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Training vs. Competition: Load and Intensity Differences Between Multi-Feeding and Simulated Match Play in High-Level Youth Badminton Players

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Abstract

Badminton is an intermittent sport with a diverse exercise profile that stresses both aerobic and anaerobic energy systems. The aim of this study was to compare the internal and external load profiles of multi-feeding (MF) drills and simulated match play (SMP) in elite junior badminton players, and to explore potential sex-based differences. Forty-two players (24 males (age 17.4 ± 2.6 years, training experience 9.9 ± 1.8 years) and 18 females (age 16.9 ± 2.9 years, training experience 9.4 ± 2.1 years)) completed MF and SM sessions while external load (e.g., relative distance, explosive distance, relative jumps) and internal load (heart rate [HR], session rating of perceived exertion [sRPE]) variables were recorded using inertial measurement units and HR monitors. Two-way ANOVA revealed that MF induced significantly greater external ($p < 0.05$) and internal ($p < 0.001$) loads compared to SM, with large effect sizes. Male players showed markedly higher jump frequency (1.60 n/min vs. 0.80 n/min) and maximum speed (19.80 km/h vs. 15.80 km/h), although HR and sRPE values were similar between sexes ($p > 0.05$), suggesting that female athletes may experience greater relative physiological load. These findings highlight the importance of using MF drills to target specific conditioning goals and reinforce the need for individualized training strategies considering sex differences.

Keywords: youth athletes; performance; internal load; external load; training; competition

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1. Introduction

Badminton is a high-intensity intermittent sport characterized by frequent changes in direction, explosive movements, and brief recovery intervals, challenging both aerobic and anaerobic energy systems [1,2]. At the elite level, the demands of match play are considerable, with rallies requiring high acceleration demands, quick changes in direction, and the ability to repeatedly produce powerful actions such as jumps and smashes with minimal recovery, under conditions of accumulated fatigue [3–5]. Recent data from international junior competition indicate that players can reach peak accelerations near 4 m/s^2, perform over 25 high-intensity accelerations per minute, and execute 30–40 jumps per match [6]. Moreover, sex-related differences have been observed in activity profiles, with male players typically exhibiting higher frequencies of explosive movements, while female players demonstrate greater consistency in rally duration and stroke execution [6]. This unique physiological and neuromuscular profile underpins the importance of well-designed training strategies that replicate the sport-specific load and intensity observed during competition.

In recent years, badminton coaches have increasingly adopted specific on-court training modalities such as multi-feeding drills (MF), designed to enhance technical skills under fatigue while providing a high density of actions in a short time frame [7]. These drills allow for targeted technical refinement while imposing physiological and neuromuscular load, particularly when work-to-rest intervals are manipulated. However, questions remain as to how well these sessions replicate the demands of actual match play. Prior research in intermittent sports suggests that training should mimic or exceed peak competition loads to prepare athletes for worst-case scenarios [8–10]. However, in badminton, comparisons of physiological and mechanical load between training modalities and match play remain scarce. Edel et al. [11] have recently shown that conventional technical drills often underestimate the metabolic stress observed during matches, since they typically fail to replicate the high reliance on phosphagen metabolism and the need for rapid phosphocreatine (PCr) resynthesis, underscoring the pivotal role of phosphagen metabolism in badminton match play. Consequently, these drills differ from competition not only in energetic profiles but also in the consistency and predictability of work-to-rest ratios. However, the effectiveness of MF drills to reproduce simulated match play (SMP) demands remains underexplored. However, the relative effectiveness of MF drills—one of the most widely used training tasks by coaches—to reproduce simulated match play (SMP) external demands remains underexplored. Given the increasing use of inertial measurement devices in applied settings, analyzing the external load profile of these drills is crucial to inform evidence-based training design, optimize load management, and ensure that physical demands align with the competitive context.

