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Research article

Changes in the Game Characteristics of a Badminton Match: A Longitudinal Study through the Olympic Game Finals Analysis in Men's Singles

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Abstract
The goal of this study was to analyze, through a longitudinal study, the Olympic Badminton Men's singles finals from the Barcelona Games (1992) to the London Games (2012) to assess some changes of the Badminton game characteristics. Six Olympic finals have been analyzed based on the official video of the Olympic Games (OG) through the temporal structure and with a notational approach. In total, 537 rallies and 5537 strokes have been analyzed. The results show a change in the game's temporal structure: a significant difference in the rally time, rest time and number of shots per rally (all $p<0.0001$; $0.09 < \eta^2 < 0.16$). Moreover, the shot frequency shows a 34.0% increase ($p<0.000001$; $\eta^2 = 0.17$), whereas the work density revealed a 58.2% decrease (from 78% to 30.8%) as well as the effective playing time (-34.5% from 34.7±1.4% to 22.7±1.4%). This argues for an increase in the intensity of the game and a necessity for the player to use a longer resting time to recover. Lastly, the strokes distribution and the percentage of unforced and forced mistakes did not show any differences throughout the OG analysis, except for the use of the clear. This results impact on the way the training of Badminton players should be designed, especially in the temporal structure and intensity.

Key words: Notational analysis, elite, racket sport, video analysis, shuttlecock.

Introduction

Badminton is a racket sport which is characterized by a temporal structure with actions of short duration and high intensity coupled with a short resting time, as recently reviewed (Cabello Manrique and González-Badillo, 2003). The number of different shots used during a game can vary a lot, allowing numerous tactical choices (Hong and Tong, 2000). This sport gathers five disciplines, including Men's and Women's singles, doubles and mixed doubles, each of them requiring a specific preparation in terms of patience, control and physical fitness (Chen and Chen, 2008; 2011; Laffaye, 2011; Pearce, 2002). For more details, a recent review summarizes all the characteristics of this game (Phomsoupha and Laffaye, 2015).

Since this sport became Olympic in Barcelona in 1992, few studies reported temporal structure at a definite moment according to the total time, working time, resting time, effective playing time (EPT) (sum of the rally times divided by the match duration multiplied by a hundred) and shot frequency (number of shots divided by the effective playing time) (Abian-vicen et al., 2013; Cabello Manrique and González-Badillo, 2003; Faude et al., 2007). During elite player matches, mean rally and rest duration revealed a high variability, with values respectively ranging from 4.6s to 9.0s and 9.7s to 24.1s (Abian-vicen et al., 2013; Cabello and Lees, 2004; Cabello Manrique and González-Badillo, 2003; Chen and Chen, 2008; Faude et al., 2007; Ming et al., 2008). In the literature, the EPT ranged from 27.3 ± 2.4% (Abian-vicen et al., 2013) to 38.5 ± 3.8% (Chen and Chen, 2011), with a mean value of 32.1% (Phomsoupha and Laffaye, 2015).

Another way to analyze matches has been recently proposed, by using a notational analysis with video recordings focusing on different kinds of shots and on the way the point is won (direct point, unforced error and forced error) (Abian-vicen et al., 2013; Hong and Tong, 2000). For instance, a recent study on the Beijing Olympic Games analysis revealed a percentage of unforced error at about 41.0 ± 9.4% while the best shot for finishing a rally by direct point is the smash (29.1 ± 8.4%) (Abian-vicen et al., 2013). In another study with national level players (Taiwanese players), the percentage of unforced errors increases to 61.5% suggesting that this variable depends on the expertise (Chen and Chen, 2008). Liddle et al (1996) reported that 54.0% of the shots are overheads in singles, while a few years later, another study showed that the three most popular strokes were the smash, the overhead clear and the overhead drop (Ghosh et al., 2008). However, Ming et al. (2008) showed another stroke repartition with more clears, lobs and net shots. This suggests that the Badminton game has considerably evolved over the last two decades and that the notational analysis appears to be a good way to understand this change over time.

