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ORIGINAL ARTICLE

Game analysis and energy requirements of paddle tennis competition

Analyse du jeu et exigences physiologiques dans la pratique du padel en competition

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KEYWORDS
Paddle tennis;
Competition;
Physiological demands;
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Summary
Objective. — To determine the physiological demands as well as the structural characteristics of the competitive practice of paddle tennis.
Equipment and methods. — A total of 12 top level male players (age, mean ± standard deviation: 16.57 ± 1.51 years) participated in the study. Twenty-four hours before paddle tennis competition, subjects performed a graded exercise test on a treadmill to determine maximal oxygen consumption, second ventilatory threshold, and maximal heart rate. Total time of game, in-play-time, and out-of-play-time were registered in 12 simulated paddle tennis matches, recording also the frequency and typology of the strokes performed by the analyzed subjects. In addition, oxygen consumption and heart rate values were continuously obtained during the competitive effort.
Results. — Mean oxygen consumption values measured during paddle tennis competition reached values below 50% of maximal oxygen consumption assessed in treadmill test, whereas the mean value for heart rate during the matches represented approximately a 74% maximal heart rate reached in the same laboratory test. On the other hand, in-play-time:out-of-play-time ratio was 1:1 s, being the direct strokes, and especially the volley, those which showed higher frequency scores.

MOTS CLÉS
Padel ;

Résumé
Objectif. — Déterminer les exigences physiologiques ainsi que les caractéristiques structurelles de la pratique compétitive du padel.

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Compétition ;
Exigences physiologiques ;
Analyse du jeu

Matériels et méthodes. — Un total de 12 joueurs de haut niveau de sexe masculin (âge, moyenne ± écart-type : 16,57 ± 1,51 ans) ont participé à l'étude. Vingt-quatre heures avant la compétition du padel, les sujets ont effectué un test d'exercice progressif sur un tapis roulant pour déterminer la consommation maximale d'oxygène et, par ailleurs, un seuil ventilatoire et la fréquence cardiaque maximale. Le temps total de jeu, en play-time, et out-of-play-time ont été enregistrées en 12 matches simulés de padel, l'enregistrement ainsi que la fréquence et la typologie des coups par les sujets analysés. En outre, la consommation d'oxygène et les valeurs de la fréquence cardiaque ont été obtenues en continu pendant l'effort concurrentiel.
Résultats. — La consommation moyenne d'oxygène mesurée pendant la compétition de paddle-tennis atteint des valeurs inférieures à 50 % de la consommation maximale d'oxygène évaluée sur tapis roulant, tandis que la valeur moyenne de la fréquence cardiaque pendant les matchs a représenté environ un taux de 74 % de la fréquence cardiaque maximale atteinte. Par ailleurs, dans le temps de jeu, le ratio hors sur temps de jeu était de 1:1 s, étant des coups directs, et en particulier de volée, ce qui montrait des scores de fréquences plus élevées.

1. Introduction

Paddle tennis is a racquet sport that can be described as a scaled-down composite of tennis and squash, since it uses primarily tennis rules and the tennis scoring system with some adaptations such as an underhand serve. Also, paddle tennis is always a doubles game that is played in an enclosed synthetic glass and metal court that allows for the use of side and back walls for rallies, an action very common in squash. The court is rectangular in shape, measuring 10 m wide by 20 m long and divided in the middle by a normal tennis net (0.88 m at the center strap and 0.92 m at the post). At the end of each court lies a ''half box'' shaped wall, which measures 10 m wide and 3 m tall. It also has two sidewalls that are 4 m wide and 3 m tall. The remainder of the court is enclosed with 3 m high wire mesh (Fig. 1).