A further limitation in the current literature is the lack of attention to sex-based differences. While coeducational training (i.e., train together in mixed-gender groups) is common practice in youth badminton [12], this approach may overlook critical physiological and maturational distinctions between male and female athletes. For example, recent studies conducted in badminton showed that males typically produced higher jump counts, accelerations, and total workloads, whereas females experienced greater relative physiological strain for comparable tasks [6,13]. Without individualized load monitoring, coeducational training may result in disproportionate demands and elevate injury risk, particularly for female athletes.

To inform evidence-based training design, it is essential to quantify and compare both internal (e.g., heart rate (HR), rate of perceived exertion (RPE)) and external (e.g., movement demands, jump frequency) load metrics across different training formats [14]. However, while similar studies have been conducted in other racket sports [15], there is a scarcity of empirical studies in badminton that directly contrast activity profile and physiological responses in specific high-intensity training formats like MF with match play scenarios, particularly with attention to sex-specific responses in elite youth players.

Therefore, the aim of this study was to analyze and compare the activity profile and physiological-perceptual responses (i.e., HR, RPE) between multi-feeding training sessions and simulated match play in elite male and female youth badminton players. A secondary aim was to explore whether sex moderated these responses, with the goal of informing individualized training practices.

It was hypothesized that multi-feeding sessions would induce different internal and external load profiles compared to simulated match play, and that sex would affect these responses. This hypothesis was informed by prior literature [4,11], and reinforced by coach and athlete observations, which suggest that structured drills and match-like scenarios impose distinct physical demands, and that sex-related physiological differences may influence how junior athletes respond to these stimuli.

2. Materials and Methods

2.1. Participants

A total of forty-two competitive badminton players participated in the study: twenty-four males (age 17.4 ± 2.6 years, body height: 173.1 ± 9.4 cm, body mass: 64.2 ± 10.1 kg, and training experience 9.9 ± 1.8 years) and eighteen females (age 16.9 ± 2.9 years, body height: 163.8 ± 9.5 cm, body mass: 52.5 ± 4.4 kg, and training experience 9.4 ± 2.1 years). Participants were required to be actively competing at the national or international level and classified as Tier 3 (Highly Trained/National Level) based on Participant Classification Framework suggested by McKay et al. [16], with a minimum of five weekly training sessions. Exclusion criteria included present musculoskeletal injuries, recent surgery, or rehabilitation within the past 6 months. All players participated in 18.4 ± 2.8 h per week of combined badminton and physical training per week (i.e., 5 and 4 sessions per week, respectively). Each session typically consisted of a first part carried out in the gym, focused on strength development, activation, and injury prevention, followed by a second part on court dedicated to technical, tactical, and sport-specific conditioning work. The study was conducted after a recovery microcycle and training content and volume were adjusted according to the demands of the ongoing mesocycle.

Prior to data collection, all participants and their legal guardians were informed about the tests protocols and potential risks and signed an informed consent. The sample size was justified by an a priori power analysis (using G*Power 3.1.9.5, University of Düsseldorf, Düsseldorf, Germany) for a mixed-design ANOVA with one between-subjects factor (group: male vs. female) and one within-subjects factor (training modality: multi-feeding vs. match play). The analysis assumed a medium effect size (f = 0.25), an alpha level of 0.05, and a desired power of 0.85. Results indicated that a total sample size of N = 38 participants would be required to detect a significant interaction between factors with sufficient power. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (Universidad de León; ETICA-ULE-004-2024)

2.2. Experimental Design

This study employed a crossover repeated-measures design to compare physical demands between two training modalities: (1) multi-feeding drills (MF) and (2) simulated match play (SMP). Each participant completed both conditions during standard training sessions scheduled within the same week to avoid seasonal variation in fitness or competitive readiness. To reduce potential order effects, the sequence of participation in training and match conditions was counterbalanced. Each player completed MF and SM sessions on separate non-consecutive days within the same week, with a minimum 48 h recovery interval between sessions to avoid residual fatigue. Sessions took place in an indoor badminton facility with seven courts that adhered to the Badminton World Federation (BWF) standards, and were conducted between 10:30 and 13:30 h. The intervention took place at the end of the winter competitive season, after a recovery microcycle, and previous to a 2-week winter break (i.e., Christmas holidays). To reduce the interference of uncontrolled variables, all the participants were lodged in a players' residence within the training facility to control meals and resting times and were instructed to maintain their habitual lifestyle during the study.

