Analysis of changes in heart rate variability before and after a table tennis match depending on the outcome

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Summary

The aim of this study was to compare heart rate variability (HRV) indices before and after a table tennis match, depending in match result. HRV indices were measured before (PRE) and after (POST) match periods to 21 table tennis players (21.86 ± 8.34 yr) in 30 matches. No significant differences were found neither in PRE nor in POST measures comparing winners and losers. A significantly lower value ($p < 0.05$) was found in mean of RR intervals (mean RR), standard deviation of RR intervals (SDNN), the natural logarithm transform of the root mean square of successive differences between normal heartbeats (LnRMSSD), relative number of successive RR interval pairs that differ more than 50 ms (pNN50), cross (SD1) and longitudinal (SD2) axis of Poincaré plot comparing POST values with PRE values. Nevertheless, low frequency index expressed in absolute power (LF Power) and high frequency indices expressed in absolute power (HF power) and normalised power (HF Power) showed different trends depending on the results ($p < 0.05$). The obtained results show a HRV decrease after table tennis match regardless the match result, in both time domain and non-linear indices. However, frequency domain indices show a different trend depending on the match outcome.

Key words:
Fatigue. Table tennis.
Autonomous nervous system.
Competition. Performance

Análisis de la evolución de la variabilidad de la frecuencia cardíaca antes y después de un partido de tenis de mesa en función del resultado

Resumen

El objetivo del estudio fue analizar el comportamiento de la variabilidad de la frecuencia cardíaca (VFC) de jugadores de tenis de mesa antes y después de un partido ateniendo al resultado (ganar o perder). Se midió la VFC antes (PRE) y después (POST) del partido a 21 jugadores de tenis de mesa en un total de 30 partidos. No se observaron diferencias significativas ni en el PRE ni en el POST en función del resultado. Se observó un descenso ($p < 0,05$) en la media de los intervalos RR (media RR), la desviación estándar de los intervalos R-R (SDNN), el logaritmo natural de la raíz cuadrada del valor medio de la suma de las diferencias al cuadrado de todos los intervalos R-R (LnRMSSD), el porcentaje de los intervalos RR consecutivos que discrepan en más de 50 ms entre sí (pNN50), el eje transversal (SD1) y longitudinal (SD2) del diagrama de Poincaré en el POST con respecto al PRE en ambos grupos. Sin embargo, las variables de la banda de baja frecuencia expresada en fuerza absoluta (LF Power), la banda de alta frecuencia expresadas en fuerza absoluta (HF Power) y fuerza normalizada (HF Power) mostraron tendencias distintas en función del resultado ($p < 0,05$). Los resultados muestran un descenso en la VFC después de disputar un partido de tenis de mesa independientemente del resultado del partido en el dominio del tiempo y en variables no lineales. No obstante, el dominio de la frecuencia muestra una tendencia distinta en función del resultado.

Palabras clave:
Fatiga. Tenis de mesa.
Sistema nervioso autónomo.
Competición. Rendimiento.

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Introduction

Table tennis is an intermittent racket sport, alternating short cycles of high-intensity effort with incomplete recovery periods[1–3]. Due to the demands of competition, table tennis is considered a mixed sport, with a continuous use of both the aerobic and anaerobic systems[4]. The aerobic system is the main source of energy during matches, allowing adequate recovery during interruptions that occur during the game[2,3]. On the other hand, due to the continuous high-intensity actions that occur during matches, the anaerobic system is essential in periods of exertion[2,3]. In addition to the related physical demands, table tennis is characterized by requiring athletes to perform, different technical actions—in a coordinated manner and at maximum speed—with the upper limbs after having made short and fast displacements with continuous changes of direction[2]. At the same time, players must deploy a large repertoire of movements to select the correct shot as quickly as possible based on their opponent's actions[5]. In addition to the high physical demands, continuous tactical decisions, and the need to accurately execute different technical actions, players are also subject to a high cognitive demand and a high level of mental stress[6]. This form of sport is, therefore, one with high physical and psychological demands[2,6].