Paddle tennis players use a special racquet that shows remarkable differences in size and composition in comparison to tennis and squash ones. Solid and made mostly of light, composite materials, the surface of a paddle tennis racquet is perforated for lightness and allows for easier airflow. The face of the racquet measures 26 × 29 cm and is 45 cm long. Taken into account that the ball used is a less-pressure bright-yellow tennis ball, this short paddle is easier to control than a longer stringed racquet, thus allowing novices of all ages and skills to enjoy a well-paced game with plenty of rallies. In this sense, over the last few years, the number of paddle tennis players in official competitions has increased markedly making necessary, like in other racquet sports, to develop a detailed analysis of the elements it consists of, something essential to design more accurate training programs in order to improve players' performance.

However, the physiological demands in racquet sports competition are not very well known. Recently, Fernandez-Fernandez et al. [1] examined the differences in the activity profile and physiological demands between advanced and recreational veteran tennis players reaching both groups of 55 and 53% of their maximal oxygen consumption (VO_{2max}), respectively. Similar data were collected by Ferrauti et al. [2] who obtained mean VO_2 values of 23 and 25 ml kg^{-1} min^{-1} in six females and six males senior tennis players during 2 h of singles tennis match, respectively. These data were corresponded to 54 (women) and 56% (men) of their respective VO_{2max}. Comellas and López [3] analyzed the metabolic profile of the tennis game reaching values of VO_2 about 65% of VO_{2max}. Davey et al. [4] developed a simulated tennis match protocol recording heart rate (HR) values between 73—81% maximal heart rate (HR_{max}) in top-level tennis players that were consistent with the ranges reported previously [5,6].

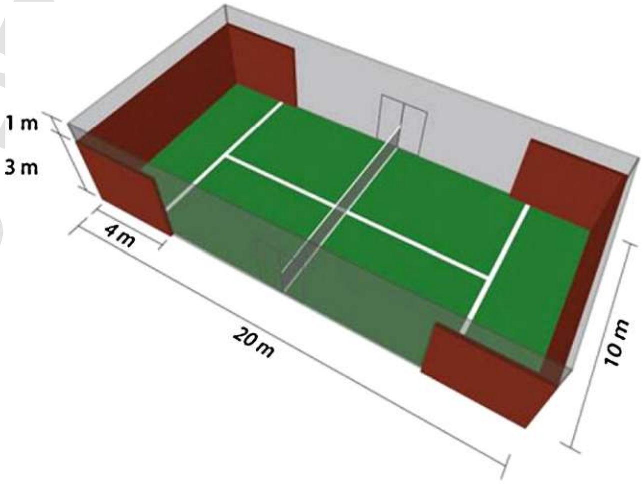

Figure 1 Paddle tennis court dimensions.

Unfortunately, not many studies have been performed to determine the energy cost of squash competition. In one of them, Girard et al. [7] registered mean VO_2 and HR values of 54.4 ml kg^{-1} min^{-1} and 177 beats min^{-1}, respectively, in seven elite players who played a total of 21 matches. These mean values were 86 and 92% of VO_{2max} and HR_{max}, respectively, determined from a previous squash-specific continuous incremental test. Moreover, Alvero et al. [8] analyzed the physiological responses of experienced squash players during competition, obtaining mean HR values of 162–175 beats min^{-1}, being these values similar to those reported previously [9]. Even in table tennis, Zagatto et al. [10] analyzed the physiological responses of the game, reporting HR values of 164 beats min^{-1}, corresponding to 81.2% of the predicted maximum HR, while Shieh, Chou and Kao [11] also investigated the energy expenditure and cardiorespiratory responses during training and simulated table tennis match in 30 elite and 30 amateurs players reaching VO_{2max} values of 29.8 ± 7.2 ml kg^{-1} min during the simulated competition, which reflects the 71% of the maximum reached in the test.

Structural characteristics have also been studied in racquet sports focusing on the temporal patterns of the game. Accordingly, several investigations focused on tennis competition have defined variables such as rally time, recovery time between points, game time and time between games, and total match time [12,13]. Taking into account that playing surface type can be decisive to evaluate these variables [14], Davey et al. [4] reported mean rally time ranged between 2.9 and 12.0 s; recovery time between points of 19.4 s; game and match times of 191.4 s and 167.7 min, respectively; and mean time between games of 81.1 s. In addition, Torres et al. [15] found an effective playing time (real playing time/total playing time) of 30%.

