Analysis of successive badminton matches accumulation on neuromuscular fatigue and perceived effort in a national badminton competition

Análisis de la acumulación sucesiva de partidos de bádminton en la fatiga neuromuscular y el esfuerzo percibido en una competición nacional de bádminton

Carlos Rubio-Arrabal [1,2], Francisco J. Barrera-Domínguez [1], Héctor Vázquez-Lorente [3], Elena Planells [3] & Jorge Molina-López [1,3] *

1 Faculty of Education, Psychology and Sport Sciences, University of Huelva, Huelva, Spain.
2 Andalusian Centre Specialized for Sports Technification (CAETD) in Badminton, Huelva, Spain.
3 Institute of Nutrition and Food Technology, Biomedical Research Centre, Health Sciences Technological Park, University of Granada, Granada, Spain.

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Abstract

The present study explores how fatigue evolves throughout a single-day national badminton tournament involving five consecutive matches, by examining practical and low-cost fatigue metrics. Eleven U-17 athletes (14-16 years old; 45% women) were evaluated in a real competition using subjective assessments, including the rate of perceived exertion (RPE), session RPE (sRPE), the muscular fatigue visual analog scale (MFVAS), and the total quality recovery test (TQR), as well as objective measures like countermovement jump peak height (CMJh), drop jump peak height (DJh), and drop jump reactive strength index (RSI) before and after each match. Results showed significantly higher RPE, sRPE, and MFVAS scores and significantly lower CMJh and DJh values in the last matches compared to the first ($p<0.05$; large effect). sRPE showed a positive moderate-strong relationship with match characteristics, including the number of points ($p<0.01$), sets played ($p<0.05$), and match duration ($p<0.01$). The findings indicate that RPE, sRPE, and MFVAS are the most sensitive metrics for assessing fatigue, with DJh being more effective than CMJh among objective measures, while RSI and TQR showed limited sensitivity. These results offer coaches practical tools for monitoring athlete fatigue during competitions.

Keywords: *competition, fatigue, performance, badminton, youth.*

Resumen

El presente estudio explora cómo evoluciona la fatiga a lo largo de un torneo nacional de bádminton de un solo día que incluyó cinco partidos consecutivos, examinando métricas subjetivas y objetivas. Once atletas sub-17 (14-16 años; 45% mujeres) fueron evaluados en una competición real utilizando evaluaciones subjetivas, incluyendo la tasa de esfuerzo percibido (RPE), la RPE de la sesión (sRPE), la escala visual analógica de fatiga muscular (MFVAS) y la prueba de recuperación de calidad total (TQR), así como medidas objetivas como la altura máxima del salto con contramovimiento (CMJh), la altura máxima del salto con caída (DJh) y el índice de fuerza reactiva del salto con caída (RSI) antes y después de cada partido. Los resultados mostraron puntuaciones significativamente más altas de RPE, sRPE y MFVAS y valores significativamente más bajos de CMJh y DJh en los últimos partidos en comparación con el primero ($p<0,05$; gran efecto). El sRPE mostró una relación positiva, moderada-fuerte, con las características del partido, incluyendo el número de puntos ($p<0,01$), los sets jugados ($p<0,05$) y la duración del partido ($p<0,01$). Los hallazgos indican que el RPE, el sRPE y la MFVAS son las métricas más sensibles para evaluar la fatiga, siendo el DJh más eficaz que el CMJh entre las medidas objetivas, mientras que el RSI y el TQR mostraron una sensibilidad limitada. Estos resultados ofrecen a los entrenadores herramientas prácticas para monitorizar la fatiga de los atletas durante las competiciones.