Up to now, studies on Badminton game characteristics focused on isolated match analysis. The aim of this study is to analyze the change of the Badminton in Men's singles through the notational and temporal structure of all the Olympic finals since 1992. It is hypothesized that Badminton has become more intensive with a higher number of offensive strokes. For validating this hypothesis, it is expected to observe an increase in the shot frequency, a decrease in the rest time and a change in the distribution of the strokes.

Methods

Period and matches

The matches selected are the Men's singles finals in all Olympic Games since 1992 (Table 1). The different finals

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Table 1. Badminton final Men's singles: opponents and score.

	Final score	Total duration (min)	Mean inning duration (min)
Match game 15 points, prolongation at 13-13 by 2 or 5 points			
Barcelona 1992	15 / 12 – 18 / 13	59	22
Atlanta 1996	15 / 12 – 15 / 10	43	12
Match game 15 points, prolongation at 14-14 by 1 or 3 points			
Sydney 2000	15 / 4 – 15 /13	45	14
Athena 2004	15 / 8 – 15 / 7	42	12
Match game for 21 points			
Beijing 2008	21 / 12 – 21 / 08	39	10
London 2012	15 / 21 – 21 / 10 – 21 / 19	78	18

(1996: Atlanta (OG-96), 2000: Sydney (OG-00), 2004: Athens (OG-04), 2008: Beijing (OG-08) and 2012: London (OG-12) were recovered from the archives of French Federation of Badminton, and the final of 1992: Barcelona (OG-92) from a private recording of a Chinese television broadcast. The mean age of the players is 25.8 ± 2.78 years. In total, 537 rallies and 5537 strokes have been analyzed. To be more accurate as possible, we choose to study only balanced high level matches. This was not the case for one of the semi-final during OG-00 (15-12, 15-4), OG-04 (15-9, 15-2) and OG-12 (21-12, 21-10). Consequently, we analyzed only finals from OG-92 to OG-12.

Procedures

The study received approval from the University's ethics committee.

Video-coding process

The film footage was analyzed frame-by-frame using Dartfish (Dartfish 4.5.2, Fribourg, Switzerland) at a frequency of 25 Hz. The movements of the players were filmed from a front-on and up-side perspective. Two categories of variables were recorded:

(i) the temporal variables were defined as proposed in the literature and include the rally time (time elapsed from the serve until the shuttlecock hits the ground or one of the players makes a mistake), number of shots per rally (total number of times the shuttle is hit by both players during the rally time), stroke time (rally time divided by the number of shots per rally), the shots' frequency, the resting time (the time elapsed from when the shuttlecock hits the ground until the next serve), the effective playing time (Abian-vicen et al., 2013; Cabello Manrique and González-Badillo, 2003; Chen and Chen, 2008; Faude et al., 2007);

(ii) the notational variables include the different shots and the way the point is ended, and are defined in the following manner: (1) the smash is an aggressive overhead shot with downward trajectory, (2) the clear is an overhead shot with a flat (offensive clear) or rising trajectory (defensive clear) towards the back of the opponent's court, (3) the drop is a smooth shot from above the head with downward trajectory towards the front of the court, (4) the net shot is a precise shot from near the net which includes the net drop, the lob (offensive with a flat trajectory towards the back of the opponent's court and defensive with a rising trajectory) and the kill (aggressive shot with downward trajectory), (5) the drive is a powerful shot made at middle body height and in the middle of the court with a flat trajectory, (6) a direct point is a point which ends when the shuttlecock directly hits the ground, (7) a forced error is when the player is under excessive pressure from his opponent and makes an error after doing his shot (which goes in the net or outside the court) and (8) an unforced error is when the player makes an error in an expected situation without excessive pressure from the opponent (Abian-vicen et al., 2013; Cabello Manrique and González-Badillo, 2003).

In order to facilitate the data acquisition process and accuracy, a software using macro on Excel (Microsoft©, 2007) has been build, allowing data collection. The video has been analyzed twice: in a first analysis, the observer used the software to time the temporal structure of the game and in the second analysis, the observer took notes on the category of the shots. For this purpose, a grid representing the court and the different areas has been drawn on the software and the observer simply have to select the name of the shot and to start the chronometer (accuracy: ±0.01s) and stop it for each sequence of game (temporal structure).

