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Effects of 2 consecutive badminton matches on motor and cognitive abilities among adult elite badminton players

An observational study

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Abstract

The goal of our study was to investigate the effect of 2 consecutive badminton matches among elite badminton players on visuomotor integration, dynamic balance ability, inhibitory control, short-term memory capacity, and changes in cardiovascular fitness. Badminton is the fastest racket sport regarding the speed of the shuttle leaving the racket. The play with open move skills is characterized by series of short range and high intensity workload phases. The effectiveness is affected by the execution of the specific movement techniques within a certain time period and the optimal function of decision-making techniques. The experiment included a tournament with 2 simulated matches among elite, adult, male badminton players. The quality of visuomotor integrity and dynamic balance task were measured with Blazepod modified adapted Y-Balance Test induced reactive balance test, pre and post matches. Stroop test was used to evaluate the inhibition capability, and Digit Span Test was applied to measure the cognitive short-term capacity. Remarkable changes could not be detected in the visuomotor reaction in each time points. Gradual increase was observed in balance errors due to the dominant leg (right) support. Digit Span Test decreased between pre and post match measurements, however, significant changes ($P < .01$) could be detected after the restitution period between pre and post match. No alteration could be seen with Stroop test in each time points, nevertheless, notable increase in false results were observed at the 4th measurements points. Heart rate did not remarkably differ. In summary, the intensive, consecutive strength had a negative effect on peripheral system, and therefore on dynamic balance control. Cognitive ability indicated gradual deterioration, but showed optimal regeneration between loads.

Abbreviations: DST = Digit Span Test, mYBT = modified Y-balance test, RT = reaction time, VTS = Vienna Test System.

Keywords: badminton, cognitive flexibility, dynamic balance, interference, visuomotor integration

1. Introduction

Badminton is one the fastest racquet sport in the world, where ball speed may achieve up to 360 km/h.[1,2] The game dynamic is characterized by intermittent, high-intensity strength periods.[3] The average heart rate of the players can exceed 90% of the maximum heart rate in the course of matches.[4] In case of badminton players, the footwork agility is relevant with sport performance,[5] therefore, it is always emphasized. In single matches, the most frequently used movement is the outbreak, which is applied in 15% of all movements.[4,6–8] Zengyuan Lin said that neuromuscular fatigue of the lower limb is significantly expressed because of the high number of outbreaks, and elevated on the dominant side.[9] The 63% to 69% of the injury is developed on lower extremities among badminton athletes.[3,10] Keeping the body in optimal balance is exceptionally important for sport performance and to avoid injuries.[11,12] The player has to react to the ball moving at high speed, thus rapid and continues body position changes are needed during the game according to the certain situation.[13] At the same time, the player may need to make decisions within short time period as a result of the flight path of the ball and the anticipation

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Informed consent was obtained from all subjects involved in the study.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Scientific and Research Ethics Committee of the Hungarian Medical Research Council (protocol code BM/14010-1/2023) on June 12, 2023.

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of the opponent,[14] which can be linked to dynamic balance capacity.[3,15] Giesche et al stated that neuromuscular factors, inhibitory control, and cognitive flexibility are determining components to carry out the rapid athlete movements effectively and safely.[16] The motor performance stimulus together with cognitive process demands are considered to be a double task performance. This double task performance means to carry out 2 tasks simultaneously.[17] Dual task interference is the processing interference that cognitive and motor tasks exert on each other, and thus demolish the outcome of one or both tasks.[18] The interference that develops during the interaction between cognitive and motor tasks is the cognitive motor interference.[18] The simultaneous occurrence of cognitive activity and motor enforcement can be objectified by visuomotor reaction times (RT).[19] The visuomotor RT means the time is taken from perception to complete the movement. It includes visual perception, visual processing, visuomotor transformation, and motor execution time.[20] With the use of reactive balance tests, developed to detect dual task performance,[20,21] visuomotor RT and movement execution accuracy can be concluded. Athletes play several matches in a tournament day, which can lead to significant physical and mental fatigue due to the repetitive, intense workload, despite the rest periods between matches. An adult elite men's singles match lasts between 40 and 50 minutes.[4] The rest period between matches is always determined by the organizing committee of the competition according to the official rules of the competition. According to the Badminton World Federation tournament rules, any player is entitled to a minimum of a 60-minute interval between matches, that can be shortened to a 30-minute interval in special cases.[22] The aim of this study was to investigate the changes during consecutive high-intensity badminton matches in certain cognitive and motor ability affecting the dynamic balance control and decision-making in adult, elite badminton players. We hypothesized that serial high-intensity physical and cognitive load has a negative influence on the visuomotor integration, dynamic balance control and the quality of maintaining focus.