Palabras clave: *competición, fatiga, rendimiento, bádminton, joven.*

Corresponding author: Jorge Molina-López, jorge.molina@ddi.uhu.es

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INTRODUCTION

Badminton is a racket sport characterized by intermittent actions, jumping, changes of direction and rapid arm movements with a high demand on aerobic power, alactic anaerobic and to a lesser extent lactic anaerobic metabolic systems (Cabello Manrique & González-Badillo, 2003). Achieving high levels of physical performance is essential for success, given the sport's intense physiological requirements (Phomsoupha & Laffaye, 2015). Torres-Luque et al. (2019) investigating both male and female high-level adult badminton players across group and elimination phases of international competitions, recorded notable differences in match characteristics as championships progressed. Similarly, in a study focusing on Olympic-level male singles (Chiminazzo et al., 2018), observed that point duration and strokes per point increased from the group phase to the elimination phase, particularly in the third set. In competitive badminton, athletes often face multiple matches in a single day, especially during tournaments. While the physical toll of such match schedules has been acknowledged, there is limited research addressing how the cumulative demands of several matches affect young athletes' performance during real competitions. Existing studies have primarily focused on isolated matches or simulated conditions, in many cases with adult athletes (Birdsey et al., 2019; Ojala & Häkkinen, 2013), whereas Moreno-Perez et al. (2020) did examine junior players, underscoring the need for research on how multiple matches within a single day affect fatigue and recovery in developmental-aged badminton athletes under real competitive conditions.

Monitoring athlete response to fatigue or physical performance during competition is a common approach that reveals the competition requirements, facilitating preparation and guiding athletes and coaches towards practices that can lead to increased athletic performance (Abián-Vicén et al., 2014; Faude et al., 2007; Gomes et al., 2014; Maraga et al., 2018; Ojala & Häkkinen, 2013). Understanding the progression of fatigue during competition is essential for coaches and athletes to optimize performance and recovery strategies. Monitoring tools like the rate of perceived exertion (RPE), session RPE (sRPE), and the Muscle Fatigue Visual Analog Scale (MFVAS) offer practical, subjective methods to assess internal load (Foster et al., 2001; Kenttä & Hassmén, 1998). Meanwhile, objective measures such as countermovement jump peak height (CMJh) provide insights into neuromuscular fatigue, although their sensitivity in racket sports remains debated (Heishman et al., 2020; Abián-Vicén et al., 2012).

In relation to the perceived load and the characteristics of the matches, it has been reported that after two accumulated matches in a real competition, no significant differences are seen in perceived exertion in the match during the session sRPE, muscle pain or lower limb strength determined by CMJh - suggesting that the muscular performance of the lower limbs is not negatively affected by the accumulation of matches. Moreno-Perez et al. (2020) and Abián-Vicén et al. (2014) found that although a single match did not lead to a reduction in CMJh in a real competition, the accumulation of competitive rounds during competition did lead to a reduction in relation to the post-match vertical jump of previous rounds. Moreover, CMJh was not only not negatively affected after a singles badminton match, but the peak jump height was greater post-match versus pre-match, suggesting a lack of muscle fatigue caused by the match (Abián-Vicén et al., 2012). The absence of negative effects on CMJh would agree with the results obtained in tennis (López-Samanes et al., 2018; Maraga et al., 2018; Ojala & Häkkinen, 2013) and in accordance with other authors (Bishop et al., 2023) indicating the lack of sensitivity of CMJh as a neuromuscular fatigue monitoring metric. Thus, to date, the data found in the scientific literature are controversial and inconsistent.

Many studies have examined a simulated competitive situation or analyzed the effect of one or two badminton matches on jumping ability, vertical strength or RPE of elite senior athletes (Abián-Vicén et al., 2012, 2014; Lin et al., 2023), though no studies to date have analyzed the cumulative effect of more than two matches during a real competition on the same day in young athletes.

To address this gap, the present study aimed to investigate the evolution of fatigue across five consecutive matches during a single-day U17 national badminton tournament. A combination of subjective —RPE, sRPE, MFVAS, total quality recovery test (TQR)— and objective —CMJh, drop jump peak height (DJh), reactive strength index (RSI)— measures was employed to examine changes in internal and neuromuscular load. These tools were selected based on their frequent use in monitoring fatigue and recovery in athletic populations, although their sensitivity in youth badminton contexts remains unclear. Rather than offering generalizable claims, this study seeks to provide context-specific insights that may assist coaches and practitioners in understanding the fatigue profiles of youth athletes and selecting practical monitoring tools in real-world competition.