Previous studies have shown that both physical and psychological demands affect the state of the autonomic nervous system (ANS)[7]. During exercise, increases in intensity entail increases in sympathetic activity and decreased parasympathetic activity, resulting in an increased heart rate (HR)[8,9]. Heart rate variability (HRV) has been used to understand the activation of the ANS, both in individual and collective sports[10,11]. HRV is a non-invasive tool that shows the variation in the time elapsed between successive beats by analyzing R-R intervals, thereby allowing an analysis of ANS activity and, thus, showing the activation level of the sympathetic and parasympathetic nervous system[12,13]. In this sense, HRV analysis allows one to observe the response of the ANS in different exercise situations[9,14]. The variables used to measure HRV are based on time-domain, frequency-domain, and non-linear variables[15]. The parameters commonly used in time-domain analysis are the square root of the mean squared difference of all successive R-R intervals (RMSSD) and the standard deviation of consecutive R-R periods (SDNN)[16]. These variables analyze HR variations, owing to which they depend on it[15]. To isolate the analysis of HRV for each participant's HR, and thus to be able to compare different situations independently of the HR, the natural log-transformed root mean square of successive R-R intervals (LnRMSSD)[17] was used. On the other hand, frequency-domain analysis breaks down the R-R signal into different components, thus showing: i) the high frequency band (HF), which shows parasympathetic nervous system activity, ii) the low frequency band (LF), affected by both the sympathetic and parasympathetic nervous system and iii) the LF/HF ratio, which reflects sympathetic dominance when it has a high value[17]. However, it has previously been observed that breathing patterns affect frequency-domain values, which makes it difficult to interpret results[7,18]. In addition, analyses with non-linear HRV parameters show parasympathetic modulation without the involvement of breathing[19]. Specifically, the parameters used are SD1, which reflects parasympathetic activity in the heart, and SD2, which reflects both sympathetic and parasympathetic activity[20].

In light of the information obtained on ANS activation, HRV has been researched in different training and competition situations in individual and collective sports[8,9,21,22]. Several studies have analyzed HRV variation before and after different physical exertion with the aim of assessing the influence of physical activity on HRV[9,17,22,23]. Specifically, in badminton players, a sport similar in structure to table tennis, decreased post-exercise values of SDNN and RMSSD have been observed in comparison to pre-exercise values, thus showing an increase in the activity of the sympathetic nervous system induced by accumulated effort[8,22,24]. In addition, a recent study—also with badminton players—analyzed pre-post competition HRV based on competitive outcome (win or lose), to observe whether the competitive outcome could affect changes in HRV[25]. In that study, it was observed that the players who won the match had higher values in the LF/ HF ratio and a lower magnitude of the HF and LF variables than the losing players, thus showing a greater sympathetic activation of the ANS in the winners. However, no significant differences were obtained in time-domain parameters or non-linear variables. Despite the significance of possible changes in HRV before and after playing a table tennis match according to the outcome, there are no studies that analyze this aspect. This analysis would provide more exhaustive knowledge of competitive demand and the behavior of the ANS in table tennis as relates to winning or losing the match, since the match's outcome seems to affect the HRV[25].

Therefore, the objectives of the present study were, firstly, to analyze the HRV behavior of table tennis players before and after playing a match according to their outcomes (win or lose) and, secondly, to analyze if match duration affects HRV.