Participants completed a 15 min standardized warm-up, including cardiovascular activation, general mobility, core and shoulder strengthening, and specific movement drills, followed by sparring practice. Then participants were engaged in the multi-feeding protocol or the simulated match play.

2.2.1. Characteristics of Simulated Match Play (SMP)

For the simulated matches, players were paired based on performance level (similar national rankings) and sex under Badminton World Federation rules [17]. Each set was divided into two intervals: from the beginning until the first player reached 11 points, and from that point until the end of the set. First and second sets were played to the best of 21 points. Timeouts of 2 min between sets and 1 min rest periods when one side reached 11 points were taken. The third set, when necessary, was played to the best of 11 points [18]. Players were allowed to drink water and 6% carbohydrate/electrolyte drink ad libitum to support hydration and energy replenishment during the matches, at the end of each interval (60 s rest) or at the end of each set (3 min rest), as no additional breaks were scheduled.

2.2.2. Characteristics of Multi-Feeding Training (MF)

The multi-feeding training protocol was structured into six blocks of five minutes each. Each block was composed of alternating work and rest intervals (10 s of work followed by 7 s of rest). This structure was intentionally selected to replicate the intermittent and high-intensity demands observed during elite-level match play, characterized by short explosive rallies followed by brief pauses. The 10:7 ratio was chosen based on practical evidence and internal load patterns reported in elite competition [7], aiming to maintain a balance between physiological overload and technical execution under fatigue.

Players were assigned to groups of three per court, a format commonly employed in high-performance environments to manage intensity and ensure continuity in training flow. Within each group, one player served as the primary measurement subject (Player W), while another acted as "feeder," delivering shuttles using either hand-feeding or racquet-feeding techniques in randomized sequences. This configuration was designed to simulate chaotic game-like demands while allowing precise control over shuttle placement and intensity.

Each block was designed to target specific tactical contexts and movement patterns commonly encountered during high-level competition:

- Block 1: Player W executed full-court singles drills within a neutral tactical zone covering six designated areas, with shuttle feeds provided by racquet-feeding. Rest period: 60 s.
- Block 2: Player W performed a full-court singles sequence focused on a defensive tactical zone with moderate pressure, with the feeder providing shuttles via hand-feeding. Rest period: 120 s.
- Block 3: Player W engaged in a full-court doubles format, initiating an attack from the backcourt and following up with mid-court coverage, with shuttle feeds delivered through racquet-feeding. Rest period: 60 s.
- Block 4: Player W returned to full-court singles, combining an attack from the back-court with movement toward the net, fed via racquet-feeding. Rest period: 120 s.
- Block 5: A full-court, free-form multi-shuttle drill was conducted, combining both defensive and offensive patterns. Rest period: 60 s.

- Block 6: The session concluded with a free-form multi-shuttle drill combining defensive and counterattack sequences in full court, fed via racquet-feeding.

Between the training blocks, players were allowed to drink water and 6% carbohydrate/electrolyte drink ad libitum to support hydration and energy replenishment.

2.2.3. Measurement of Anthropometric Characteristics

Body height was measured using a fixed stadiometer (±0.1 cm; Holtain Ltd., Crosswell, UK), sitting height with a purpose-built table (±0.1 cm; Holtain Ltd., Crosswell, UK), and body mass with a digital balance (±0.1 kg; ADE Electronic Column Scales, Hamburg, Germany).