Temporal structure in squash is quite different from that of tennis. In their study, Girard et al. [7] informed about mean rally time of 18.6 s, recovery time between points of 8.4 s, total match time of 25.1 min, and effective playing time of 69.7%, results that are in line to those reported previously [16–18]. Regarding the match characteristics of table tennis, Zagatto et al. [10] recorded the duration of rally, rest time, effort and rest ratio, total playing time and effective playing time, this variable was close to 44% which would place this sport between the two aforementioned.

Moreover, stroke selection and distribution is another common factor related to racquet sports analyses [19]. In tennis, and independently of the serve, the most frequent strokes are forehand and backhand topspins, being half volley and overhead the strokes less used by top-level tennis players [20]. These authors registered the frequency per game of each one of the above-mentioned strokes in three Grand-Slam tournaments, reaching values of 3.0–4.4 for forehand topspin; 2.6–3.0 for backhand topspin; 0.2–0.3 for half volley, and 0.02–0.2 for overhead stroke.

Stroke distribution analysis in squash was performed by Hughes and Robertson [17], who reported a remarkable frequency difference between short and long strokes along elite squash competition. Indeed, long strokes (straight and cross) were used 399 times during matches analyzed (74% of total strokes), whereas a total of 143 short strokes (26% of total strokes) were registered. Straight long was the stroke more used by squash players (43%); among short strokes, drop, volley drop, and boast were the most used (12.40, 7.27, and 5.36 times per game, respectively).

Taking into account the abovementioned studies and the lack of research over the paddle tennis practice characteristics, the aim of this study is to determine the physiological exigencies as well as the most relevant structural characteristics in paddle tennis competition, offering significant information to use in the training planning of this sport.

2. Methods

2.1. Subjects

Twelve top-level paddle tennis players, all of them right-handed males (age, mean ± sd: 16.57 ± 1.51 years; height: 1.72 ± 0.08 m; body mass: 66.00 ± 11.37 kg; body mass index: 22.24 ± 2.73 kg m^{-2}) participated voluntarily in this study. Before participating, they read and signed an informed consent to this end. In addition, this study was approved by the University of Seville Research Ethics Committee.

2.2. Graded exercise test

During the 24 h before participating in a simulated match, paddle tennis players were submitted to a graded exercise test on a treadmill (Baum Electronic Ergo-run Medical 8) to assess VO_{2max} and second ventilatory threshold (VT2). Furthermore, percentages of VT2 related to VO_{2max} were calculated.

The incremental test began at 6 km h^{-1} for 5 min (warm-up). The speed was then increased to 8 km·h^{-1} for the first stage (1 min), increasing 1 km h^{-1} each minute until exhaustion. Treadmill inclination was kept constant at 1% throughout testing.

Breath-by-breath gas analysis was conducted throughout using an automated portable system (MetaMax 2B CORTEZ Biophysik GMBH, Germany) that showed acceptable levels of validity and reliability in previous studies [21]. Heart rate (HR) was monitored using standard HR telemetry (S610i; Polar Electro Oy, Finland) and recorded every 5 s.

2.2.1. Physiological variables

VO_{2max} was defined as the highest 15 s VO_2 value reached during the incremental test. All the subjects fulfilled the following two criteria for VO_{2max}: a) respiratory exchange ratio (R) greater than 1.1; and b) peak HR at least equal to 90% of the age-predicted maximum [22]. The second ventilatory threshold (VT2) was determined from gas exchange measurements using the V-slope method [23] in conjunction with analyses of the ventilatory equivalents. Moreover, other physiological variables such as HR at VO_{2max} (HR_{max}), and HR at VT2 (HR_{VT2}) were also determined for each subject using Metasoft 3 software.

2.3. Paddle tennis match analysis

In order to design the match analysis process, previous investigations which have defined the game structure in sports like tennis and squash through observational methodology were considered [24–26]. In this case, one set was analyzed for each paddle tennis player included in the study, recording both time parameters and all strokes performed during the games analyzed.