Materials and method

Participants

The sample was composed of 21 table tennis players (21.86 ± 8.34 years, 1.73 ± 0.08 m, 64.09 ± 13.39 kg and 21.46 ± 4.38 $kg \cdot m^{-2}$), who competed in one of the official categories of table tennis, both nationally and provincially in the autonomous community of the Basque Country. The criteria for inclusion in the study were to have a valid license issued by the Spanish Table Tennis Federation and not to be injured or recovering from an injury at the time of the research study. All participants had at least two years' experience in table tennis competitions. All were informed of the objectives and procedures of the research study and voluntarily agreed to be part of it, signing an informed consent form. In the case of underaged players, the informed consent form was also signed by their parents or legal guardians. The study was conducted with the consent of the club to which they belonged. All procedures followed the guidelines set out by the Declaration of Helsinki (2013), respecting the provisions of the Organic Law on the Protection of Personal Data (LOPDCP). Likewise, the study was approved by the Ethics Committee for Research with Human Beings (CEISH, Nº 2080310018-INB0059) of the University of the Basque Country (UPV/EHU).

Procedure

We analyzed 30 best-of-5 table tennis matches played outside the competitive season, thereby obtaining 60 records. In each of the matches, the outcome obtained by the players (win or lose) was noted. The participants' HRV was measured before and after the matches. The HRV was recorded for 8 minutes PRE and POST match, taking into account the last 3 minutes PRE and the first 3 minutes POST. Each participant was instructed to lie on their backs for 8 minutes before[26,27] and after the match[8,9,23,28]. Pre-match logs were made before the 2-minute warm-up and POST match logs were made immediately after the end of the match. A warm-up was carried out prior to each match, which consisted of 2 minutes of forehand and backhand exchanges, including topspin hitting.

Measurement

HRV analysis: The heart rate signal was measured using a chest band with Bluetooth Smartyse technology, which was recorded on a Polar monitor (V800, Kempele, Finland). The data obtained were transferred to a computer using a specific software (Polar Flow, Kempele, Finland) and were exported for HRV analysis using the Kubios v3.0 software (Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland).

The time-domain parameters obtained were the following: i) the mean R-R interval (Mean RR), ii) the standard deviation of the R-R intervals (SDNN) which describes both alterations in the sympathetic and parasympathetic system; (iii) the mean heart rate (Mean HR); (iv) standard deviation of heart rate (STD HR); (v) the minimum recorded heart rate (Min HR); vi) the maximum recorded heart rate (Max HR); vii) log-transformed root mean square of successive R-R intervals (LnRMSSD), which reflects the variance between HR beats and estimates vagal changes ; and viii) the percentage of successive R-R intervals more than 50 milliseconds apart (pNN50), which has been observed to correlate with changes in the parasympathetic nervous system and RMSSD[29]. The above parameters quantify the amount of HRV observed in the monitoring periods[29].

In regard to frequency-domain parameters, which show the contribution of both the sympathetic and parasympathetic nervous systems, the following were recorded: i) power peaks between 0.04-0.15 Hz (Low frequency (LF)), ii) power peaks between 0.15-0.40 Hz (High frequency (HF)) and iii) the ratio between LF and HF (LF/LF), high values of which are associated with the sympathetic system domain[17]. These values analyze the frequency with which the distance of the R-R interval changes[17], drawing measurements in three different units; i) absolute force (ms2); (ii) logarithmic force (log) (iii) normalized force (u.n.).

The following non-linear parameters were analyzed: i) the transverse axis of the Poincaré diagram (SD1), which analyzes HRV in the short term and is an indicator of sympathetic activity[29]; ii) the longitudinal axis of the Poincaré diagram (SD2), which analyzes HRV in the long term, correlates with LF, and is an indicator of parasympathetic activity[29]; and iii) the SD2/SD1 ratio used to analyze autonomous balance and the balance between sympathetic and parasympathetic activity[29].