2. Materials and methods

2.1. Participants

Table 1 shows the features of athletes.

The cross-sectional, revealing study involved 12 adult male elite badminton players from the Hungarian first division championship. Recruitment was carried out by personal contact, or an email with a detailed description of the test day, which was sent exclusively to Hungarian "A" class players. The selection criteria were as follows: (a) adult age; (b) Hungarian "A" category competition; (c) valid competition license; (d) regular international competition participation. Exclusion criteria were as follows: (a) undergoing lower limb surgery in the past 6 months prior to testing; (b) acute injury or illness. Participation was free of charge in the program, and was voluntary, no honorarium was received. After a written and verbal description of the experimental protocol, and being aware of the possible risks and benefits, participants signed a consent form. The study was conducted in accordance with the principles of the Helsinki Declaration, which was approved by the Scientific and Research Ethics Committee of the Hungarian Medical Research Council (BM/14010-1/2023).

Table 1

Demographic information.

Elite Badminton Players	Mean ± SD
Number	12
Sex, man	12
Age, year	23.5 ± 12
Height, cm	183 ± 6,2
Weight, kg	75.3 ± 1.7
BMI	22.5 ± 2.26
Training, year	13.25 ± 14.14
Badminton training, h/wk	9.3 ± 1.5
Dominant side, right	12
Wake up heart rate, bpm	44.66 ± 7.77
Resting heart rate, bpm	55.77 ± 3.53

Training = years of training experience; badminton training = weekly training time; BMI = body mass index; bpm = beats per minute; h/wk = hour per week.

2.2. Study design and operation

The experiment was conducted in 2 occasions, in the form of a simulation competition day, with 2 groups of equal numbers, and 1 week apart. On the tournament day, the athletes played 2 individual matches with the same opponent to keep the time schedule. Player pairs were matched based on their national ranking in order to ensure similar playing performance. On the test day, after the presentation of the program, anthropometric (height, weight) and baseline (Y-Balance) measurements, necessary for the experiment, were carried out after the trial.[23] Thereafter, players could have 30 minutes to warm up before start of the trial. In the experimental study, the tests were measured 4 times: Baseline measurement before the first match (Measurement 1); Immediately after the first match (Measurement 2); After a thirty min rest, prior to the second match (Measurement 3); and Immediately after the second match (Measurement 4). The programme included 3 different tests for the players at each measurement time. Y-balance test modified by Blazepod system (mYBT); Digit Span Test; and Stroop interference test (STROOP). As well as, the athlete were monitored by a heart rate monitor (Polar Verty Sense) during the entire matches. The matches were played according to Badminton World Federation rules, and following the regulations the minimum possible rest period (30 minutes) between matches was granted to the players.[22] The basic measurement was then started at 10.00 AM and the matches started with a 15 minutes gap between each pair of players. The prematch warm-up and refreshment was performed by an individual protocol in accordance with the rules of badminton competition. The experiment was conducted in a hall of the Hungarian Badminton Association, which fully complied with the international standard. Figure 1 shows the course of the investigation.

2.3. Outcomes

The same test assistants carried out the measurements in the same testing order in case of primary and secondary outcomes.