MATERIALS AND METHODS

Participants

A total of 11 badminton players with a mean age, height and weight of 15±0.7 years, 172.2±7.81 cm and 63.3±9.77 kg were voluntarily recruited from two Specialized Centers for Sports Technification (CETD). All the athletes were U17 Spanish players. Among the athletes, four had been selected at least once as members of the National Team to participate in International Competitions, including

one of the athletes participating in the U15 European Championship the previous year, and another of them ranked third in the U17 European Badminton Circuit Rankings in Singles (Table 1). As inclusion criteria for participation in the study, all the athletes had to train regularly at least 5 days a week (12-15h per week); were required to have a minimum of two years of experience in strength training; were required to have been competing at a national level for at least 5 years; had to participate annually in National and International Competitions; and had to be free of current injury or injury in the three months prior to the competition.

Design & procedures

A quasi-experimental repeated measures study was designed to determine the evolution of neuromuscular fatigue before and after each match, as well as its evolution throughout 5 matches in a one-day national competition, and its influence on sports performance. The measurements were performed during a badminton competition scoring for the National Ranking (8/10*) at the beginning of the competitive season in Huelva (Spain), in October 2020. The present study was conducted according to the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants, and the study was approved by the local Research Ethics Committee.

Two weeks before the competition, the organizational staff were informed, and the study protocol was approved. The week prior to the competition, the athletes were informed of the objectives of the study and were specifically familiarized with the protocol and the tests to be performed. On the day of the competition itself, and before it began, the club managers and referees were informed of the pre-match and post-match measurement procedures for data collection.

The competition was indoors and at a room temperature of 21ºC. The matches were played on painted courts on the floor of the facility (floating platform) or on a two-piece badminton court, and the shuttlecocks used were “Yonex Aerosensa 30” speed 3 - both approved by the Badminton World Federation (BWF). No nutritional, recovery or warm-up recommendations were given before or during the competition, so as not to influence the individual competitive routine of each athlete. The athletes played a total of 5 matches throughout the same day (9:00 am to 9:00 pm) during a real competition and scoring for the National Ranking (8 stars complying with the requirements imposed by the Spanish Badminton Federation) (Federación Española de Bádminton [FESBA], n.d.). The measurements were taken both before (pre-match) and after (post-match) each match played. The pre-match measurement was performed just after the warm-up and approximately 5 minutes before the match started (MFVAS, TQR, CMJh and DJh). Post-match measurements in turn were taken within 5 minutes after the end of the match (MFVAS, RPE, sRPE, CMJh and DJh). Both the pre- and the post-match measurements were performed in the same order.

Session Rating of Perceived Session Effort Ratio (sRPE)

The internal load imposed on the athletes by each match was monitored through the rate of perceived exertion RPE in the 5 minutes following the end of each match. The measurement was made based on a scale from 0 to 10, where the athletes were informed that 0 meant “not being fatigued at all” and 10 meant “the most extreme physical fatigue they could imagine”. This value was then multiplied by the corresponding match time in minutes, indicating the total match load (sRPE) in Arbitrary Units (AU) (Foster et al., 2001). Athletes were encouraged to give the most representative value of the real situation.

Muscle Fatigue Visual Analog Scale (MFVAS)

To determine the level of muscle fatigue in the lower body, the Muscle Fatigue Visual Analog Scale MFVAS was used both pre- and post-match (Leung et al., 2004). This scale consisted of a 100 mm line on which the athletes were instructed to mark a transversal line with a ballpoint pen. Bearing in mind

Table 1
Sample characteristics

Characteristics	Age (years)	Height (cm)	Body mass (Kg)	Category	National Team	Training frequency (days/week)	Training volume (hours/week)	National experience (years)	International experience (years)	Singles ranking (position)	Doubles ranking (position)
Athlete 1	15	185	71	17	Si	5	12	5	1	9	-
Athlete 2	15	167	58	17	No	5	12	5	1	22	2
Athlete 3	15	164	51	17	No	5	12	5	1	16	2
Athlete 4	15	168	62	17	Si	5	14	5	5	43	-
Athlete 5	15	160	62	17	Si	5	14	6	6	6	71
Athlete 6	16	173	63	17	No	5	10	5	1	15	1
Athlete 7	16	178	62	17	No	5	14	5	2	37	5
Athlete 8	14	168	59	17	Si	5	14	5	5	-	-
Athlete 9	16	183	79	17	No	5	12	5	1	116	-
Athlete 10	14	176	79.7	17	No	5	14	5	3	114	-
Athlete 11	15	172	50	17	No	5	14	5	5	108	-

that the beginning of the line meant "very muscularly rested" and the end "very muscularly fatigued", the athlete had to mark the point within the range with which he/she best identified muscle fatigue in his/her legs at that moment. The final value was the distance in millimeters from the beginning of the line to the mark made by the athlete.