Statistical analysis

The results are shown in mean and standard deviation (SD). Data standardization was analyzed using the Shapiro-Wilk test, observing that the data did not display a normal distribution. The Mann-Whitney U test was used to analyze the differences between players who won and those who lost at both pre and post times. On the other hand, the Wilcoxon test was used to analyze independent differences between the PRE match and POST match values in each of the groups. The percentage difference (Δ. %) was calculated in each case using the following formula: Δ. (%) = [(mean POST – mean PRE) / mean PRE] x 100. The effect size (ES) was calculated both for the differences between groups at each moment and for the differences between the PRE and POST in each of the groups[30]. Effect sizes less than 0.2, between 0.2 and 0.5, between 0.5 and 0.8 and above 0.8 were considered trivial, low, moderate and high, respectively. The relationship between the duration of the matches and the different HRV variables was analyzed using the Spearman correlation coefficient (r). The correlations obtained were considered high when the absolute value was between 1 and 0.70, moderate between 0.69 and 0.50, low between 0.49 and 0.20, and very low between 0.19 and 0.0931. Statistical significance was established at $p < 0.05$. Statistical analysis was performed with the Statistical Package for Social Sciences program (version 23.0, SPSS® Inc. Chicago, IL, USA).

Results

Table 1 shows the results obtained for the HRV time-domain values in the PRE match and POST match, by both the players who won and lost the match. Neither the PRE values nor the POST values of any of the HRV time-domain variables showed significant differences between the players who won the match and those who lost ($p > 0.05$, ES = -0.4 to 0.28, low). The mean parameters RR, SDNN, LnRMSSD and pNN50 showed a significant decrease in the POST match with respect to the PRE ($p < 0.05$, ES = -0.44 to -2.26, moderate to high) both in the group of players who won and those who lost the match. However, Mean HR, Min HR, and Max HR showed a significant increase in the POST match with respect to the PRE ($p < 0.05$, ES = 1.25 to 1.7, high) in both groups. No significant differences were observed between PRE and POST in the STD HR variable in either group ($p > 0.05$, ES = 0.1 to 0.12, trivial).

Table 2 shows the HRV frequency-domain values obtained by both the players who won and those who lost the match, in the PRE and POST match. Neither the PRE values nor the POST values of any

Table 1. Descriptive parameters of heart rate variability in the pre-match (PRE) and post-match (POST) time domain, categorized by match outcome (win or lose).

		PRE	POST	Δ. (%)	ES
Average RR (ms)	WIN	784.81 ± 126.01	591.59 ± 90.04**	-24.62	-2.15
	LOSE	771.68 ± 125.02	574.96 ± 87.12**	-25.49	-2.26
	Δ. (%)	-1.67	-2.81		
	ES	-0.11	-0.19		
SDNN (ms)	WIN	41.48 ± 16.47	31.97 ± 21.76**	-22.92	-0.44
	LOSE	38.79 ± 12.96	29.23 ± 20.64**	-24.64	-0.46
	Δ. (%)	-6.49	-8.57		
	ES	-0.21	-0.13		
Mean HR (beats/min)	WIN	78.12 ± 11.06	103.60 ± 15.02**	32.62	1.7
	LOSE	79.49 ± 11.39	106.85 ± 17.54**	34.42	1.56
	Δ. (%)	1.75	3.13		
	ES	0.12	0.18		
STD HR (beats/min)	WIN	5.38 ± 2.34	5.89 ± 4.09	9.44	0.12
	LOSE	5.29 ± 1.49	5.62 ± 3.21	6.24	0.1
	Δ. (%)	-1.78	-4.65		
	ES	-0.06	-0.09		
Min HR (beats/min)	WIN	66.34 ± 7.32	85.48 ± 12.13**	28.86	1.58
	LOSE	68.17 ± 10.15	89.84 ± 17.31**	31.8	1.25
	Δ. (%)	2.76	5.1		
	ES	0.18	0.25		
Max HR (beats/min)	WIN	93.93 ± 16.86	131.42 ± 23.86**	39.91	1.57
	LOSE	96.27 ± 14.04	138.08 ± 24.12**	43.44	1.73
	Δ. (%)	2.48	5.07		
	ES	0.17	0.28		
LnRMSSD (ms)	WIN	3.37 ± 0.56	2.92 ± 0.75**	-13.31	-0.6
	LOSE	3.25 ± 0.46	2.75 ± 0.71**	-15.33	-0.71
	Δ. (%)	-3.43	-5.69		
	ES	-0.25	-0.24		
pNN50 (%)	WIN	12.36 ± 16.75	6.21 ± 11.73**	-49.78	-0.52
	LOSE	8.75 ± 11.16	3.13 ± 7.72**	-64.27	-0.73
	Δ. (%)	-29.16	-49.61		
	ES	-0.32	-0.4		