2.3.1. Temporal analysis

When temporal structure of a sport is studied, an important parameter that is taken into account is the total volume of activity or competition, normally expressed as total time

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Table 1 Physiological parameters of paddle tennis players measured in laboratory and on-court conditions.

Laboratory test		On-court test	
$VO2_{max}$	55.64 ± 8.84	VO_{2mean}	24.06 ± 6.95
VT2 (HR)	184.14 ± 17.37	$\%VO_{2max}$	43.73 ± 11.04
VT2 (VO_2)	46.57 ± 9.11	HR_{mean}	148.3 ± 13.63
HR_{max}	200.43 ± 15.76	HR_{max}	169.72 ± 18.41
$\%VT2/VO2_{max}$	83.53 ± 7.12	$\%HR_{mean}:HR_{max}$	87.38 ± 5.10
		$\%HR_{mean}:HR_{max}TM$	73.99 ± 4.65
		$\%HR_{max}:HR_{max}TM$	84.9 ± 9.16
		$\%VO_{2mean}:VT2$	52.52 ± 15.50

Data are expressed as mean ± SD. VO_{2mean}: mean oxygen uptake (ml kg^{-1} min^{-1}); VO_{2max}: maximal oxygen uptake (ml kg^{-1} min^{-1}); $\%VO_{2max}$: percentage of mean oxygen uptake respect to maximal oxygen uptake; HR_{max}: maximal heart rate (beats min^{-1}); HR_{mean}: mean heart rate (beats min^{-1}); $\%HR_{mean}/HR_{max}$: percentage of mean heart rate respect to maximal heart rate; $\%HR_{mean}/HR_{max}$: percentage of mean heart rate respect to maximal heart rate (treadmill test); $\%HR_{max}/HR_{max}TM$: percentage of maximal heart rate (match) respect to maximal heart rate (treadmill test); VT2 (HR): heart rate corresponding to anaerobic threshold (beats min^{-1}); $\%VO_{2mean}/VT2$: percentage of mean oxygen uptake respect to oxygen uptake corresponding to anaerobic threshold; VT2 (VO_2): oxygen uptake corresponding to anaerobic threshold (l·min^{-1}); $\%VT2/VO_{2max}$: percentage of oxygen uptake corresponding to anaerobic threshold respect to maximal oxygen uptake.

(TT) [27]. Under the TT concept, it is necessary to discriminate between the in-play-time of game (amount of time in which the ball is in play; iPT) and the out-of-play-time of game (pause periods or amount of time in which the ball is not in play; oPT). From these parameters, we could express the duration of each rally (Tr) and time between them (PTr), acting as indicative parameters of mean effort and recovery of set.

2.3.2. Paddle tennis strokes

An analysis of strokes performed by the players can help to understand the importance of technical and tactical efficiency as well as the correct decision-making process to obtain the best result in the rally [28]. In order to get a complete registration of every stroke and to make a correct interpretation, the classification proposed by González Carvajal [29] was taken as a reference, although paddle tennis strokes were grouped into three categories because of simplifying: a) direct strokes: forehand, backhand, volley and lob; b) boast or indirect strokes (ball rebounded from the wall): forehand, backhand, overhead (smash) and lob, and c) serve (not registered in the study).

2.3.3. On-court physiological variables

The same portable gas analyzer (MetaMax 2B CORTEZ Biophysik GMBH, Germany) was employed to measure VO_2 in each one of the paddle tennis players during the matches studied. In addition, HR was continuously monitored using the same HR monitor (S610i; Polar Electro Oy, Finland).

2.3.4. Data recording and processing

Every match was recorded from the beginning till the end (without pauses) with a digital video camera recorder (Hitachi DZ-HS300) placed so that it could film the player and his interaction with the ball in any court localization. Also, a chronometer was inserted into the picture record to make easier to determine the time parameters. Every match video was viewed by two previously trained observers that had an error percentage less than 2% (1.56%). The reliability of the training method was established in an intraobserver reliability study using video-recorded sets of paddle tennis from eight different matches containing a total of 851 actions.