Inter- and intra-observer validity

In order to ensure the validity of the data coding process, two independent observers expert in Badminton (trainers having the qualification required by the French Federation of Badminton) have coded the same sequence twice, allowing to measure the inter- and intra-observer validity (Triolet et al., 2013). The observers' measure reliability has been assessed by measuring the coefficient of variation (CV %), the intraclass correlation (ICC) and a Student-T test was performed for the temporal data.

Before selecting the different shots, a pre-experiment had been conducted with three observers on an entire game to check the repeatability of the coding. Based on this feedback, we have reduced the number of different shots from 8 to 5: the slice has been coded as a drop shot, the two different clears (defensive and offensive) have been gathered as one and the two different lobs (defensive and offensive) as well. With this new notational coding, the results show a high intra-class correlation (ICC = 0.99 and CV% = 0.12 for intra observer) on temporal data. For the notational analysis, the inter-coder CV is 2.8% with variations between 1.0% for the net and 5.0% for the drive while the intra-coder CV is 2.4% and with variations between 0.4% for the net and 3.9% for the smash. This proves a significant validity of the method used (CV< 5% and ICC >80%) (Donner and Eliasziw, 1987).

Table 2. Change in temporal structure of Badminton Men's singles final during Olympic Game (OG). Data are means (±SD).

Variables	OG-92	OG-96	OG-00	OG-04	OG-08	OG-12	F	Effect size (η^2)
Rest Time (s)	22.0 (1.5)^{e,f}	14.8(1.4)^{a,c,d,e,f}	22.6 (1.6)^{a,b,e,f}	21.6 (1.7)^{b,d}	30.3(2.0)^{a,b,c,d}	33.5 (1.5)^{a,b,c,d}	24.4**	.164
Rally Time (s)	12.9 (1.0)^{b,c,d,e,f}	5.5(.6)^{a,c,d,e,f}	9.6 (.7)^{a,b}	8.4 (.7)^{a,b}	9.3 (.9)^{a,b}	10.1 (.7)^{a,b}	11.8**	.094
N° of shots per rally	12.3 (.9)^{b,c,d}	5.4 (.3)^{a,c,d,e,f}	9.7 (.8) ^{a,b,f}	9.8 (.9) ^{a,b,f}	10.8 (1.0)^{b}	12.0 (.9)^{b,c,d}	12.5**	.100
EPT	34.7 (1.4)^{b,d,e,f}	26.8 (1.2)^{d,f}	30.8 (1.5)^{a}	26.6 (1.5)	25.3 (1.8)^{b}	22.7 (1.4)^{a,b,c}	8.3**	.069
Shot frequency	.9 (.2)^{c,d,e,f,g}	1.0 (.3)^{a,c,d,e}	1.1 (.3)^{a,d,e,f}	1.2 (.2)^{a,b}	1.2 (.2)^{a,b,c}	1.3 (.3)^{a,b,c}	23.8**	.175

*p < 0.001 ;** p < 0.0001 [a] difference with OG-92, [b] difference with OG-96, [c] difference with OG-00, [d] difference with OG-04, [e] difference with OG-08, [f] difference with OG-12. EPT= effective playing time.

Statistical analysis

Temporal structure statistics analyze with one-way measure of the variance (ANOVA) with Fisher LSD post-hoc test using Statistica 10. Moreover, to understand the link between variables, a uni-variated correlation study with Pearson correlation was performed. The notational analysis (the percentage of stroke and errors) were analyzed with a χ^2-test by comparing the theoretical number of occurrences with a mean value to the real number of occurrences. The null-hypothesis is that the distribution of strokes and the number of unforced errors and direct points depend on the Olympic Games (OG). The criterion for statistical significance was set at $p<0.05$ and effect size (η^2) was defined as small ($\eta^2>0.01$), medium ($\eta^2>0.09$) and large ($\eta^2>0.25$). For post-hoc effect size (Cohen's D) was defined as large (D>.80), moderate (>.50) and small (D> 20) (Cohen, 1988). 95% Confidence Interval are provided between square brackets.

Results

Temporal structure

The change of the temporal structure has been summarized in Table 2. The ANOVA for all the studied variables shows significant changes in the rally time, resting time, number of shots per rally and shot frequency.