Mean RR: Mean of the R-R interval; SDNN: Standard deviation of R-R intervals; Mean HR: Mean heart rate; STD HR: Standard deviation of heart rate; Min HR: Minimum heart rate; Max HR: Maximum heart rate; LnRMSSD: log-transformed root mean square of successive R-R intervals; pNN50: Percentage of successive R-R intervals that exceed more than 50 milliseconds with each other; ES: Effect size; Δ. (%): Percentage of variation.

**$p < 0.01$ significant differences with respect to the PRE.

of the frequency-domain variables showed significant differences between the players who won the match and those who lost ($p > 0.05$, ES = -0.66 to 0.53, moderate). The variables LF Power (log) and HF Power (log) showed a significant decrease in the POST with respect to the PRE split values ($p < 0.05$, ES = -0.43 to -0.82, moderate to high) in both the players who won and those who lost the match. However, the LF Power (ms2), HF Power (ms2) and HF Power (u.n.) displayed a different trend in both groups. While the LF Power (ms2) in the group that won the match decreased significantly in the POST with respect to the PRE ($p < 0.05$, ES = -0.45, moderate), it increased significantly ($p < 0.05$, ES = 0.02, trivial) for the players who lost the match. As for HF Power (ms2) and HF Power (u.n.), no significant changes were observed in the POST match with respect to the PRE match in the group that won ($p > 0.05$, ES = -0.03 to 0.07, trivial), while the group that lost the match displayed a significant decrease ($p < 0.05$, ES = -0.18 to -0.51, trivial to moderate). With respect to LF Power (u.n.) no significant changes were observed between the PRE and the POST match in the group that won ($p > 0.05$, ES = 0.03, trivial), while the group that lost the match displayed a significant increase

Table 2. Descriptive parameters of heart rate variability in the pre-match (PRE) and post-match (POST) frequency domain, categorized by match outcome (win or lose).

		PRE	POST	Δ. (%)	ES
LF Power (ms^2)	WIN	1250.28 ± 1263.59	756.09 ± 1099.08**	-39.53	-0.45
	LOSE	948.03 ± 836.46	998.96 ± 2500.83**	5.37	0.02
	Δ. (%)	-24.17	32.12		
	ES	-0.36	0.1		
LF Power (log)	WIN	6.74 ± 0.89	6.06 ± 1.02**	-10.15	-0.67
	LOSE	6.55 ± 0.78	5.69 ± 1.54**	-13.22	-0.56
	Δ. (%)	-2.86	-6.18		
	ES	-0.25	-0.24		
LF Power (u.n.)	WIN	68.02 ± 15.03	68.49 ± 18.78	0.69	0.03
	LOSE	68.79 ± 14.47	76.19 ± 14.53**	10.76	0.51
	Δ. (%)	1.12	11.24		
	ES	0.05	0.53		
HF Power (ms^2)	WIN	657.82 ± 935.46	816.72 ± 2431.46	24.16	0.07
	LOSE	439.21 ± 487.93	297.09 ± 789.74**	-32.36	-0.18
	Δ. (%)	-33.23	-63.62		
	ES	-0.45	-0.66		
HF Power (log)	WIN	5.87 ± 1.03	5.17 ± 1.63**	-12.01	-0.43
	LOSE	5.66 ± 0.88	4.36 ± 1.58**	-22.95	-0.82
	Δ. (%)	-3.68	-15.65		
	ES	-0.25	-0.51		
HF Power (u.n.)	WIN	31.91 ± 14.99	31.44 ± 18.76	-1.49	-0.03
	LOSE	31.13 ± 14.44	23.71 ± 14.45**	-23.83	-0.51
	Δ. (%)	-2.45	-24.58		
	ES	-0.05	-0.53		
LF/HF Power (ms2)	WIN	3.32 ± 2.51	3.03 ± 1.63	-8.72	-0.18
	LOSE	4.06 ± 2.89	3.78 ± 2.69	-6.67	-0.1
	Δ. (%)	22.31	24.93		
	ES	0.26	0.28		