2.4. Statistical analysis

Every variable was quantified and registered into the designed forms used to this end. The main feature of these forms was its simplicity and effectiveness; since from them, data were transcribed and statistically treated with SPSS 15.0 software. This statistical analysis was based in measures of central tendency and dispersion, highlighting frequency measurement.

3. Results

Table 1 shows physiological parameters related to incremental exercise test on treadmill (laboratory test) and to competitive paddle tennis practice.

It is important to note that mean VO_2 during paddle tennis competition was 24.06 ± 6.95 ml^{-1} kg^{-1} min^{-1}, that means a percentage of 43.73 ± 11.04% in regard to VO_{2max} assessed in laboratory test. Also, HR_{max} values obtained during the games were 18% lower than those found in treadmill test (169.72 ± 18.41 and 200.43 ± 15.76 beats·min^{-1}, respectively), while mean HR values reaching a percentage of 73.99 ± 4.65% of HR_{max} registered in treadmill test. $\%VO_{2mean}$: VT2 was 52.52 ± 15.50% indicates can be used to define the intensity of paddle tennis competition, being moderate.

Related to the structural game analysis, timing action results and stroke distribution analysis are shown in Table 2 and Fig. 2, respectively.

Temporal analysis permitted to find a specific characteristics of paddle tennis competition such as Tr ($7.24 \pm 8 \cdot 10^{-4}$ s), and iPT:oPT ratio (0.97). Also, iPT:TT ratio showed that pause or recovery time represents more than 50% of TT (Table 2).

Table 2 Temporal analysis of the games analyzed.

	TT (s)	iPT (s)	oPT (s)	Tr (s)	PTr (s)	iPT:oPT	iPT:TT
Mean	163.06	71.43	73.40	7.24	9.11	0.97	0.44
SD	3.04	$2{\cdot}10^{-2}$	$1.7{\cdot}10^{-3}$	$8{\cdot}10^{-4}$	$3{\cdot}10^{-4}$		

TT: total time of the game; iPT: in-play-time of game; oPT: out-of-play-time of the game; Tr: time of the rally; PTr: pause time between rallies; iPT:oPT: in-play-time/out-of-play-time of the game ratio; iPT:TT: in-play-time/total time ratio.

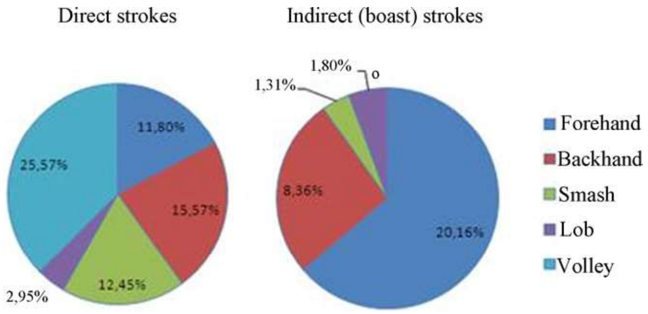

Figure 2 Strokes distribution during paddle tennis competition.

As it can be seen in Fig. 2, and regardless of the serve, the most frequent direct stroke used during the games analyzed was volley (25.57% of the total strokes performed). At a lower frequency, we appreciated backhand (15.57%), overhead or smash (12.45%), and forehand (11.80%). Finally, the lob was the less used stroke during paddle tennis competition (2.95%). In regard to boast or indirect strokes, the forehand was the most used stroke (20.16%), while the backhand showed a frequency of 8.36%. Lob and overhead were the indirect strokes less used, accounting only for frequencies of 1.80 and 1.31% of the total indirect strokes performed, respectively.

4. Discussion

The results obtained in this study provides an initial description of the physiological requirements implicated in this sport practice as well as time structure and frequency in which several actions take place during the game.