For instance, the number of shots shows a twofold increase from 12.3 ± 0.9 at the OG-92 to 12.0 ± 0.9 at the OG-12 (p < 0.0001; [4.57;8.46], Cohen's D = 0.40). The size effects are small to large for all significant post-hoc (from 0.3 to 1.1). The rally time and the resting time double between the OG-92 and the OG-12 respectively from 12.9 ± 1.0s to 10.1 ± 0.7s (p<0.0001; [2.74;6.56], Cohen's D = 0.30) and 14.8 ± 1.4s to 33.5 ± 1.5s (p<0.0001; [14.9;22.4], Cohen's D = 0.70) meaning a difference in the time management with large effect size. At the same time, the effective playing time from 34.7 ± 1.4 % at the OG-92 to 22.7 ± 1.4 % at the OG-12 (p<0.0001; [7.9;15.9], Cohen's D = 0.84).

The rally time and the resting time changes reveal significant curvilinear fluctuations, showing that the rally time decreases between OG-92 and OG-96, then increases between OG-96 and OG-00, and stays stable until OG-08, before increasing again (Figure 1). The resting time reveals the same trend but with a shorter phase of stabilization (only between OG-00 and OG-04). In addition, we found a significant correlation between the intensity of the exercise through the shot frequency and the resting time just after this rally (r = 0.25; p<0.01).

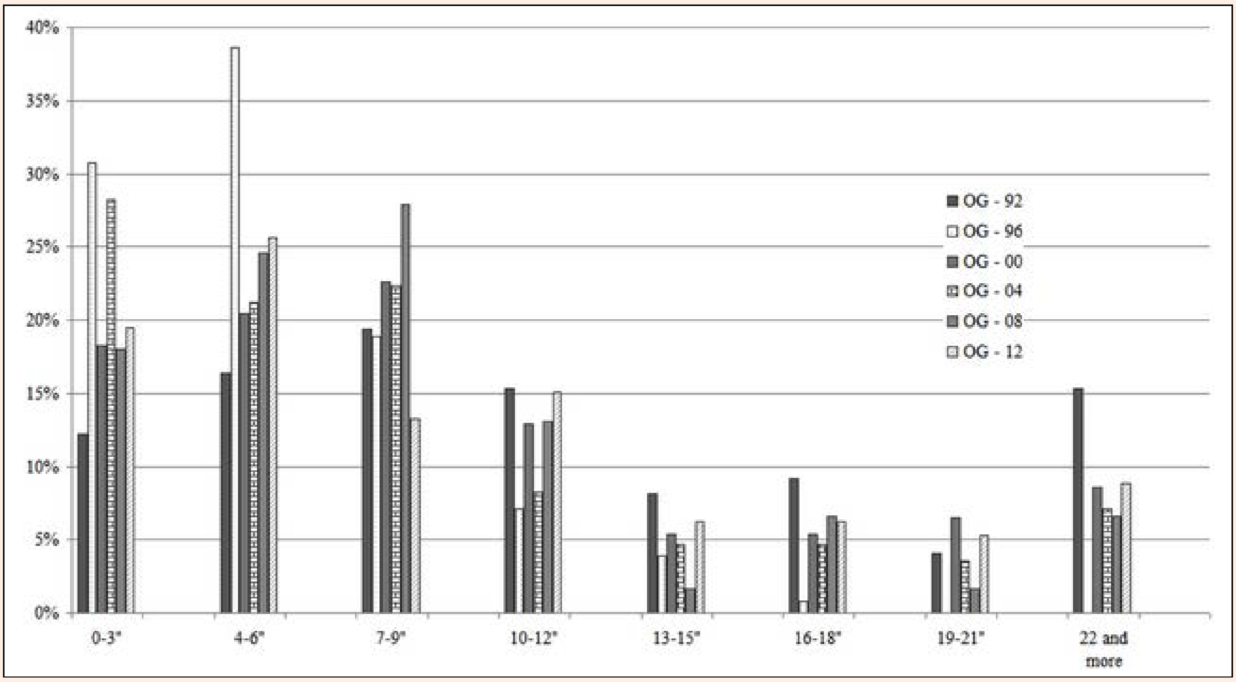

Figure 1. Rally time distribution (3s-interval) throughout the different Olympic finals from 1992 (Barcelona) to 2012 (London) in Men's Singles.