2.2.4. Measurement of External Load Variables

The assessment of the external load during MF and SMP was conducted using inertial measurement units (IMU, WIMU PRO™, RealTrack Systems, Almería, Spain), which have been employed in previous studies with badminton players [6,19]. These devices include different sensors (accelerometer, gyroscope, magnetometer) to record time-motion data (outdoor: Global Navigation Satellite System, GNSS; indoor: Ultra-Wideband, UWB), as well as metrics related to specific actions and skills. Each unit features an internal microprocessor, 2 GB of flash memory, and a high-speed USB interface to record, store, and upload data. They were powered by an internal battery with a 4 h lifespan, had dimensions of 81 mm × 45 mm × 16 mm, and a total mass of 70 g. The sensors operated at a sampling frequency of 18 Hz for UWB and 1000 Hz for the accelerometer, magnetometer, and gyroscope [19–21]. Before data collection during MF and SMP drills, a Local Positioning System (LPS) was established using eight ultra-wideband antennas, placed according to the manufacturer's guidelines and previous studies [6,19]. The antennas were arranged in a rectangle, spaced from 10 to 16 m apart, and mounted on tripods at a height of 3 m. Calibration of the UWB system was performed following established protocols [6,19,21], and the intra-unit and inter-unit reliability have previously been reported for WIMU PRO™ in indoor conditions [20]. Briefly, the antennas were switched on sequentially, with the master antenna activated last. A 5 min auto-calibration protocol synchronized all antennas to a common clock. Afterward, at each position update (18 Hz), the master antenna sent a time synchronization signal. Then, the tracking devices were turned on, undergoing a 1 min recognition and communication process with the antennas. The accuracy of the system was tested, yielding a mean absolute error for the x-position of 5.2 ± 3.1 cm and for the y-position of 5.8 ± 2.3 cm [20]. Similarly, accelerometer calibration was conducted according to the methodology outlined in prior research [19], which also reported intra- and inter-unit reliability (CV values of 0.5–1.05 and 1.1–1.2%, respectively) with near-perfect inter-device correlations (r = 0.99–1.00), and very low day-to-day variability (r = 0.84–0.97). The IMU device was secured to the interscapular level (i.e., at approximately the level of the 2nd thoracic vertebra) of the players five minutes prior to the warm-up [19] using a specially designed neoprene vest provided by the manufacturer. This ensured a secure fit without restricting typical badminton movements. To avoid inter-unit error, participants wore the same device for all observations [22].

All data obtained from the devices were linked and extracted after matches for analyses using the specific manufacturer's software (SPRO™, RealTrack Systems, Almería, Spain).

Based on previous research [6], suggesting that the following variables were the most representative during an international badminton tournament, and in order to reduce the number of variables included in the study, we included the following in the analysis: (1) relative distance, RD (m/min): total distance covered related to total playing time; (2) maximum acceleration, AccMAX (m/s^2): maximum acceleration reached during the different situations (training/match); (3) AccRel (n/min): number of accelerations related to total playing time; (4) SpeedMAX (km/h): maximum speed performed throughout the situation; (5) average HR, HRAVG (bpm); (6) relative jumps, RJumps (n/min): number of jumps performed related to playing time; (7) average takeoff force; TakeOffAVG; (8) force average measured at all takeoffs during the different situations; (9) average landing force, LandingAVG; (10) force average measured at all landings during the different situations.

2.2.5. Measurement of Internal Load Variables

Heart rate (HR). The assessment of the MF and SMP internal load was conducted with an HR device (GARMINTM, Olathe, KA, USA) which was positioned near the xiphoid using specifically designed straps and sent data to the IMU using Ant+ technology [6,23]. Average HR (HRavg) and maximum HR (HRpeak) recorded during the session were recorded after each training block, as well as during the whole simulated match. The data were linked and extracted after matches using the specific manufacturer's software (S PRO™, RealTrack Systems, Almería, Spain).

RPE and Session RPE. The training intensity was measured using the 0 to 10 category scale [24]. During training drills, players were asked "How intense was the block?" after each training block and were requested to ensure that their RPE referred to the intensity of the most recent exercise. During matches, players were asked the same question 10 min after the end of the match. The session RPE was calculated using the CR-10 scale, which was administered 10 min after the training session and simulated match, and the training load (TL) of each session was calculated through the multiplication of RPE and session duration (in minutes) [25].