2.3.1. Primary outcomes. The visuomotor RT, the movement execution accuracy and the number of balance errors resulted from mYBT execution were applied as primary outcome, the dynamic balance control can be observed with the help of these indicators.[20]

2.3.1.1. Measurements of visual stimulation RT. The BlazePod™ (Play Coyotta Ltd., Aviv, Israel), part of the Light Sport Training System,[24] was used for visual stimulation and RT measurement. The BlazePod is a highly reliable RT measurement device.[25,26] Wireless LED discs with a high-sensitivity touch sensor can be controlled via smart phone and application. The pods are deactivated by a user touch after lighting up, while the program detects the RT with millisecond accuracy.

2.3.1.2. Modified Y-Balance meter test (mYBT). The mYBT is a reactive balance test based on the recommendations of Jo Verschueren et al.[20] The reliability of the Y-Balance test has been reported previously.[23] The test was performed by placing one

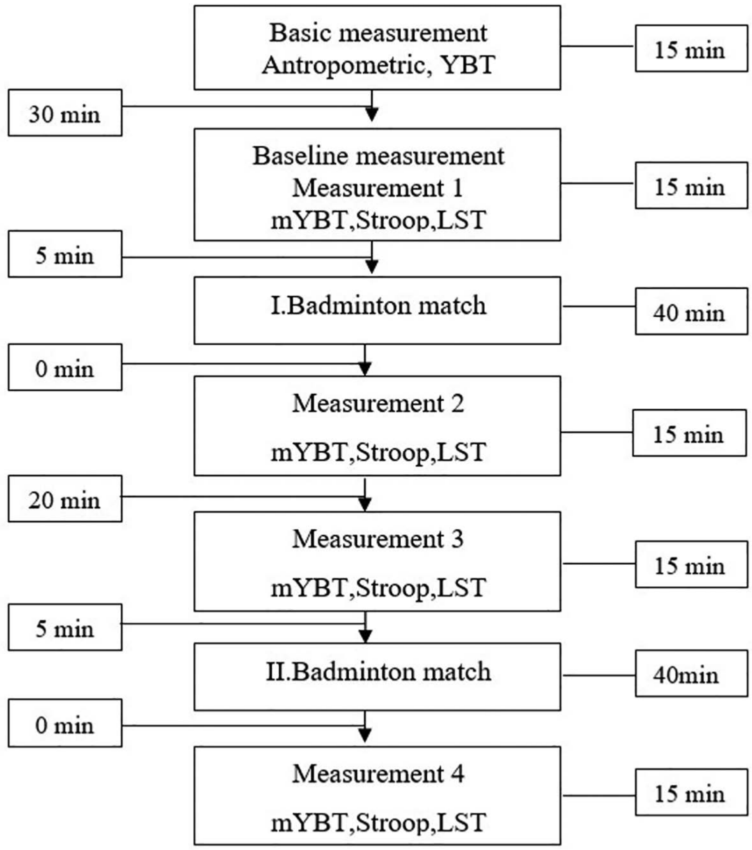

Figure 1. Study flowchart.

Table 2

All measurements of study.