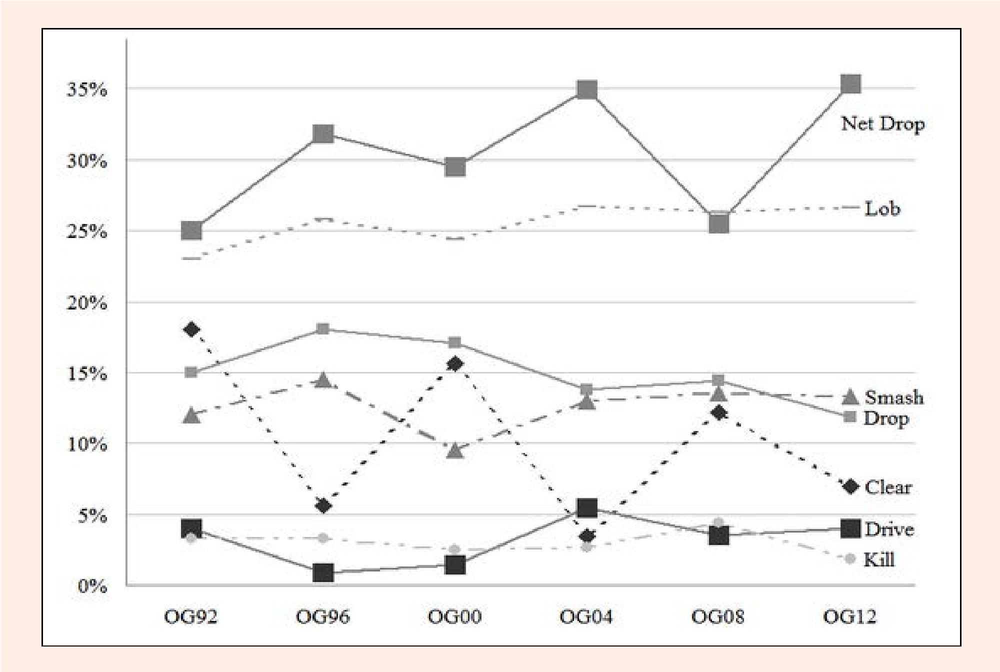

Figure 2. Change of the distribution of various types of strokes throughout the different Olympic finals from 1992 (Barcelona) to 2012 (London) in Men's Singles, χ² significant for the clear (p < 0.05)

Notational analysis

The percentages of the repartition of the strokes are presented in Figure 2. The χ² test revealed only a difference for the clear (χ² (5) = 16.5; p<0.001) with a variability from 3.0% at the OG-04 to 18.0% at the OG-92, while the other strokes show low and insignificant fluctuations of their values through all the OG finals. The net drop is the most used stroke (from 25.0% at the OG-92 to 35.0% at the OG-04), followed by the lob (from 23.0% at the OG-92 to 27.0% at the OG-04). The smash is used in about 10.0% to 14.0% of the strokes, whereas the drives are the less frequent (1.0% to 5.0%). Finally, 36.6% of the strokes come from the back of the court and 60.3% from the net.

Regarding the way the points are won, the χ² test did not reveal any changes throughout the different Olympic Games finals (Table 3) with an average of 36.0% for the direct points, 23.0% for the forced errors and 41.0% for the unforced errors. The forced error predicts 100.0% of the inning winner whereas the players with the most direct points win the inning in only 20.0% of the cases.

Discussion

Temporal structure

One of the main results is the increase of 34.0% in the shot frequency from the first final to the last one, from $0.9s^{-1}$ to $1.3s^{-1}$. For the others temporal indicators OG-92 final seems to be an exception in this change, with values comparable to the OG-04 for the resting time and higher than all others for the rally time. The number of shots (5.5 at the OG-96 to 10.2 at the OG-12), which is an associated variable of the rally time, increases during this period of time (+119.0%), except for OG-92. All the indicators used to assess the temporal structure show a change of the game intensity during the last two decades.