2.3. Statistical Analysis

The results are expressed as mean ± SD. Data analysis was conducted using Jamovi statistical software version 2.3.28. The normality of the distributions and homogeneity of variances were assessed with the Shapiro–Wilk test. Logarithmic transformations were applied when assumptions were violated. A two-way ANOVA was performed to examine the main effects of training condition (multi-feeding (MF) vs. match play (SMP)) and gender (males vs. females) as well as interaction effects. Post hoc comparisons were conducted with Bonferroni correction. The significance level was set at $p < 0.05$. Effect sizes were calculated and interpreted using Cohen's d, based on previously proposed thresholds for highly trained athletes, and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2), and large (≥1.2 and <2) or very large (≥2.0) [26]

3. Results

Table 1 shows the descriptive statistics for each variable, organized by sex and training situation (MF vs. SMP). When considering interaction effects, relative jumps (RJumps) showed a trend toward a sex × situation interaction (F = 3.49, $p = 0.069$), with post hoc analysis indicating significantly more jumps in males compared to females in both MF ($p = 0.007$, d = 1.49) and SMP ($p < 0.001$, d = 2.38), along a significant reduction in RJumps for both sexes from MF to SMP ($p < 0.001$ for both). Similarly, SpeedMAX presented a significant interaction (F = 6.08, $p = 0.019$), with female players showing a large decrease in MF to SMP ($p = 0.014$, d = 1.52), while male players maintained similar values across situations ($p = 0.999$, d = 0.05). No significant interaction effects were found for the other metrics analyzed.

Table 1. Descriptive statistics for analyzed variables, organized by sex and training situation (multi-feeding [MF] vs. simulated match [SMP]). Values represent $\tilde{x} \pm SD$.

				p Value	
		Females (n = 18)	**Males (n = 24)**	**Situation (MF vs. SMP)**	**Interaction Situation—Sex (Cohen's d [95% CI])**
RD (m/min)	MF	61.3 ± 8.9	60.3 ± 8.5	<0.001	0.215 [−0.2579 to 0.995]
	SMP	41.0 ± 7.9	51.2 ± 11.4		
ExplD (m)	MF	497.6 ± 165.1	432.9 ± 121.0	0.028	0.392 [−0.3882 to 0.853]
	SMP	286.4 ± 110.3	291.5 ± 138.5		
AccMAX (m/s^2)	MF	6.7 ± 1.5	8.2 ± 1.7	0.008	0.26 [−0.369 to 0.873]
	SMP	9.1 ± 0.4	8.5 ± 1.2		
AccRel(n/min)	MF	38.0 ± 4.1	41.4 ± 1.4	0.639	0.727 [−0.490 to 0.788]
	SMP	37.8 ± 9.9	40.1 ± 2.5		
RJumps (n/min)	MF	0.80 ± 0.3 $^{**\$\$\$}$	1.60 ± 0.9 $^{\$\$\$}$	<0.001	0.069 [−0.0594 to 1.844]
	SMP	0.34 ± 0.2 ***	0.52 ± 0.3		
SpeedMAX (km/h)	MF	15.8 ± 5.5 $^{\$}$	19.8 ± 6.0	0.027	0.019 [−1.735 to 0.128]
	SMP	23.8 ± 5.0	19.6 ±4.7		
HRavg (bpm)	MF	184 ± 9.3	185 ± 5.0	<0.001	0.616 [−1.241 to 0.738]
	SMP	154 ± 9.3	152 ± 15.9		
HRpeak (bpm)	MF	195 ± 8.4	199 ± 6.8	<0.001	0.450 [−1.1337 to 0.843]
	SMP	184 ± 10.2	183 ± 14.8		
TakeOffAVG (g)	MF	2.20 ± 0.39	2.27 ± 0.39	0.312	0.330 [−0.322 to 1.558]
	SMP	1.77 ± 0.90	2.27 ± 0.93		
LandingAVG (g)	MF	3.88 ± 0.32	4.45 ± 0.62	0.132	0.420 [−0.193 to 1.035]
	SMP	3.56 ± 1.36	3.85 ± 1.28		
Session RPE (AU)	MF	287 ± 22	273 ± 30	<0.001	0.101 [−0.059 to 1.634]
	SMP	191 ± 52.8	232 ± 78		