			Measurements			
			1	2	3	4
Variables			**Mean ± SD**			
mYBT	Right side	Reaction time (sec)	2.28 ± 0.73	2.12 ± 0.65	2.29 ± 0.57	2.23 ± 0.49
		Balance error (rep)	1.5 ± 1.08	2.41 ± 0.99	1.66 ± 0.65	3.16 ± 0.71
		Accuracy error (rep)	0.34 ± 0.01	0.32 ± 0.007	0.34 ± 0.006	0.31 ± 0.007
	Left side	Reaction time (sec)	1.9 ± 0.27	1.98 ± 0.6	2.04 ± 0.5	1.95 ± 0.51
		Balance error (rep)	1.41 ± 1.08	1.5 ± 0.79	1.41 ± 0.79	1.83 ± 0.57
		Accuracy error (rep)	0.34 ± 0.01	0.33 ± 0.01	0.34 ± 0.007	0.33 ± 0.01
Stroop Naming		(sec)	0.68 ± 0.12	0.66 ± 0.09	0.62 ± 0.04	0.64 ± 0.08
		Mistake (%)	2.01 ± 1.12	2.14 ± 0.88	1.82 ± 1.06	2.6 ± 1.3
		Interference (sec)	0.06 ± 0.05	0.11 ± 0.23	0.1 ± 0.15	0.07 ± 0.02
Stroop Reading		(sec)	0.69 ± 0.08	0.7 ± 0.1	0.67 ± 0.07	0.7 ± 0.12
		Mistake (%)	1.31 ± 1.04	2.34 ± 1.15	1.43 ± 1.04	3.25 ± 1.44
		Interference (sec)	0.07 ± 0.04	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
Digit span task		(rep)	6.66 ± 0.88	6.08 ± 0.99	7.25 ± 0.62	6.16 ± 1.11
Match		Time (min)	38.5 ± 10.56	39 ± 4.74		
		Average heart rate (%)	81.71 ± 3.43	84 ± 5.23		
		Max. heart rate (%)	96.31 ± 2.65	98.28 ± 4.53		

Note: N = 12; mYBT = modified Y-balance meter; sec = second; min = minute; rep = repetition.

pod on each of the 3 axes of the YBT, on platforms set to 80% of the previously assessed maximum reach distances. During the testing, 3 colors were applied simultaneously, of which 1 relevant (green) and 2 disturbing (red, blue) colors were defined. During testing with both dominant and nondominant lower limbs, athletes received 36 stimuli with a variable distribution per axis to increase cognitive load. To avoid predictability, the inter-stimulus time between pod flashes (1.5–2.5 s) and the order of appearance of the colors were also randomized. The athlete was instructed to position himself on the central platform in start position, and then, from the simultaneously flashing pods of different colors, to perform the test task in the direction of the predetermined relevant color in the shortest possible time by deactivating the pod by touching it, and then settle back to

Table 3

Effect size between each condition of the mYBT variable.

	Reaction time/sec./					
	Right side (*P* = .825)					
			Measurements			
Measurements	**M**	**SD**	**1**	**2**	**3**	**4**
1	2.750	0.739	1	0.433	0.937	0.814
2	2.250	0.654		1	0.209	0.638
3	2.500	0.574			1	0.814
4	2.500	0.497				1
Measurements			Left side (*P* = .729)			
	M	SD		Measurements		
			1	2	3	4
1	2.667	0.277	1	0.875	0.583	0.754
2	2.333	0.609		1	0.754	0.814
3	2.750	0.503			1	0.308
4	2.250	0.519				1
Measurements (right side)			Right – left side comparison			
	M	SD		Measurements (left side)		
			1 M = 1.910 SD = 0.277	2 M = 1.983 SD = 0.609	3 M = 2.043 SD = 0.503	4 M = 1.958 SD = 0.519
1	2.286	0.739	0.136			
2	2.123	0.654		0.480		
3	2.296	0.5740			0.185	
4	2.231	0.497				0.184
			Balance error/rep./			
Measurements			Right side (*P* = .00)			
	M	SD		Measurements		
			1	2	3	4
1	1.500	1.087	1	0.024*	0.946	0.000***
2	2.417	0.996		1	0.083	0.083
3	1.667	0.651			1	0.000***
4	3.167	0.718				1
Measurements			Left side (*P* = .526)			
	M	SD		Measurements		
			1	2	3	4
1	1.417	1.084	1	0.994	1	0.574
2	1.500	0.798		1	0.994	0.731
3	1.417	0.793			1	0.574
4	1.833	0.577				1
Measurements (right side)			Right – left side comparison			
	M	SD		Measurements (left side)		
			1 M = 1.417 SD = 1.08	2 M = 1.500 SD = 0.798	3 M = 1.417 SD = 0.793	4 M = 1.833 SD = 0.577
1	1.500	1.087	0.853			
2	2.417	0.996		0.021*		
3	1.667	0.651			0.408	
4	3.167	0.718				0.000***
			Accuracy (rep.)			
Measurements			Right side (*P* = .000***)			
	M	SD		Measurements		
			1	2	3	4
1	0.345	0.011	1	0.003**	0.878	0.003**
2	0.323	0.008		1	0.003**	0.042*
3	0.343	0.007			1	0.002**
4	0.316	0.008				1
Measurements			Left side (*P* = .091)			
	M	SD		Measurements		
			1	2	3	4
1	0.346	0.011	1	0.431	1	0.070
2	0.338	0.016		1	0.431	0.739
3	0.346	0.008			1	0.070
4	0.333	0.012				1
Measurements (right side)			Right – left side comparison			
	M	SD		Measurements (left side)		
			1 M = 0.346 SD = 0.011	2 M = 0.338 SD = 0.016	3 M = 0.346 SD = 0.008	4 M = 0.333 SD = 0.012