LF: Low frequency; HF: High frequency; LF/HF: Ratio between LF and HF; Power (ms2): Absolute force; Power (log): Logarithmic force; Power (u.n.): Normalized force; ES: Effect size; Δ. (%): Percentage of variation.
**p < 0.01 significant differences with respect to the PRE.

($p < 0.05$, ES = 0.51, moderate). No significant differences were observed between PRE and POST in either group in the variable LF/HF Power (ms2) ($p > 0.05$, ES = -0.1 to -0.18, trivial).

Table 3 shows the results obtained by both the players who won the match and those who lost in the PRE match and POST match in terms of the non-linear HRV values. Neither the PRE values nor the POST values of any of the non-linear variables showed significant differences when comparing the players who won the match with those who lost ($p > 0.05$, ES = -0.37 to 0.2, trivial to low). SD1 and SD2 showed a significant decrease in the POST with respect to the PRE ($p < 0.05$, ES = -0.38 to -0.48, low) in both the players who won and lost the match. No difference was observed between PRE and POST in either group in SD2/SD1 ($p > 0.05$, SD = 0.24 to 0.28, low).

There was no significant association between match duration and HRV variables in either PRE or POST match in any of the groups. Significant correlations were only found between match duration and Δ. (%) Min HR in the group that won ($r = 0.375$, $p < 0.05$) and in the group that lost the match ($r = 0.479$, $p < 0.01$).

Discussion

The objective of this study was to analyze the HRV behavior of table tennis players before and after playing a match, taking into account the outcome (win or lose). HRV is a useful and non-invasive tool that allows one to analyze the behavior of the ANS[12,32] and has previously been used to analyze over-training states, to better gauge adjustments to training,

Table 3. Descriptive parameters of heart rate variability in the non-linear pre-match (PRE) and post-match (POST) domain, categorized by match outcome (win or lose).

		PRE	POST	Δ. (%)	ES
Poincaré Plot, SD1	WIN	24.47 ± 17.16	17.85 ± 17.47**	-27.05	-0.38
	LOSE	20.45 ± 10.95	14.43 ± 12.55**	-29.46	-0.48
	Δ. (%)	-16.41	-19.17		
	ES	-0.37	-0.27		
Poincaré Plot, SD2	WIN	52.48 ± 18.41	40.96 ± 26.06**	-21.95	-0.44
	LOSE	50.45 ± 16.12	37.73 ± 26.60**	-25.21	-0.48
	Δ. (%)	-3.87	-7.88		
	ES	-0.13	-0.12		
Poincaré Plot, SD2/SD1	WIN	2.60 ± 1.01	2.86 ± 0.94	10.04	0.28
	LOSE	2.79 ± 0.92	3.05 ± 1.10	9.34	0.24
	Δ. (%)	7.1	6.43		
	ES	0.2	0.17		

SD1: Cross-sectional axis of the Poincaré plot; SD2: Longitudinal axis of the Poincaré plot; SD2/SD1: Ratio between SD1 and SD2; ES: Effect size; Δ. (%): Percentage of variation.
**p < 0.01 significant differences with respect to the PRE.