RD (m/min): relative distance covered; ExplD (m): distance covered with an acceleration greater than 1.2 m/s^2; AccMAX (m/s^2): maximum acceleration; AccRel (n/min): relative acceleration; RJumps (n/min): relative jumps; SpeedMAX (km/h): maximum speed; HRavg (beats/min): average heart rate; HRpeak (beats/min): maximum heart rate; TakeOffAVG (g): average takeoff force; LandingAVG (g): average landing force; Session RPE: total session training load; UA: arbitrary units. ** $p < 0.01$ significantly different between sexes; *** $p < 0.001$ significantly different between sexes; $^{\$}$ $p < 0.05$ significantly different between situations; $^{\$\$\$}$ $p < 0.001$ significantly different between situations. Symbols indicate significant post hoc differences ($p < 0.05$) only in cases where a significant interaction (situation × sex) or a statistical trend ($p < 0.10$) was observed. Main effects of situation are reported in the table but are not marked in individual cells.

RD showed a main effect, being significantly higher during MF compared to SMP (F = 25.14, $p < 0.001$; d = 1.58). Similarly, ExplD was also significantly greater in MF than in SMP (F = 5.24, $p = 0.028$; d = 0.72). Heart rate responses varied significantly as well, with both HRpeak (F = 16.56, $p < 0.001$; d = 1.34) and HRavg (F = 88.95, $p < 0.001$; d = 3.09) showing higher values in MF compared to SMP.

For the remaining variables analyzed, including AccMAx, AccRel, TakeoffAVG, and LandingAVG, no significant main effects were observed (all $p > 0.05$). Session RPE was also significantly greater in MF (F = 17.69, $p < 0.001$; d = 1.31).

4. Discussion

The present study revealed that multi-feeding (MF) drills elicited significantly higher external and internal loads compared to simulated match play (SMP) across key variables, including RD, ExplD, RJumps, and heart rate responses (HRavg and HRpeak). In addition, players perceived more intense MF drills than SMP, as reflected by higher Session RPE scores. These results support our original hypothesis and align with previous research in badminton [7,11] and other racket sports, such as tennis [10,27], which demonstrated that structured drills can induce substantial neuromuscular and cardiovascular stress, often exceeding that observed during match play. Notably, the large effect sizes observed for RD (d = 1.58), HRavg (d = 3.09), and RJumps (d > 1.4 in both sexes) suggest that these differences are not only statistically significant but also practically meaningful, highlighting MF drills as a potent stimulus capable of inducing high training loads. These findings suggest that MF drills offer a valuable opportunity for controlled overload, particularly when aiming to target specific physical capacities such as repeated accelerations, jump frequency, and explosive efforts. Given that MF sessions elicited greater overall loads than SMP, practitioners should consider strategically implementing these drills to enhance player conditioning, simulate peak match demands, and improve players' tolerance to high-intensity efforts. Moreover, load monitoring during multi-feeding should be emphasized to ensure adequate recovery periods are prescribed, minimizing the risk of non-functional overreaching or injury in developing athletes.

A secondary aim of this study was to explore whether sex moderated internal and external load profiles of MF and SMP. In this regard, males demonstrated consistently higher RJumps and preserved higher SpeedMAX across both MF and SMP conditions, with statistically significant sex × situation interaction effects observed for these two variables. This confirms earlier findings, reported during an international junior tournament [6], showing sex-based differences in movement demands, with male athletes typically achieving greater distances, more accelerations, and higher frequencies of explosive actions. Notably, HR and RPE values were similar between sexes despite these external differences, which may indicate that female players experience greater relative internal strain when exposed to comparable workloads [13]. These observations highlight the limitations of homogenized, mixed-gender training practices in badminton [6,11], and reinforce the need for individualized conditioning strategies that account for sex-specific responses. This dissociation between internal and external load responses reinforces the practical significance of individualized load management, especially in female athletes, even when statistical interactions are modest (e.g., SpeedMAX interaction effect, d = 1.52 in females, negligible in males).