(*Continued*)

Table 3

(*Continued*)

	Reaction time/sec./					
	Right side ($P = .825$)					
			Measurements			
Measurements	M	SD	1	2	3	4
1	3.450	0.011	0.853			
2	0.323	0.008		1		
3	0.343	0.007			0.408	
4	0.316	0.008				0.0004***

sec = seconds; rep = repetition; M = Mean; SD = standard deviation.
* $P \leq .05$.
** $P \leq .01$.
*** $P \leq .001$.

the starting position. The test was performed with the players without shoes on, starting and finishing position on 1 foot, holding on to the hips. In all cases, the test task was performed with the left foot supported first. Average exercise execution times were recorded during the test, and the performance was qualified after video analysis.

2.3.2. Secondary outcomes. The Stroop test measures the ability to inhibit irrelevant information and to maintain focused attention. The short-term memory span of athletes was assessed using the Verbal Work Memory Test (Digit Span Test). The average HR and HR maximum values well characterize the match load intensity and cardiovascular endurance.

2.3.2.1. Stroop test. In our study, Stroop test was applied, also used by the Vienna Test System),[27] to measure cognitive flexibility, which includes components of decision making and time pressure. The test differentiates between the reaction velocity of congruent and incongruent items. In the first half of the test including 2 parts, the athletes should respond to the letter color, ignoring the word meaning. In the second part of the test, task focuses on the read meaning of the word, without abstracting from the letter color of the read word. Players are asked to press the correct color as quickly as possible on the working panel while performing the test. Each testing block was preceded by 10-10 practice tasks. The entire test was completed within 10 minutes. In the statistical analysis, the color naming and word reading RTs and interference values were analyzed with the percentage of false responses to establish the probability of RT associated in different time points. In our study, the Vienna Test System, S8 test format was used.

2.3.2.2. Digit Span Task. Subjects hear number sequences from 3 to 9, in ascending order. While reading the number sequences, the investigator pauses for 1 second after each number. After listening, the subject had to repeat the number sequence in the same order. For a given range of numbers of a certain length, there are 4 different sets of numbers. The subject's short-term memory span is described by the certain length of the number sequence where 2 correct number sequence repetitions occur.[28,29]

2.3.2.3. Heart rate. Through the entire matches, the players wore a heart rate monitor armband (Polar Verity Sense), which can record and store the data of an event in its memory. Heart rate data was downloaded after the matches using an application (Polar Flow) to be used for statistical analysis.

2.4. Statistical analysis

The statistical analysis of our research was performed by using TIBCO Software Inc. (2020). Our study included 4 measurements (Measurement 1: baseline; Measurement 2: post-load I; Measurement 3: post-restitution; and Measurement 4: post-load II). Firstly, Shapiro–Wilk normality test was applied, the results of which were used to perform a parametric repeated measures ANOVA test followed by a post hoc Tukey test, or a Friedman test for nonparametric data. For heart rate values, a parametric paired *t* test or Wilcoxon test were used. Values were expressed as mean ± SD. The level of statistical significance is $P \leq .05$.

