of the variance in one technique can be explained by performance in the other. This finding suggests that individual factors have a much more substantial influence on energy cost than the specific technique employed. Players who demonstrated efficient movement in one technique tended to be equally efficient in the other technique, which has important implications for training individualization. Similar to shuttle runs, the energy cost of footwork in badminton is higher (about 5 times) than the energy cost of straight-line, constant speed, running (about 4 $J{\cdot}kg^{-1}{\cdot}m^{-1}$).[26] This "extra cost" of footwork can be attributed to the greater muscular work required to accelerate and decelerate the body, also during the changes of direction.[19,27–31] It should also be considered that the participants were asked to return to the center base using backward running after approaching the net with the RS or SS. Therefore, the exercise consisted of 2 forward and 2 backward maximal efforts. Backward running (at constant speed) has been shown to have a higher energy cost than forward running,[32,33] and the higher cost also was constantly higher on gradient,[32] which is considered a good equivalent of the acceleration cost;[20] this could also contribute to explaining the high values of energy cost measured in our study. Finally, it is plausible that the different muscular interventions of the upper body and arms in the execution of the specific badminton movements, compared with straight-line running, could have contributed to the increase in energy cost.

Figure 3 shows that the energy cost of badminton footwork increases with the average progression speed. This same trend was reported in different shuttle running protocols,[16,18] and it is mainly due to the increase in the mechanical counterpart: the muscular work required to accelerate and decelerate.[19,31] Furthermore, the cost versus speed relationship found here on badminton players is superimposed on that obtained on basketball players while performing a 5 + 5 m shuttle run with a 180° change of direction.[17] This seems to suggest that the magnitude of the mechanical variables (such as, acceleration/deceleration and kinetic energy) is the main determinant of the cost, whereas the sport and change of direction modality have less impact. Our analysis of the relationship between energy cost and movement speed revealed a significant positive linear correlation ($r = .62$, $r^2 = .39$, $P = .0009$). Further examination using a linear mixed model confirmed this relationship, with the model explaining approximately 44.5% of the variance in energy cost. The mixed model coefficient (13.78 [2.96] $J{\cdot}kg^{-1}{\cdot}m^{-1}$ per $m{\cdot}s^{-1}$ increase) provides a robust estimate of how energy cost increases with speed. This relationship between energy cost and speed could be useful for defining the energy expenditure of a match or a tactical training session. As a matter of fact, when the number of repetitions, the average time, and the distance of the proposed drill are counted, the total of burned jules (or calories) can be easily computed. Because the energy cost of the footwork, and in general of unsteady running, is definitely higher than constant speed one, a better definition of the energy expenditure is needed to guide an adequate nutritional plan among training sessions and competition tournaments.

Practical Applications

The findings of this study offer valuable insights for badminton players, coaches, and sports scientists, enhancing performance monitoring and nutritional planning. By determining the specific energy cost of badminton footwork, coaches can design training programs that better mimic match conditions, helping players to improve efficiency. In addition, the study reveals that there is no significant difference in energy cost between RS and SS for approaching the net starting from the center of the court, allowing players and coaches to focus on other factors like tactical advantages or player comfort when selecting footwork techniques. The high correlation between individual performances in both techniques ($r = .91$) further suggests that players who are economical in one technique tend to be economical in the other, emphasizing the importance of individual movement quality rather than specific technique selection. This knowledge can inform more effective management of training loads and recovery periods, contributing to better performance monitoring and injury prevention. Moreover, coaches can use the provided cost versus speed equation or the coefficient of 13.78 (2.96) $J \cdot kg^{-1} \cdot m^{-1}$ per $m \cdot s^{-1}$ to estimate energy expenditure during different drills, allowing for more precise planning and adjustment of training intensities. Understanding the high energy costs associated with badminton footwork also leads to targeted strength and conditioning programs that can enhance movement efficiency and reduce the risk of injuries. Coaches should focus on developing the acceleration–deceleration capabilities of players as these mechanical factors appear to be the primary determinants of energy cost regardless of the specific technique employed. For nutritional planning, the substantially higher energy cost of badminton movements compared with steady-state running (approximately 5 times higher) highlights the importance of appropriate fueling strategies for both training and competition. Applying these findings can significantly enhance training prescription, recovery strategies, and nutritional planning, ultimately leading to improved performance in competitive badminton.

Conclusions

Data from this study show that the experimental protocol used is valid for calculating the energy cost of footwork in badminton. Our analysis confirmed that the energy cost increases significantly as a function of speed (as for the shuttle runs), with movement velocity explaining approximately 44.5% of the variance. However, there is no significant difference between the 2 types of footwork examined. The high correlation between individual performances in both techniques indicates that player-specific factors have substantially greater influence on energy cost than the choice of footwork technique. Players and coaches can then choose the most appropriate combinations of steps according to individual characteristics, technical proficiency, and specific game requests. This study has limitations that should be considered. Our relatively small sample size ($n = 14$) may limit statistical power and generalizability. Furthermore, we analyzed only 2 specific movement patterns for approaching the net, which does not represent the full range of footwork in competitive badminton. In addition, despite identifying high interindividual variability, we did not systematically examine underlying factors such as anthropometric characteristics or training background that might explain these differences. Future studies will be necessary to calculate the energy cost of badminton footwork from the middle to the rear of the court and vice versa or covering longer distances (eg, from the rear court to the net and vice versa). Research with larger samples and broader movement patterns would further enhance our understanding of the metabolic demands of badminton-specific movements.

Acknowledgments

The authors would like to acknowledge all of the participants and the Italian Badminton Federation for the assistance and technical support.

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