Despite the substantial differences identified in several metrics, not all variables showed significant effects of training condition or sex. Interestingly, some mechanical variables such as AccRel, TakeOffAVG, and LandingAVG did not differ significantly across training formats (MF vs. SMP) or between sexes. These findings suggest that certain movement characteristics may be relatively stable, and MF drills may effectively replicate the mechanical demands of competition in terms of movement quality. Considering that the literature has highlighted these mechanical parameters as key contributors to badminton performance [6], the use of MF drills appears particularly relevant when aiming to reproduce match-specific neuromuscular demands. Although the effect sizes for these variables were small or trivial (d < 0.3), the lack of difference itself is informative—indicating that MF drills can mirror key performance-related mechanics of real match play, offering a training environment that safely replicates sport-specific neuromuscular load. This stability could be attributed to the highly specific and repetitive movement patterns inherent in badminton [11], where jumps and landings are frequent but often standardized in their execution. This stability in mechanical loads may also suggest that neuromuscular demand is modulated more by overall intensity and density of movement (as in MF) than by isolated jump or landing mechanics.

From a practical perspective, these results emphasize the importance of carefully designing multi-feeding drills when aiming to replicate or exceed match demands. Coaches should consider interval duration, work-to-rest ratio, and tactical focus depending on the desired physiological adaptation. In this regard, previous research has shown that if the training goal is to emphasize alactic power and explosive output, shorter intervals with limited rest—as implemented in certain MF blocks—may be optimal [7]. Conversely, to improve aerobic or lactate tolerance, coaches may opt for longer work intervals with more sustained movement [11].

Importantly, given the observed sex-related differences in external load and similarity in internal responses, individualized adjustments in volume, intensity, and recovery should be considered to avoid potential overuse or under-stimulation, particularly in female players [13].

Finally, our results suggest that although simulated match play can approximate certain aspects of competitive badminton (e.g., tactical decision-making, psychological pressure), it may underrepresent the highest physiological demands encountered during tournaments. Thus, integrating both MF and SM formats within a periodized training plan appears essential for holistic athlete preparation.

This study has several limitations that must be acknowledged. The short-term, cross-sectional design limits our ability to infer chronic adaptations or long-term performance effects. Internal load was assessed solely via HR and RPE, omitting additional physiological markers such as blood lactate or hormonal fluctuations. Furthermore, technical execution and tactical decision-making, which may differ considerably between MF and SMP, were not directly measured. Lastly, while our findings are relevant to elite junior badminton, caution should be taken when generalizing results to elite or novice populations. Future research should expand to include longitudinal designs, broader internal load monitoring, and assessments of technical-tactical efficiency. Additionally, the MF-SMP comparison model presented here could be adapted to other racquet or intermittent sports lacking such direct evidence.

5. Conclusions

This study demonstrated that MF drills elicited greater internal (HRavg, HRpeak, session RPE) and external (RD, ExplD, RJumps) loads compared to SMP in elite junior badminton players. These findings indicate that MF sessions can serve as an effective strategy for imposing high physiological and neuromuscular stress in a controlled training environment. Although male players exhibited higher absolute physical values across conditions, significant sex $\times$ situation interactions were limited to RJumps and SpeedMAX. The similarity in HR and RPE responses between sexes suggests that female players may experience greater relative physiological strain under matched external loads. From a practical perspective, MF drills can be used to target specific physical capacities—such as repeated explosive efforts and aerobic load—but should be tailored to individual player characteristics, including sex, training status, and recovery capacity. Training programs should integrate both MF and SMP formats to balance physiological overload with tactical and decision-making realism. Given the limitations of short-term observation and the exclusion of technical-tactical and biochemical measures, future research should assess long-term adaptations, expand physiological monitoring, and examine the transfer of these training formats to performance outcomes in both racket and other intermittent sports.

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Informed Consent Statement: All participants and their parents/guardians were fully informed about the study protocol and both parents/guardians and participants provided their written informed consent.

Data Availability Statement: The data sets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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