Our shot frequency since OG-04 is higher than those reported by previous studies [0.92-1.08 s^{-1}] at the same period (table 4). By comparison with the literature, this indicator seems to be a key variable correlated with the level of the players: with a higher expertise level, comes a better capacity to accelerate the shuttlecock trajectory. The difference could be explained by the fact that we analyzed only the final whereas other authors mixed all the round of a tournament and especially in Beijing in 2008 (Abian-vicen et al., 2013). The number of shots per rally is in accordance with the literature, showing mean values from 4.6 to 12.7 shots per rally (Abian-vicen et al., 2013; Cabello and Lees, 2004; Chen and Chen, 2008; Faude et al., 2007; Ming et al., 2008).

The resting time, which is the time necessary to recover a lower heart rate level threshold for the next rally, reveals the same change over time (Fahimi and Vaezmousavi, 2011). Values found are higher than in other studies (Table 4), revealing the high intensity of an Olympic final and the necessity for players to increase resting time. This intensity is reinforced by the one-third increase in the effective playing time all along this period, despite a higher value recorded at OG-00 (45.5% and

Table 3. Repartition of direct points, forced and unforced errors (%) during Badminton Olympic Men's singles Final

	Averaged	OG-92	OG-96	OG-00	OG-04	OG-08	OG-12
Direct Point (%)	36.0	44.0	31.0	33.0	30.0	44.0	31.0
Forced Errors (%)	23.0	27.0	27.0	16.0	24.0	16.0	29.0
Unforced Errors (%)	42.0	29.0	43.0	51.0	45.0	40.0	40.0

Table 4. Comparative results of the temporal structure in the literature of Badminton.

Variables	Author	Date	level	Condition	Results (M±SD)
Rest Time	Cabello Manrique et al.	2003	International	Real Condition	14.2 ± 3.4 s
	Cabello Manrique and González-Badillo	2003	International	Real Condition	12.9 ± 2.7 s
	Faude	2007	International	Simulated Match	11.4 ± 6.0 s
	Ming et al	2008	Young National	Real Condition	9.7 ± .2 s
	Abian-Vincen et al.	2013	Olympic Games	Real Condition	24.1 ± 3.8 s
Rally Time	Cabello Manrique and González-Badillo	2003	International	Real Condition	6.4 ± 1.3 s
	Cabello and Lees	2004	Top National	Real Condition	7.3 ± 1.3 s
	Faude	2007	International	Simulated Match	5.5 ± 4.0 s
	Ming et al	2008	Young National	Real Condition	4.6 ± .9 s
	Chen and Chen	2008	Word Top	Real Condition	8.1 ± 6.3 s
	Abian-Vincen et al.	2013	Olympic Games	Real Condition	9.0 ± .9 s
Shot Frequency	Cabello Manrique and González-Badillo	2003	International	Real Condition	.9 ± .1 s^{-1}
	Faude	2007	International	Simulated Match	.9 ± .3 s^{-1}
	Ming et al	2008	Young National	Real Condition	1.0 ± .2 s^{-1}
	Abian-Vincen et al	2013	Olympic Games	Real Condition	1.1 ± .1 s^{-1}

26.8% respectively). Indeed, the value is about 50.0% for national players (Cabello and Lees, 2004) and for young competitive players (Ming et al., 2008) and is only 38.0% during the OG-12 (Abian-vicen et al., 2013) with an average value of 30.8% throughout the finals analyzed in the present study.