3. Results

Table 2 shows all measurements of study.

3.1. Primary results

3.1.1. Modified Y-Balance test. Visuomotor RT. In terms of visuomotor RT (sec) measurements, no significant difference was found between the 2 lower limbs after performing the paired *t* test and Wilcoxon test in Measure 1 ($P = .14$), Measure 2 ($P = .48$), Measure 3 ($P = .19$) or Measure 4 ($P = .19$). No remarkable changes were detected side by side. Visuomotor RT (sec) data of the nondominant leg support showed the value $P = .07$ after Friedman ANOVA test, while the dominant leg support showed a $P = .83$.

Balance error (n). As a first step, a Shapiro–Wilk normality test was performed, the results of which were used to perform a parametric two-sample *t* test to compare the 2 limbs. Significant changes were found in Measurement 2 ($P = .02$) and Measurement 4 ($P = .00$). However, no remarkable difference was observed in Measurement 1 ($P = .85$) or Measurement 3 ($P = .41$) comparing the 2 limbs. In case of each limbs, nondominant leg support Balance Error (n) did not show any alteration at each time points ($P = .52$). Nevertheless, in case of Dominant leg support Balance Error (n), significant changes were assessed between Measurement 1 and Measurement 2 ($P = .02$), Measurement 1 and Measurement 4 ($P = .0001$), and Measurement 3 and Measurement 4 ($P = .0003$).

Accuracy (n). Firstly, Shapiro–Wilk normality test was performed, the results of which were used as the basis for a parametric repeated measures ANOVA test followed by a post hoc Tukey test. No important differences were evaluated in either of nondominant or dominant side. No major changes were established between the different sides in Measurement 1 ($P = .85$), Measurement 2, or Measurement 3 ($P = .41$), but significant difference was observed in the Measurement 4 parameters ($P = .00$). Table 3 shows effect size between each condition of the mYBT variable.

3.2. Secondary outcomes

3.2.1. Stroop test. Reading (sec). No significant difference ($P = .85$), analyzed by Friedman ANOVA test, was found

Table 4

Effect size between each condition of the Stroop task variable.

Naming												
	Reaction time (*P* = .44)				**Interference (*P* = .15)**				**Incorrect answer (*P* = .152)**			
Measurement	**{1} 2.917**	**{2} 2.667**	**{3} 2.250**	**{4} 2.167**	**{1} 2.333**	**{2} 2.458**	**{3} 2.083**	**{4} 3.125**	**{1} 2.333**	**{2} 2.458**	**{3} 2.083**	**{4} 3.125**
1	1	0.583	0.158	0.433	1	0.859	0.678	0.08	1	0.767	0.594	0.161
2		1	0.347	0.638		1	0.401	0.141		1	0.484	0.141
3			1	0.814			1	0.10			1	0.142
4				1				1				1
Reading												
Measurement	Reaction time (*P* = .849)				Interference (*P* = .001)				Incorrect answer (*P* = .001)			
	{1} 2.667	{2} 2.667	{3} 2.333	{4} 2.333	{1} 1.917	{2} 2.667	{3} 1.833	{4} 3.583	{1} 1.917	{2} 2.667	{3} 1.833	{4} 3.583
1	1	0.845	0.48	0.875	1	0.047*	0.515	0.003**	1	0.041*	0.554	0.003**
2		1	0.638	0.754		1	0.059	0.123		1	0.083	0.141
3			1	0.969			1	0.007**			1	0.006**
4				1				1				1

* $P \leq .05$.
** $P < .01$.

Table 5

Effect size between each condition of the Digit Span Task variable.

			Number of measurements			
Variables	**M**	**SD**	**{1}**	**{2}**	**{3}**	**{4}**
Digit Span Task I.	6.667 rep.	0.888 rep.	1	0.203	0.203	0.326
Digit Span Task II.	6.083 rep.	0.996 rep.		1	0.002**	0.992
Digit Span Task III.	7.250 rep.	0.622 rep.			1	0.004**
Digit Span Task IV.	6.167 rep.	1.115 rep.				1

M = mean; SD = standard deviation; rep = repetitions.
* $P < .05$.
** $P < .01$.

between the 4 measurements (Measurement 1, Measurement 2, Measurement 3, and Measurement 4).