and to quantify the level of pre-competitive stress[23,33,34]. These aspects allow for one to more adequately plan training strategies to improve sports performance. Although HRV analysis has previously also been used to compare pre- and post-match values in various sports[9,21,35] and also in racket sports such as badminton[8,22], this type of analysis has not been performed on table tennis players. In addition, the present work is the first study in which the changes in HRV before and after playing a match has been analyzed based on the sports outcome (win or lose) in table tennis, having found only one study in this line in badminton[25]. Analyzing HRV before and after matches makes it possible to observe changes in the sympathetic-parasympathetic balance, thus showing the athlete's state of fatigue[9]. Moreover, the differentiated analysis depending on the outcome may be relevant because winning or losing the match can generate different levels of fatigue, thus affecting the activation of the ANS[25]. In this sense, this analysis provides more exhaustive knowledge of competitive demand in a differentiated way between those who win and lose the game.

HRV time-domain variables have been used in other racket sports, such as badminton, to analyze post-match fatigue[8,22,24], showing a decrease in the values of SDNN and pNN50, while an increase in HR variables is observed, possibly related to increased fatigue[17]. The results of this study showed a decrease in the mean RR, SDNN, LnRMSSD and pNN50 of the POST values with respect to the PRE values, both in the players who won and in those who lost the match. On the contrary, there was an increase in the mean HR, Min HR and Max HR in the POST with respect to the PRE in both groups. These results coincide with those obtained in previous studies[8,24,36], which showed a decrease in time-domain variables and an increase in HR variables, associated with an increase in competitive fatigue. In addition, this research provides differentiated information as it takes into account the match outcome. In this way, it coincides with the results obtained in a previous study carried out with badminton players[25]. Those authors found decreases in time-domain variables of the POST values with respect to the PRE in badminton matches, both in the players who won and in those who lost, without finding significant differences between the groups[25]. Those results coincide with those obtained in the present study since the HRV time-domain variables showed no differences between the winners and losers in their change in HRV between PRE and POST. The results obtained suggest that the level of fatigue may have been similar in both groups. The absence of differences in changing HRV between the winning and losing players may be due to the fact that the matches that were analyzed were played between players of similar levels, with very tight scores and high competitive demand until the end of the matches. Therefore, it could be interesting in future studies to analyze whether the change in HRV may be associated with the burden of competition and whether the competitive burden is different for winning or losing players.

The frequency-domain variables break down the strength of the RR signal into different frequency components, thus showing the state of the autonomic nervous system[15]. Although the analysis of frequency-domain variables has previously been used in other sports to analyze post-match fatigue[21,24,25,35], it has not been used previously in table tennis. The results obtained in the present study showed a decrease in the LF Power (log) and HF Power (log) as relates to POST vs. PRE values, both in the players who won and in those who lost the match. These results are partially consistent with previous studies in badminton[24,25], rugby[21], basketball and football[35]. In badminton players, decreases were found in HF Power (%) comparing pre- and post-match values, but this difference was not obtained in LF Power (%)[24,25]. On the other hand, in rugby[21], basketball and football[35] players, although they did not differentiate between players who won and lost matches, a decrease was obtained in the post as compared to pre-exercise in both LF and HF, thus showing an exercise-induced activation of the sympathetic nervous system. Likewise, in the present study, no significant changes were observed between the pre- and post-match values in the LF/HF variable in either group. However, previous studies found a significant increase in this variable in badminton players[24,25], football or basketball players[35] and athletes[36], thus showing a greater activation of the sympathetic system after competition as compared to pre-competition values. One of the main novelties of this study is that it analyzes the change in HRV in a differentiated way according to the match outcome (win or lose) in table tennis. The results obtained suggest that the variables LF Power (ms2), HF Power (ms2), HF Power (u.n.) and LF Power (u.n.) displayed different trends depending on the match outcome. In the group that won the match, decreases were observed in the variable LF Power (ms2), while the variable HF Power (ms2) increased and the variables LF Power (u.n.) and HF Power (u.n.) did not vary, when comparing the PRE and POST match values. On the other hand, in the group that lost the match it was observed that the variables HF Power (ms2) and HF Power (u.n.) decreased, while the variables LF Power (ms2) and LF Power (u.n.) increased, when comparing the values before and after the match. These results do not coincide with the results obtained in a similar study conducted with badminton players[25], in which they observed the same pre-post trends in both players who won and those who lost the match. The only exception to this was for the variable LF Power (%), which despite having non-significant pre-post differences, displayed a decrease in the group that won while an increase was observed in the group that lost the match. As previous studies indicate[7,18], it is possible that these contradictory results are due, on the one hand, to the fact that frequency-domain values may be affected by breathing patterns, which were not monitored in this study, and on the other hand, to the fact that the type of exercise performed may affect frequency-domain variables[34], as well as the athlete's attention, stress or mood[7,25]. In this sense, as indicated by other studies[18], it is recommended that HRV be analyzed using time-domain or non-linear measurements, since they provide data that is unaffected by breathing patterns. For future research, it would be advisable to analyze aspects such as stress management or breathing in order to know how they affect frequency-domain values depending on match outcome.