Considering the mean on-court VO_2 values obtained in the present study ($24.06 \pm 6.95\,ml^{-1}\,kg^{-1}\,min^{-1}$), it seems that energy requirements of paddle tennis are closer to those reported previously for tennis [2,5]. However, VO_2 during paddle tennis matches is remarkably lower than that reported by Girard et al. [7] in squash matches ($54.4\,ml^{-1}\,kg^{-1}\,min^{-1}$). Also, taking into account the percentage of on-court over VO_{2max} registered in laboratory conditions ($43.73 \pm 11.04\%$), our data are lower than those previously found in single tennis, all of them between 53 and 65% of the corresponding VO_{2max} [1–3] or even in table tennis [11]. In addition, the percentage of mean VO_2 respect to VO_{2max} described by Girard et al. [7] in squash players is two-folds higher in comparison to that expressed by paddle tennis players.

Mean HR values registered in paddle tennis during the match was 148.30 ± 13.73 beats min^{-1} that means a percentage of $73.99\% \pm 4.65$ in relation to HR_{max} reached in the laboratory test. Otherwise, the HR_{max} registered during the match (169.72 ± 18.41 beats min^{-1}) meaned a percentage of $84.90\% \pm 9.16$ respect to HR reached during the treadmill graded exercise test. These data are newly related to those found previously in single tennis. Indeed, Torres et al. [15] registered a mean HR value of 158.4 ± 8.5 beats min^{-1} during a single tennis match. In this line, Christmass et al. [5] reported a HR_{max} value of 189 ± 3 beats min^{-1} during a single tennis match, reaching a percentage of $85.1 \pm 1.3\%$ of HR_{max} achieved in laboratory test, while during squash competition, Alvero et al. [8] observed mean HR values between 167 and 175 beats min^{-1} (winners and losers, respectively) and also similar (163.8 ± 13.7 beats min^{-1} to the values reached in table tennis [10]. As happened with VO_2 and VO_{2max}, competitive squash practice induces higher cardiovascular responses (mean HR and HR_{max}) than those observed during tennis and paddle tennis matches.

On the other hand, the structural analysis of paddle tennis determined a mean TT of each one of the games analyzed of 163.06 ± 3.04 s; iPT was $71.43 \pm 2.3{\cdot}10^{-2}$ s, whereas a mean time of $7.24 \pm 8\,10^{-4}$ s was measured for Tr. Mean oPT was $73.4 \pm 1.7{\cdot}10^{-2}$ s, and mean PTr was established in $9.11 \pm 3{\cdot}10^{-4}$ s. In both cases, the pause time clearly overcame real time, an aspect to bear in mind when programming the paddle tennis training. Comparing these data with those derived from single tennis, it is important to note that TT is very similar to that found by Davey et al. [4], who reported mean values of 191.4 s. Moreover, it is possible to conclude that Tr is certainly similar to mean values of 7.5 and 8.2 s registered in tennis by König et al. [13] and Smekal et al. [12], respectively. Despite this, and also in single tennis analysis, Filipcic [30] registered Tr values between 18.7 (Wimbledon) and 23.1 s (French Open). As previously stated, playing surface type can be decisive to evaluate these variables [13]. Indeed, Davey et al. [4] informed about Tr between 2.9–12.0 s when matches are played on category 2 surfaces (i.e., US Open). Considering the data provided by Girard et al. [7], Tr in paddle tennis was shorter than that registered in squash (18.6 s), although PTr found in squash was very similar to the mean values obtained in the present study (8.4 vs. 9.1 s, respectively). In any case, the ratio iPT:TT found here (relationship between real time and pause time into the games analyzed) was 0.44 or what is the same, an effective playing time of 44%. This data is the same reported in table tennis within a match [10], above the 30% found in tennis [15] but at the same time is lower than the 69% registered in squash competition [7]. Moreover, considering the ratio iPT:oPT (work vs. recovery periods), data from paddle tennis showed a relationship near to 1:1, a proportion that is different from 1:2.6 which was found in tennis [30] and from 1:0.45 described in squash competition [7]. This information, together with the previously defined on-court VO_2, can lead to define the dynamics of efforts in paddle tennis matches and, in consequence, to design paddle tennis specific fitness trainings.