Total Quality Recovery (TQR) scale

As a method of monitoring the psycho-physiological recovery of the athletes between matches, use was made of the Total Quality Recovery TQR scale, a numerical score from 6 to 20, where the athlete was required to report the subjective value within the scale that best represented his/her current recovery status (Kenttä & Hassmén, 1998). Before the start of each match, the athletes were asked about their state of recovery using this scale. On the latter, the athletes were instructed to indicate a value between 6 ("totally rested") and 20 ("not rested at all"), encouraging them to give the value most representative of reality.

Lower Extremity Muscle Strength

The countermovement jump CMJ and drop jump DJ tests were performed (Chronojump BoscoSystem®, Barcelona, Spain) with the objective of measuring the application of force in lower limb plyometric actions of long (CMJ) and short (DJ) stretch shortening cycles (SSC) (Young et al., 1995). Both jumps were performed bilaterally, and the athletes were instructed to jump with their hands on their waists to limit contribution of the upper limbs to jump height. The landing contact position had to be identical to the take-off position. In this way, if at the first landing contact the ankle, knee and hip were not fully extended, the jump was not considered valid and had to be repeated after a brief rest. The CMJ and DJ by peak height and minimum contact time were performed according to the described literature (Young et al., 1995). The reactive strength index RSI was calculated using the time of flight to contact time ratio - both times drawn to the DJ test. For both jumps, a total of two attempts were performed, with a resting time of 90 seconds between jumps. Then, the mean of the peak height achieved in both attempts was used for further analysis. The reliability of CMJh, DJh and RSI was established, yielding a coefficient of variation (CV) of 8.7%, 9.3% and 14.8%, with an inter-class correlation coefficient (ICC) of 0.94, 0.87 and 0.82, respectively.

Analysis

Data analyses were performed using the SPSS version 25 statistical package for MS Windows (SPSS, Inc., Chicago, IL, USA). Data were expressed as means and standard deviations (SD). The normality of the data was tested using the Shapiro-Wilks test. The student t-test for paired samples was used to determine the mean differences between paired observations. Statistical differences were calculated, and the precision of the estimates was indicated with 95% confidence. Cohen's d coefficient determined the magnitude of the differences: trivial (0-0.2); small (0.2-0.6); moderate (0.6-1.2); large (1.2-2); or very large (>2) (Batterham & Hopkins, 2006). Pearson's correlation coefficients (r) were calculated to examine the relationship between the match characteristics and the athlete performance variables of interest: trivial (0.0-0.1); small (0.1-0.3); moderate (0.3-0.5); high (0.5-0.7); or very high (> 0.7) (Hopkins et al., 2009).

RESULTS

Match characteristics

Table 2 shows the match characteristics during the one-day competition. The match duration was 27.9±9.29 minutes, with an average rest time of 51.7±45.0 minutes between matches. Games were decided into 2.27±0.46 sets and 80.6±19.8 points per match.

Pre-post-match effect on physical performance

Table 3 shows the physical performance outcomes before and after the matches. Regarding CMJh, DJh and RSI, no significant changes were observed for any of

Table 2
Match characteristics

Variable	Match 1	Match 2	Match 3	Match 4	Match 5	Total
Rest time (min)	-	54.4 (48.3)	66.8 (60.0)	46.6 (33.7)[d3]	75.6 (32.9)[d3]	51.7 (45.0)
Points (nº)	85.4 (17.1)[a3]	72.1 (17.8)[a3]	80.5 (21.9)	81.54 (24.0)	83.36 (18.45)	80.6 (19.8)
Sets (nº)	2.36 (0.5)	2.18 (0.40)	2.27 (0.5)	2.27 (0.5)	2.27 (0.47)	2.27 (0.5)
Match duration (min)	29.0 (6.6)[a3]	22.6 (10.14) [a3,b3]	28.2 (8.9)	28.4 (11.9)	31.2 (8.9)[b3]	27.9 (9.3)