As mentioned above, the non-linear HRV variables show parasympathetic modulation without the involvement of respiration[19]. Non-linear methods have been used previously in other sports as a fatigue analysis tool[8,22,24,25]. The results of this study show a significant decrease between PRE and POST in SD1 and SD2 in both players who won and those who lost the match. These results are consistent with studies carried out previously in other racket sports such as badminton[8,22,24,25], in which there is an increase in sympathetic activity and a reduction in parasympathetic activity at the end of the match with respect to the beginning. However, contrary to the results obtained in the frequency-domain variables, there were no differences in the non-linear variables between the players who won and those who lost, which coincides with the results of a previous study carried out with badminton players[25]. These differences in the trends observed between frequency-domain variable values and non-linear HRV variables may be due to the fact that in non-linear methods the breathing patterns do not affect the results obtained[7,18,25], while respiration can affect frequency-domain variables.

Although previous researchers observed that the duration and time of the exercise session directly affect HRV[7], mainly due to the activation of the sympathetic system and decreased activity of the parasympathetic nervous system, there is controversy in this regard. Contrary to the results presented in previous studies[7], a study conducted with long-distance runners showed that HRV immediately after exercise was not related to exercise duration[37]. However, those authors explained that the higher the intensity of the exercise, the longer it took for the post-exercise HRV values to return to baseline[37]. In the present study, with the exception of Min HR, no significant correlations were found between HRV variables and the duration of the table tennis match in either the group of players who won or lost the match. The absence of a significant association between match duration and HRV parameters obtained in this study seems to confirm the conclusions obtained in previous studies[37,38], which state that, both in continuous and intermittent exercise, HRV may be influenced to a greater extent by the intensity of the exercise than by its duration. Therefore, in future studies it would be interesting to control changes in HRV and also to quantify the intensity of matches to analyze any possible associations between both variables.

The main limitation of this study is the absence of previous research with which to compare the results obtained. It was only possible to compare the pre- and post-match differences in HRV depending on the competitive outcome with badminton. Nor have we found any study that analyzed HRV in table tennis players, making it necessary to compare the results obtained with other similar sports such as badminton and other less similar ones such as football, basketball or rugby. On the other hand, the results were obtained through simulated matches, so it is possible that, in a real competition, psychological stress, among other factors, could affect HRV behavior in different ways. It would be desirable for future studies to analyze whether HRV varies depending on the match outcome in official competitions, monitoring other variables that affect HRV such as match intensity, quality of sleep, or competitive stress.

Conclusions

As observed in this study, there was a decrease in HRV after playing a simulated table tennis match owing to the effort exerted, regardless of the outcome of the match. However, despite the fact that decreases were observed in both the time-domain variables and the non-linear variables in both groups, there was no trend in the frequency-domain variables, possibly due to the effect of respiration in these variables. On the other hand, the results obtained in the present study seem to show that there is no relationship between the duration of the table tennis match and HRV.

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Conflict of interest

The authors do not declare any conflict of interest.

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