Lastly, another relevant data that it can be extract from this study is stroke distribution according to its typology. In general, and regardless of the serve, direct strokes (without rebound wall) showed higher frequency than indirect (boast) strokes (40.97% vs. 31.63% of the total strokes made, respectively). The most used strokes in paddle tennis were direct volleys (25.57%) followed by backhand (15.57%) and overhead (smash) strokes (12.45%). On the other hand, less frequent strokes were: indirect overhead strokes (1.31%) and lobs, both in direct and indirect form (2.95 and 1.8%, respectively). These results are different than those observed in tennis, where the most used strokes are forehand and backhand topspins [20]. Also, half volley is a stroke that is used with low frequency in tennis matches, as occur with overhead stroke, contrary to what happens during paddle tennis competition. Something similar occurs during squash matches, where long and straight strokes (without rebound wall) are used more frequently than short strokes, including any type of volley [17]. It seems obvious that the influence of factors such us surface court dimensions (tennis vs. paddle tennis and squash), height of the net (tennis and paddle tennis vs. squash), vertical wall limits (paddle tennis and squash vs. tennis), and ball and racquets characteristics, is responsible for the frequency of use of each one of these strokes.

5. Conclusions

No studies so far have analyzed functional and structural characteristics of paddle tennis, a sport whose practice has spectacularly increased over the last few years. Acting this way and attending the proposed objectives, we have determined the physiological requirements of its competitive practice as well as the dynamics of the game, emphasizing in the temporal characteristics and the paddle tennis strokes' distribution. In this sense, the intensity developed during paddle tennis practice is close to that experimented in single tennis practice, despite differences between these two racquet sports. Moreover, one of the characteristics that define the temporal structure in paddle tennis practice is the similarity between iPT and oPT, this ratio being more balanced than others from different racquet sports.

The concise definition of most used strokes during the game provides relevant information from the technical and tactical points of view. Unlike other racquet sports, direct strokes predominate over indirect ones, volley being the most used stroke in paddle tennis competition.

Overall, data reported in this study can help to design optimized paddle tennis training, although new studies are needed in order to complete the definition of the paddle tennis practice requirements, focusing in strokes' effectiveness and tactical aspects.

Conflict of interest statement

None.

References

[1] Fernandez-Fernandez J, Sanz-Rivas D, Sánchez-Muñoz C, Pluim BM, Tiemessen I, Mendez-Villanueva A. A comparison of the activity profile and physiological demands between advanced and recreational veteran tennis players. J Strength Cond Res 2009;23:604—10.

[2] Ferrauti A, Bergeron MF, Pluim BM, Weber K. Physiological responses in tennis and running with similar oxygen uptake. Eur J Appl Physiol 2001;85:27—33.

[3] Comellas J, López P. Análisis de los requerimientos metabólicos del tenis. Apunts: Educación Física y Deportes 2001;65:60—3.

[4] Davey PR, Thorpe RD, Williams C. Simulated tennis matchplay in a controlled environment. J Sports Sci 2003;21:459—67.

[5] Christmass MA, Richmond SE, Cable NT, Arthur PG, Hartmann PE. Exercise intensity and metabolic response in singles tennis. J Sports Sci 1998;16:739—47.

[6] Therminarias A, Dansou P, Chirpaz-Oddou MF, Gharib C, Quirion A. Hormonal and metabolic changes during a strenuous tennis match: effect of ageing. Int J Sports Med 1991;12:10—6.

[7] Girard O, Chevalier R, Habrard M, Sciberras P, Hot P, Millet GP. Game analysis and energy requirements of elite squash. J Strength Cond Res 2007;21:909—14.

[8] Alvero JR, Barrera J, Mesa A. Correlations of physiological responses in squash players during competition. In: IV World Congress of Science and Racket Sports. Madrid: Alto Rendimiento; 2006.