Notational analysis

Concerning the stroke distribution, we hypothesized differences between the different OG. The averaged distribution is 10.0% for the clear, 15.0% for the drop, 13.0% for the smash, 3.0% for the drive, 30.0% for the net drop, 25.0% for the lob and 3.0% for the kill. The statistical analysis shows that there is a significant change only for the clear, which oscillates from 3.0% in OG-04 to 18.0% in OG-92, all the other stroke distributions being similar along this period. When correlating this value with the mean rally time, we found a correlation of r = 0.60 (p<0.01), revealing that the clear is a key stroke which prolongs the rally time. This means that the clear is used for tactical purposes, either to wait for an inaccuracy of the opponent or to leave it to him to take the initiative; however, it can also be used to exhaust the opponent when necessary. The aggregation of shots from a part of the court shows slight differences when compared to previous studies (Liddle et al., 1996; Ming et al., 2008; Oswald, 2006). For instance, 54.0% of the shots are overhead in singles according to a study of Liddle et al. (1996) and about 43.0% when looking only at top elite players according to another (Oswald, 2006) while the present study reveals a percentage ranging from 38.0% at OG-96 to 45.0% at OG-92, which shows the importance of the net game. Our repartition is closer to the one found in international tournaments: 39.5% of the game is played at the back of the court against 47.8% near the net (Lee et al., 2005), with a comparable percentage of strokes (Lee et al., 2008; Oswald, 2006). Indeed, when comparing to competitive young players, the percentages of smashes and lobs are quite identical (about 13.0% and 25.0% respectively) but the percentages of clears and net shots are very different (10.0% in the present study vs 16.0% for the clear, and 30.0% in the present study vs 17.0% for the net drop) (Ming et al., 2008). This argues that the net game at top-level is a more important phase of game in a tactical sense to force the opponent to raise the shuttlecock with a lift for instance.

Lastly, when analyzing the way the point is finished, no difference was found between the different OG finals. 36.0% of the points are direct points, meaning the shuttlecock hits the ground, 23.0% of the points end with forced error and 41.0% with an unforced error. Hypothesizing that the percentage of unforced errors decreases with the level of expertise, it is expected that the values of the present study are lower compared to lower level of expertise. Indeed, in a recent study with Taiwanese players (Chen and Chen, 2011), the percentage of unforced errors is 61.5% vs 41.0% during the OG-08 (Abian-vicen et al., 2013). A study with novices revealed than in 73.0% of the cases, the player who makes the less unforced errors is the winner (Cabello Manrique and González-Badillo, 2003). This variable seems more predictive of the winner than the two others. Indeed, when analyzing the link between unforced errors and victory, in 70.0% of the case, the player who makes the less unforced errors wins the inning. The direct point, the forced and unforced errors show no differences between OG, suggesting that these variables are constant at this level during balanced matches.

Tactical changes in Badminton

Further, it seems that changes have appeared in the tactical aspects of the game with time. During this period, two main rules have evolved: the possibility of coaching during the resting time between each point since May 2006 and how the points are counted. Nowadays, regardless of the server, one of the two players marks a point at the end of each rally, allowing a larger risk-taking. In other terms, before May 2006, the server could use a smash on the lateral side line risking only to lose the serve, but after May 2006, the server lose the point in the same situation. It is interesting to note that these changes do not have any influence on the percentage of unforced errors, which did not change all along the OG. It reflects a similar accuracy of the player despite an increase of the game velocity and the risk-taking. This reveals that Badminton players have become more explosive, more accurate and more tactical.

The use of the resting time between each point for tactical reasons is demonstrated by the change of its correlation with the rally time. A previous study of Cabello Manrique and González-Badillo (2003) showed a large correlation between the resting time and rally time (r = 0.87), arguing that the longer the rally, the longer the time necessary to recover the metabolic and the cardio-respiratory thresholds to engage in a new rally (Fahimi and Vaezmousavi, 2011). In our study, this correlation is much lower (r = 0.38; p<0.01), showing that the metabolic constraints is not the only reason behind the duration of this phase. We hypothesized that this difference is probably due to tactics; the resting time serves as time to think about the next point alone or to exchange a few words with the coach.