*Statistically significant differences (p<0.05): a = Match 1 vs rest of matches; b = Match 2 vs rest of matches; c = Match 3 vs rest of matches; d = Match 4 vs rest of matches; e = Match 5 vs rest of matches. Cohen's d effect size: trivial (0 to 0.2); small (0.2 to 0.6); moderate (0.6 to 1.2); large (1.2 to 2) and very large (> 2).

the analyzed study outcomes. In relation to MFVAS, a significant increase was observed as the competition evolved in both the pre-match and the post-match values, with a statistically significant increase between the average of all the pre-match and post-match values (p <0.05). Specifically, moderate to large effects were observed between the pre-match and post-match values in matches 1, 4 and 5 (all, p <0.05; ES = 1.17 to 1.81).

Effect of match accumulation on physical performance

Badminton players progressively increased RPE from the second match, with an increase between the post-match values of matches 2 and 4 (p<0.05; ES = 0.99), as well as between the post-match values of matches 2 and 5 (all p<0.05; ES = 0.83 to 0.99). In relation to sRPE, were significantly higher in the first match, match 4, and match 5 (all p < 0.05; ES = 1.18 to1.41) compared with the second match, with the last showing the highest values

Regarding lower limb strength, a moderate to large increase in CMJh was observed from post-matches 1 and 2 with match 5 (all p <0.05; ES = 1.17 to 1.38). For DJh, moderate reductions were recorded between post-matches 2 and 4, as well as a large reduction between post-matches 2 and 5 (all p <0.05; ES = 0.94 and 1.63, respectively) - evidencing a downward trend in post-match values as the competition progressed. Likewise, for the pre-match DJh values, moderate reductions were found between pre-matches 2 and 5, pre-matches 3 and 4 and pre-matches 3 and 5 (all p <0.05; ES = 0.93 to 1.17), again with a clear reduction as the competition progressed, and all with a moderate effect. Finally, for MFVAS, a moderate increase were observed between post-matches 2 and 4 (p <0.05; ES = 1.11), with an upward post-match trend from match 2, and a notable increase in match 4.

Relationship between match characteristics and physical performance

Table 4 reports the relationship between the match characteristics and physical performance. Regarding the subjective load variables, a moderate-strong association was observed between sRPE and match duration in match 2 (r=0.782; p<0.05), match 4 and match 5 (r=0.964 and r=0.966 respectively; both p<0.01); the number of sets played in match 2, match 3, match 5 (r=0.782, r=0.789 and r=0.688 respectively; all p<0.05) and match 4 (r=0.941; p <0.01); and the points played in match 4 and match 5 (r=0.902 and r=0.920; both p<0.01). In turn, TQR was associated with the points played in match 3 (r=-0.058; p=0.001). Finally, post MFVAS was moderately related to the number of sets played in match 5 (r=0.703; p = 0.035). With respect to objective load, in the case of CMJh an indirect association was observed to the number of sets played in match 5 (r=-0.767; p = 0.044), the rest time in match 4 (r=-0.785; p = 0.036), the points played in match 5 (r=-0.711; p = 0.032), and the match duration in match 5 (r=0.757; p = 0.018).

DISCUSSION

This study explores how fatigue evolves throughout a single-day national badminton tournament involving five consecutive matches, by examining subjective and objective metrics. We also aim to identify practical, cost-effective monitoring strategies that coaches and organizations with limited resources can implement. Our main findings indicate that match time,: (i) match time, RPE, sRPE and MFVAS (pre- and post-match) increased as the competition evolved, while DJh (pre- and post-match) decreased; (ii) the first match of the day was physically more demanding than the second

Table 3
Comparative analysis of the physical performance outcomes before and after match throughout one-day competition