[9] Chin MK, Wong AS, So RC, Siu OT, Steininger K, Lo DT. Sport specific fitness testing of elite badminton players. Br J Sports Med 1995;29:153—7.

[10] Zagatto AM, Morel EA, Gobatto CA. Physiological responses and characteristics of table tennis matches determined in official tournaments. J Strength Cond Res 2010;24(4):942—9.

[11] Shieh SC, Chou JP, Kao YH. Energy expenditure and cardiorespiratory responses during training and simulated table tennis match. Int J Table Tennis Sci 2010;6:182—4.

[12] Smekal G, Von Duvillard S, Rihacek C, Pokan R, Hofmann P, Baron R, et al. A physiological profile of tennis match play. Med Sci Sports Exerc 2001;33:999—1005.

[13] König D, Hounker M, Schimd A, Halle M, Berg A, Kaul J. Cardiovascular metabolic and hormonal parameters in professional tennis players. Med Sci in Sports and Exerc 2001;33:54—8.

[14] O'Donoghue P, Ingram B. A notational analysis of elite tennis strategy. J Sports Sci 2001;19:107—15.

[15] Torres G, Cabello D, Carrasco L. Functional differences between tennis and badminton in young sportsmen. In: Lees A, Khan JF, Maynard IW, editors. Science and Racket Sports III. Oxon: Routledge; 2004. p. 185—9.

[16] Montpetit RR. Applied physiology of Squash. Sports Med 1990;10:31—41.

[17] Hughes M, Robertson C. Using computerised notational analysis to create a template for elite squash and its subsequent use in designing hand notation system for player development. In: Reilly T, Hughes M, Lees A, editors. Science and Racket Sports. London: E&FN Spon; 1998. p. 227—34.

[18] Sharp NCC. Physiological demands and fitness for squash. In: Reilly T, Hughes M, Lees A, editors. Science and Racket Sports. London: E&FN Spon; 1998. p. 3—13.

[19] Hughes M, Barlett R. The use of performance indicators in performance analysis. J Sports Sci 2002;20:739—54.

[20] Johnson CD, McHugh MP. Performance demands of professional male tennis players. Br J Sports Med 2006;40:696—9.

Please cite this article in press as: Carrasco Páez L, et al. Game analysis and energy requirements of paddle tennis competition. Sci sports (2011), doi:10.1016/j.scispo.2010.12.016

[21] Vogler AJ, Rice AJ, Gore CJ. Validity and reliability of the Cortex MetaMax3B portable metabolic system. J Sports Sci 2010;28:733—42.
[22] Taylor HL, Buskirk ER, Henschel A. Maximal oxygen intake as an objective measure of cardiorespiratory performance. J Appl Physiol 1955;8:73—80.
[23] Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 1986;60:2020—7.
[24] O'Donoghue P. Is notational analysis research? A repeated investigation of tennis strategy. In: World Congress of Performance Analysis, Sport Sciences and Computers. Cardiff, Wales; 2001. p. 147—52.
[25] Lees A. Science and the major racket sports: a review. J Sports Sci 2003;21:707—32.
[26] Wells J, Robertson C, Hughes M, Howe D. Performance profiles of elite men squash doubles match play. In: Lees A, Khan JF, Maynard IW, editors. Science and Racket Sports III. Oxon: Routledge; 2004. p. 196—201.
[27] Galiano D, Escoda J, Pruna R. Aspectos fisiológicos del Tenis. Apunts: Educación Física y Deportes 1996;44-45: 115—21.
[28] Blompvist M, Luhttanen P, Laakso L. Validation of a notational analysis system in badminton. J Human Mov Studies 1998;35:137—50.
[29] González-Carvajal C. Escuela de pádel. Del aprendizaje a la competición amateur. Madrid: Tutor; 2006.
[30] Filipcic A. Tennis—training. Ljubljana: Faculty of Sport—University of Ljubljana; 2002.

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