Naming (sec). No remarkable change ($P = .44$), analyzed by Friedman ANOVA test, was showed between the 4 measurements (Measurement 1, Measurement 2, Measurement 3, and Measurement 4).

Interference. No remarkable change ($P = .44$), analyzed by Friedman ANOVA test, was assessed for either Color Naming ($P = .18$) or Word Reading ($P = .53$) for Interference (sec) between the 4 measurements.

Reading False response (%); Friedman test showed a significant difference between the 4 measures ($P = .00$). Specifically, there was a significant change between Measure 1 and Measure 2 ($P = .047$), between Measure 1 and Measure 4 ($P = .003$), and between Measure 3 and Measure 4 ($P = .007$).

Naming False Response (%); No significant difference ($P = .15$) was evaluated in Naming Error Response (%) between the results of the 4 measures. Table 4 shows Effect size between each condition of the Stroop task variable.

3.2.2. Digit Spam Task. The repeated measures parametric ANOVA test showed a significant difference in LST between the 4 measurements ($P = .00$). A significant difference in LST was found between Measurement 2 and Measurement 3 ($P = .002$) and between Measurement 3 and Measurement 4 ($P = .004$). Table 5 shows effect size between each condition of the Digit Span Task variable.

3.2.3. Heart rate. Table 6 shows the differences between the heart rate values of the 2 matches. No significant difference was found in Average Heart Rate (%) between 2 matches and in Average Heart Rate (%) ($P = .07$) in the course of 2 matches. Maximum Heart Rate (%) did not show notable change between 2 matches ($P = .099$). Within the match, Average-Maximum Heart Rate (%) ratio showed a significant difference in parametric paired *t* test in relation to Average and Max Heart Rate (%) of Match I ($P = .00$). Duration and Heart Rate values of Match I did not show correlation between the time (min) and average heart rate (%) ($P = .41$; r = –0.26), furthermore, no alteration were seen between Match I duration and Match I max heart rate (%) ($P = .94$; r = 0.25). In case of Match II, duration and heart rate values did not show any correlation between Match II duration (min) and mean heart rate (%) ($P = .99$; r = –0.26), and between Match II duration and max heart rate (%) ($P = .31$; r = 0.32).

4. Discussion

The aim of this study was to investigate the effects of consecutive badminton matches on dynamic balance ability, visuomotor RT, inhibitory control and performance changes in working memory capacity in real competitive situation with short rest periods. The main statements resulting from the 4 measurements were that dynamic balance ability gradually deteriorates, with a significant negative change on the dominant side by the end of the second match. In case of visuomotor RT, no remarkable difference was observed in the 4 measurements. Balanced results of inhibitors control were seen with a gradually increasing word reading error rate. The working memory capacity showed negative changes at the end of the matches compared to the beginning of them, but there was no difference between the 2 matches.

The maximum and average heart rates during the matches reach the maximum and sub-maximum values, however, there is

Table 6

Effect size between the heart rate values of the 2 matches.

Variables	M	SD	*P*-value
Match I average heart rate,%	82,022	3898	.088
Match II average heart rate,%	84,804	5891	
Match I maximum heart rate,%	96,355	2932	.116
Match II maximum heart rate,%	98,767	5211	

M = mean; SD = standard deviation; % = percentage.

no significant change between the maximum and average heart rates of the 2 matches. These pieces of information suggest that enhance performance decrease of cognitive ability, inhibitory control and work memory capacity were found during 2 consecutive badminton matches, while the players recovered well between the 2 matches. The same can be said in case of reaction speed. Although, muscle fatigue as a result of the increased dominant leg work negatively influence the quality of dynamic balance ability on the dominant side.