Variable	Match 1	Match 2	Match 3	Match 4	Match 5	Mean
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
RPE (AU)	7.33 (1.59)	5.21 (2.16)^{b34}	6.26 (2.41)	7.29 (1.64)^{b3}	7.12 (1.76)^{b4}	6.64 (1.91)
sRPE (AU)	195.0 (96.1)^{a4}	94.4 (95.0)^{a4,b34}	187.7(100.5)	254.9 (130.8)^{b3}	240.5 (117.5)^{b4}	194.5 (108.0)
TQR (AU)	16.1 (3.06)	15.3 (3.95)	16.1 (2.52)	14.2 (2.86)	16.0 (2.45)	15.4 (2.86)
CMJh (cm)						
Pre-match	29.6 (7.03)	29.31 (6.71)	29.2 (7.12)	28.7 (6.75)	29.2 (6.27)	29.2 (6.78)
Post-match	30.1 (5.27)	28.3 (7.38)^{b3}	28.7 (5.83)	28.6 (4.87)	29.4 (6.70)^{b3}	29.0 (6.01)
DJh (cm)						
Pre-match	24.8 (3.92)	25.8 (5.50)^{b3}	25.1 (3.80)^{c3}	22.4 (2.74)^{c3}	22.9 (3.12)^{b3,c3}	24.2 (3.82)
Post-match	25.7 (4.08)	25.7 (4.57)^{b344}	24.2 (4.32)^{c5}	24.5 (5.00)^{b3}	23.7 (4.07)^{b4}	24.7 (4.41)
RSI						
Pre-match	1.77 (0.48)	2.08 (0.42)	1.97 (0.47)	1.85 (0.39)	1.84 (0.25)	1.90 (0.49)
Post-match	1.81 (0.39)	1.95 (0.53)	1.96 (0.34)	2.00 (0.68)	1.80 (0.51)	1.90 (0.40)
MFVAS (mm)						
Pre-match	25.9 (19.8)	36.9 (29.0)	34.1 (29.1)	37.6 (23.5)	41.5 (23.1)	35.2 (24.9)
Post-match	54.0 (23.4)*^{4}	42.0 (23.9)^{b3}	53.1 (26.3)	60.7 (13.9)*^{4,b3}	54.7 (20.8)*^{3}	52.9 (21.7)*^{5}

RPE, Rate of perceived exertion; sRPE, session RPE; TQR, total quality recovery test; CMJh, countermovement jump peak height; DJh, drop jump peak height; RSI, drop jump reactive strength index; MFVAS, muscular fatigue visual analog scale. *Statistically significant pre-post differences (p<0.05): a = Match 1 vs rest of matches; b = Match 2 vs rest of matches; c = Match 3 vs rest of matches; d = Match 4 vs rest of matches; e = Match 5 vs rest of matches; f = Mean pre vs Mean post. Cohen's d effect size: 1 = trivial (0 to 0.2); 2 = small (0.2 to 0.6); 3 = moderate (0.6 to 1.2); 4 = large (1.2 to 2); 5 = very large (> 2).

and even the third in terms of match time, points played, RPE, sRPE and post-match MFVAS and; (iii) a positive stable relationship was present between sRPE and the number of points and sets played in a match, as well as its duration. This would suggest that the accumulation of 5 matches in the same day in a national U-17 8* badminton competition would lead to an increase in physical demands as the competition progresses, with RPE, sRPE, MFVAS and DJh being metrics more sensitive to such fatigue than CMJh, RSI and TQR.

Our results evidenced a clear increase in the demands imposed by the matches as the competition progressed, with an increase in match time and a slight increase in the number of sets played. The mean match duration of 27.9±9.3 minutes was shorter than that recorded in other studies analyzing Spanish badminton championships, with a mean duration of 34.6±8.4 and 41.3±15.9 minutes in the second round and quarterfinals, respectively (Abián-Vicén et al., 2014). These differences in terms of match duration with respect to the data provided by the study of Abián-Vicén et al. (2014) may be due to the fact that the competitive level of the athletes was higher in their study (an absolute category tournament versus U17 in our work). Despite this, our results are in agreement with the findings of other authors in which a mean match duration of 27.1±5.6 was reported in the "XI Spanish Junior International" (Moreno-Perez et al., 2020).

To gain a more insightful overview of match demands as the competitive round progresses, we observed changes in match duration, rest time and in the RPE, sRPE, DJh and MFVAS scores. Authors such as Moreno-Pérez et al. (2020) did not find significant differences between daytime sRPE values (148.6±66.0 versus 156.6±74.8 AU) or in post-match MFVAS scores (28±24 versus 32±21 mm) between two matches performed on the same day in 21 badminton players in an international junior competition. This suggests that two matches may not induce sufficient cumulative fatigue, whereas five matches provide a clearer picture of accumulated physical demands. In our study, the increased demands were accompanied by an increase in RPE and a reduction in DJh as the competition progressed. This would make sense given the structure and organization of the competition, where those athletes with the highest-level move from round to round so that in each round the confrontation proves more demanding than the previous one, resulting in an increase in points played per match, match time and rest time within the match due to the high