The increase of the shot frequency along the Olympic Games finals, with a similar stroke distribution, reveals another tactical change. It suggests that the trajectories used have become shorter and flatter. The player is also able to strike the shuttlecock, from a particular place of the court to another, faster today than ten years ago (Cabello Manrique and González-Badillo, 2003; Faude et al., 2007). Nowadays, trajectories are more aggressive and each player tries to impose his tactic during the exchange with descending trajectories to prevent attacks by a smash or a drive from the opponent. Players are probably becoming more explosive in order to increase the shot frequency (+34.0%) by adding speed on the racquet (Phomsoupha and Laffaye, 2014); or they are more visually fit to anticipate their displacement (Phomsoupha and Laffaye, 2015). The change of the rally time distribution also reflects this tactical change in Badminton (Figure 1). Previous studies reported values of rally time ranging from 78.0% to 87.0% for short rallies compared to the mean of 70.0%, in our study (Abian-vicen et al., 2013; Cabello and Lees, 2004; Cabello Manrique and González-Badillo, 2003; Faude et al., 2007; Liddle et al., 1996). Indeed, 90.0% of the rallies are under 10s at OG-96 and then this value decreases to 60.0%, 71.0%, 68.0% and 59.0% in the four following OG. The only exception is the OG-92 final, which have an atypical repartition of rally time. Moreover, there is a shift of the rally time frequency to those that last more than 16 seconds from 1.0% in OG-92 to 20.0% in OG-12. This shows a tendency for a new Badminton temporal structure, in which the rhythm of the strokes increases and the duration of the rallies as well.

Impact on the physiological demand

The present study suggests that the game has become more intensive and consequently argues for a change in the metabolic demands on all the bioenergy systems necessitating a higher resting time. This confirms the importance of a lactic as well as aerobic energy production, due to the intermittent nature of this sport and the fluctuations of several physiological variables, such as heart rate, blood lactate concentration and oxygen consumption (Faude et al., 2007). A couple of studies have promoted the aerobic profile of Badminton, with a high VO_{2max} (e.g, 61.8 ± 5.9 $ml \cdot min^{-1} \cdot kg^{-1}$ in international men) (Faude et al., 2007) and 54.5 ± 2.5 $ml \cdot min^{-1} \cdot kg^{-1}$ in elite male players (Majumdar et al., 1997) and high percentage (89.0%) of maximum heart rate during a match (Liddle, Murph, and Bleakley 1996). The increase in the duration of the exchanges reinforces the need for the players to have aerobic profile. The increase in the resting time supports the necessity to develop the anaerobic alactate system described previously (Cabello Manrique and González-Badillo, 2003; Carlson et al., 1985; Faude et al., 2007).

Moreover, accelerating the shuttlecock necessitates a higher muscular contraction intensity, which results in a higher recovery time. Based on these results, it seems necessary to update the knowledge on the physiology of Badminton to better understand and manage actual and future training as well as tournament time.

Limitations

One limitation of the present study is that it is based only on the finals and not the entire tournaments. This choice has been made for two main reasons:

(1): the difficulty to retrieve the videos of all matches during the OG-92

(2): the fact that the rules of the qualification for the OG are based on the quota of players per country meaning that there is huge difference of level between the best countries and the weaker one. Consequently, several matches are unbalanced, even in semi-final (e.g OG-00, OG-04, OG-12).

Another limitation is the modification of the rules that influence of the change of Badminton game between OG-92 - OG-04 to OG-08 - OG-12, it impacts notably on the effective playing time.

Conclusion

To the best of our knowledge, this study was the first longitudinal study on elite Badminton game. It clearly showed a change of the temporal structure of the Badminton game with significant fluctuations in the rally time, resting time, number of shots per rally and an important increase in the shot frequency (+34.0%), and a decrease in the effective playing time (-34.5%). Moreover, this work showed that the notational analysis may could be very useful for coaching and training (Cabello and Lees, 2004; Cabello Manrique and González-Badillo, 2003; Chen and Chen, 2008; Hong and Tong, 2000; Ming et al., 2008; Pearce, 2002).

The first study finding indicates a high shot frequency, about 1.26 shots per second, which is one of the characteristics of the modern Badminton, in accordance with other recent studies. That means that this parameter has to be included in the training design to be as close as possible to the reality of a game and to be highly competitive for elite level. This could be done by using flat trajectories rather than high trajectories, especially in the game of backcourt. The second main finding of this study is the change of the temporal structure of the game, with an increase of the rest time and a decrease of the effective playing time due to the increase of the intensity of the game. The training design for a metabolic purpose has to take into account this new data, by using a ratio of working time on rest time about 1:3 with a high intensity of the rallies.

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Key points

- Badminton game has become faster, with an important increase in the shot frequency (+34%)
- The effective playing time has decreased between first to last Olympic Games (-34.5%)
- The strokes distribution and the percentage of unforced and forced errors show no differences through the OG analysis, except for the use of the clear

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