Previous studies said that badminton players have an excellent level of dynamic balancing ability.[3] However, the effects of consecutive match workload on dynamic balance ability have not been reported. The results of the mYBT measurements clearly show that the speed of reaction is balanced for each lower limbs, but that there is a gradual increase in the number of balance errors for the dominant limb. Previous studies[30] have demonstrated an increased creatine kinase levels after a match in junior elite players, suggesting muscle damage, although muscle damage was not associated with a declination in the quality of exercise performance. While jumping capacity decreased after a sixty- minute simulated match in adults.[31] A simulated single-match study showed that the maximal voluntary isometric contraction of the knee extensor and flexor muscles was weaker in the dominant leg compared to the nondominant leg, which was contributed to the large amount of dominant-side lunges performed during the match.[9] In our study, there was a significant elevation in the number of balance errors and inaccurate executions measured at the end of the second match compared to all previous measurements at the dominant lower leg. This can suggest a negative consequence of possible muscle damage due to consecutive workload and insufficient length of restitution time between matches. Our results are related to previous data that the most common injuries among badminton players develop on lower limbs.[32–34]

In the Stroop test, used to measure inhibitory control, the results of the 4 measurements did not show difference in RT of the word reading and word naming tasks, as well as in interference values. These results suggest a balanced functioning of the inhibitory control. It has been shown that inhibitory control is remarkable in case of open-skill athletes and more effective than in closed-skill athletes.[35,36] Nevertheless, an increased number of incorrect responses were detected in the word reading task, with a significant increase in the proportion of incorrect responses in the last measurement compared to the previous measurements. This may indicate increased risk-taking as a result of increased physical performance of athletes, which may have a negative effect on validity but not on response speed.[37]

In Digit Span task, there was not found any previous results during physical activity comparable to our results. The aim of this study was to compare changes in cognitive flexibility and short-term memory capacity of athletes due to consecutive workload. It can be stated that athletes showed an increased impairment of short-term memory capacity under high-intensity load.[38] Although, the recovery of short- term memory capacity between 2 workload periods is very fast and optimal.

In our study, data of cognitive tests confirm the acute negative influence of high-intensity physical load on cognitive performance, which is typically observed in the dual-task paradigm.[38]

Similar values of previous studies could be detected in the duration of the matches and the mean and maximum heart rate values during the matches.[4] Both matches lasted approximately for 40 minutes. While the measured maximum heart rate approached the individual maximum, and the match heart rate averages were over 80% of the maximum heart rate for both matches. It can be concluded that badminton players have a high level of aerobic and anaerobic fitness.[4]

5. Limitations

Due to the lack of electromyography muscle activity testing and the isokinetic dynamometer measuring, the concentric force changes can be mentioned as the limitations of the study. Furthermore, the lack of analysis of blood lactate and creatine kinase levels can be included here, which characterize the intensity of cardio exercise and the size of muscle damage. However, in the future, the study can be extended to the recovery period investigating the time course of recovery processes.

6. Conclusions

To be concluded, the study emphasizes the negative performance changes in motor and cognitive abilities that result from players being exposed to 2 consecutive badminton matches with inappropriate rest period. Repetitive high-intensity physical and cognitive load and short restitution between load phases significantly increase the degree of central and peripheral fatigue, and thus the risk of injury. However, the results of this study may be useful for coaches and players in planning train sessions and match tactics, and in designing and adapting between-match and post-match recovery methods.

Our study points out the possible positive effects on open move skills that improve the skills essential for performing dual tasks through the development of motion control.

Considering the results of our research it can be declared as a general principle that intensified, serial physical and cognitive workload have negative effect on both the central and peripheral systems. Consequently, motor performance and the optimal functioning of executive functions steadily decline, albeit not to the same extent. However, in our study, we can hypothesize that the neuromuscular adaptation can contribute to the development of the nervous system regulation due to regular cognitive and physical training. In case of badminton players, the developed adaptive condition can be resulted from the execution of intensity and methodically used specific movements under constant decision-making pressure.

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