Table 4
Relationship between match characteristics and both pre-match and post-match performance variables

	RPE (AU)	sRPE (AU)	TQR (AU)	CMJh (cm)		DJh (cm)		RSI		MFVAS (mm)	
				Pre	Post	Pre	Post	Pre	Post	Pre	Post
Match 1											
Rest time (min)	.104	.404	.354	-.115	-.245	.033	-.108	-.237	-.256	-.434	-.150
Played points	.462	.132	-.500	-.163	.481	-.058	.590	-.383	-.083	-.195	.346
Played sets (nº)	.334	.093	.054	-.411	.234	-.127	.552	-.200	.109	-.363	.275
Match duration (min)	.669*	.441	-.122	-.210	.060	-.424	-.054	-.703*	-.641*	.086	.421
Match 2											
Rest time (min)	.457	.197	-.504	.285	-.050	-.509	-.512	-.320	-.323	-.086	.029
Played points	.252	.583	.343	-.134	-.193	-.215	-.323	-.336	-.324	-.409	-.390
Played sets (nº)	.256	.782*	.415	-.201	-.213	-.103	-.258	-.199	-.188	-.469	-.386
Match duration (min)	.434	.668*	.546	-.437	-.411	-.281	-.348	-.178	-.165	-.299	-.139
Match 3											
Rest time (min)	-.674	-.423	.307	-.175	-.011	.225	.042	.089	.082	.212	.148
Played points	-.008	.603	-.058**	-.348	-.036	-.435	.126	.815*	.830*	-.137	-.137
Played sets (nº)	.140	.789*	-.358	-.462	-.205	-.595	-.203	.669	.693	.219	.022
Match duration (min)	.001	.716	-.357	-.506	-.169	-.633	-.252	.644	.668	.299	-.012
Match 4											
Rest time (min)	.445	.699	.029	-.401	-.785*	-.618	-.683	-.083	-.092	.360	.264
Played points	.552	.902**	.357	-.225	-.484	-.067	-.528	-.311	-.342	.124	.438
Played sets (nº)	.596	.941**	.380	-.357	-.581	-.117	-.585	-.288	-.317	.171	.46
Match duration (min)	.657	.964**	.309	-.350	-.571	-.208	-.554	-.243	-.269	.139	.453
Match 5											
Rest time (min)	.324	.578	.133	-.219	-.631	.040	-.860**	-.266	-.303	.431	.309
Played points	.601	.920**	.071	-.538	-.711*	-.537	-.594	-.182	-.197	.632	.530
Played sets (nº)	.603	.688*	.148	-.767*	-.627	-.492	-.574	-.364	-.388	.664	.703*
Match duration (min)	.702*	.966**	.094	-.648	.757*	-.574	-.598	-.243	-.256	.715	.649

RPE, Rate of perceived exertion; sRPE, session RPE; TQR, total quality recovery test; CMJh, countermovement jump peak height; DJh, drop jump peak height; RSI, drop jump reactive strength index; MFVAS, muscular fatigue visual analog scale. Data are presented as Pearson correlations (r), being trivial (0.0 - 0.1); small (0.1 - 0.3), moderate (0.3 - 0.5), high (0.5 - 0.7) and very high (> 0.7). *Significant correlation (p<0.05). **Significant correlation (p<0.01).

demands and more similar levels between players. Our data are consistent with those reported by Torres-Luque et al. (2019) and Abián-Vicén et al. (2014), who found an increase in the demands of each match as the competition progressed. When comparing the demands and characteristics between the matches analyzed in this study and those found in other high-level competitions, it becomes evident that our athletes are in a process of development as badminton players.

Our findings regarding MFVAS are in accordance with those of Lin et al., (2023), who also found a significant increase between pre- and post- singles simulated 1-h matches, supporting the observation of the neuromuscular fatigue caused by a single match. Although MFVAS reflects accumulated fatigue in the lower body, this fatigue affected performance in DJh, but not CMJh or RSI. The absence of CMJh jump reduction would coincide with the observations of Moreno-Pérez et al. (2020) and Abián-Vicén et al. (2012) in several badminton matches on the same day, while differing with those of Abián-Vicén et al. (2014). In our study, the lack of CMJh sensitivity as a metric of lower limb neuromuscular fatigue, likewise reported by RPE, sRPE, MFVAS and DJh after several matches is in accordance with Bishop et al. (2023), which supports the theory that CMJ neuromuscular fatigue sensitive metrics are time-based and not output based. To our knowledge, no studies have evaluated RSI or DJh as a reliable metric of lower body neuromuscular fatigue in an official racquet sports competition involving 5 matches on the same day.

In our study, we also observed that the requirements of the first match were greater than in the second match for RPE, sRPE, points played and game duration, and even greater than in match 3 for RPE, sRPE, post-match MFVAS and game duration. Such findings are consistent with those of Maraga et al. (2018), who found the first match to be more demanding than the second match, and with the second match in turn being less demanding than the third match in junior athletes during a simulated tennis competition with three singles matches on the same day. This could be due to the psychological difficulty for athletes to solve the first match of the day and thus start the tournament, though the difference in the level of the players is even greater than in the later matches. In contrast, Gallo-Salazar et al. (2019) documented an increase in total match duration, point duration, rest duration and RPE in the second match with respect to the first match during a simulated competition with two tennis matches on the same day (one in the morning and the other in the afternoon). The comparison of our results with those of other studies is difficult, to the best of our knowledge, no other studies have analyzed 5 or more matches on the same day in a real badminton competition in this age group, and the evidence is still inconsistent.

Regarding the relationships between the match characteristics and physical performance, we found a clear correlation between the number of sets, the number of points, match time and sRPE. As match duration and points played increase, so does effort, which directly influences sRPE calculations (Foster et al., 2001), These associations align with expectations for cumulative fatigue markers. Likewise, RPE was also positively related to match time, indicating that the longer the match time, the greater the athlete perception of effort. Moreover, our match characteristics were also associated - albeit punctually - to the physical performance variables, which would indicate the lack of a stable association between the two. These findings may be indicative of the complex nature of a badminton match and competition where several factors, in addition to those contemplated in our study, may influence cumulative fatigue - thus making it difficult to identify a more stable association between match-specific demands and the physiological response of the badminton player.

This study has some limitations that should be addressed. On one hand, the public health situation caused by Covid-19 forced paralyzing training of the athletes while they advanced in category during that time. This produced a mismatch in the national ranking, due to which the level of the athletes in the category was not faithfully represented by their position in the ranking and therefore the seeded athletes in the competition. On the other hand, the organizational health and safety procedures that had to be adopted, added to the natural rhythm of the competition, did not allow the participation of a greater volume of athletes. Thus, future research should focus on clarifying the relationship between objective and subjective variables with respect to their sensitivity to fatigue, as well as the SSC mechanisms most affected by fatigue in a badminton competition with several matches on the same day in a more stable national ranking situation and with a larger volume of subjects.

CONCLUSIONS

Our results evidenced a clear increase in the demands imposed by the matches as the competition progressed, with an increase in match time and a slight increase in the number of sets played. Interestingly, the first match of the competition, contrary to expectations, was observed to be more physically demanding than the second or third matches. This seems to indicate that even the highest-level athletes within a competition find it difficult to debut and deal with the first match and start the competition. In the context of this specific U17 national badminton competition, RPE, sRPE, DJh, and MFVAS appeared to be the most sensitive parameters for monitoring fatigue across multiple matches in a single day. These findings should be interpreted as exploratory and context-specific, as further research is needed to confirm their sensitivity and generalizability to other age groups or competitive settings. Conversely, TQR, CMJh, and RSI

demonstrated more limited sensitivity in this context. Lastly, preliminary relationships were observed between match characteristics (e.g., duration) and sRPE, RPE, and other fatigue indicators. These results contribute to the scientific understanding of fatigue dynamics during youth competitions and may offer practical guidance for coaches seeking cost-effective, portable tools to assess fatigue. However, caution is warranted in generalizing these results beyond this specific competition setting.

CONTRIBUTIONS

All the authors contributed to data collection, data analysis, bibliographic review, manuscript writing, revision and correction.

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CONFLICTS OF INTEREST

No potential conflict of interest was reported by the author(s).

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