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Comparison of Heart Rate Variability Before and After a Table Tennis Match

by
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The aim of this study was to compare heart rate variability indices before and after a table tennis match. Sixteen males (21.86 ± 8.34 yr, 1.73 ± 0.08 m, 64.09 ± 13.39 kg and 21.46 ± 4.38 kg·m⁻²) were evaluated in 21 matches, before and after the match. We observed that in time domain analysis, Mean RR, SDNN, LnRMSSD and pNN50 after match values were significantly lower than before match values ($p < 0.01$ or $p < 0.05$), while Mean HR, Min HR and Max HR values were higher ($p < 0.01$) after than before the match, with no significant differences ($p > 0.05$) in STD HR. Meanwhile, frequency domain analysis showed LF Power (log), HF Power (log) and HF Power (in normalized units) after match values significantly lower than before match values ($p < 0.01$ or $p < 0.05$), while LF/HF value was higher after the match ($p < 0.01$), with no significant differences ($p > 0.05$) in LF Power (ms^2), LF Power (in normalized units) and HF Power (ms^2) values. Non-linear analysis showed SD1 and SD2 POST values significantly lower than PRE values ($p < 0.05$), while no significant differences were observed in SD2/SD1 value between POST and PRE analysis. As conclusion, due to the physiological strain of the table tennis match, changes were observed in heart rate variability values, suggesting an increase of sympathetic influence and a reduction of the parasympathetic influence.

Key words: competition, table tennis, fatigue, autonomous nervous system, stress.

Introduction

Table tennis is a racquet sport that requires repeated powerful efforts followed by short rest intervals (Katsikadelis et al., 2014; Zagatto et al., 2008, 2010). During competition, table tennis players need to perform movements with a high component of muscle power, velocity, force and agility (Zagatto et al., 2010). At the same time, table tennis requires a broad repertoire of movements from players who need to select the correct stroke as fast as possible, adapting to the continuously changing conditions (Faber et al., 2016; Katsikadelis et al., 2014). With regard to the physiological demands, table tennis is considered a sport where both aerobic and anaerobic systems are taxed throughout the matches (Zagatto et al., 2010). On the one hand, the aerobic system is the principal energy contributor during matches,

enabling recovery to the next rally. On the other hand, due to the repeated high-intensity bouts during matches, the anaerobic system is also highly present (Zagatto et al., 2008, 2010), making the planning of the training process complicated because of its complex physiological demands (Katsikadelis et al., 2014). In addition, table tennis is characterized by periods of rest between points and rallies, where the aerobic metabolism enables rapid recovery, because of the relatively long pause times in a match between points (about 8 s in relation to 3-4 s of effort) (Kondrič et al., 2013).

Not only the physiological stress, but also the psychological stress generated by tactical aspects of playing each point and the constant analysis of the game that occurs during the rest periods between points of the match have been shown to affect performance (Abenza et al., 2016).

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Occasionally, in other individual and team sports, the influence of the competitive stress on the autonomic nervous system (ANS) has been analysed by means of the heart rate variability (HRV) (Bricout et al., 2010; Cervantes et al., 2009). HRV has not been analysed in table tennis matches to date, although the heart rate has been examined in other tasks in this sport, such as serve kinematics and multiball training (Katsikadelis et al., 2014; Ngo et al., 2017). HRV refers to the variation between consecutive heartbeats, with indices derived from analysis of the R-R intervals, and allows a non-invasive, pain free, economic and simple assessment of the ANS function, giving information about sympathetic and parasympathetic branches of the ANS (Laborde et al., 2017). It provides insights into the response of the ANS to exercise and psychological stress, offering relevant information on the balance between work and recovery in sports and many psychophysiological aspects, such as self-regulation mechanisms linked to cognitive, affective, social and health phenomena (Hernández-Cruz et al., 2017; Laborde et al., 2017). In general, when sympathetic system activation increases, there is an increase in the heart rate (HR), while simultaneously the parasympathetic system is withdrawn (Katsikadelis et al., 2014; Hernández-Cruz et al., 2017; Laborde et al., 2018). HRV can be represented by the time domain, frequency domain or non-linear indices (Laborde et al., 2017). The most used variables in the time domain analysis of HRV are the square root of the mean of the sum of the squares of differences between adjacent normal R-R intervals (RMSSD) and the standard deviation of instantaneous beat-to-beat N-N interval variability (SDNN) (Bourdillon et al., 2017). In order to reduce the large scattering of the HRV across participants, the natural logarithm of the root mean square of successive R-R interval differences (LnRMSSD) is calculated (Djaoui et al., 2017; Ravé and Fortrat, 2016). The frequency domain analysis of HRV can provide the high frequency (HF) band, showing the contribution of parasympathetic activity in power ranging between 0.15 and 0.40 Hz which is highly correlated with RMSSD (Laborde et al., 2017), the low frequency (LF), determined by both sympathetic and parasympathetic systems, and the LF/HF ratio, which represents the balance between the sympathetic and parasympathetic

systems, reflecting sympathetic dominance when it is high (Djaoui et al., 2017; Laborde et al., 2017). The non-linear analysis of HRV reflects parasympathetic modulation without any involvement of breathing (Buchheit, 2014), since the latter can affect some selected HRV measures (Aubert et al., 2003; Shaffer and Ginsberg, 2017). Non-linear analysis is characterized by the standard deviation of the Poincaré plot perpendicular to the line of identity (SD1) that measures the short-term HRV, the standard deviation of the Poincaré plot along the line of identity (SD2) that measures the long-term HRV and the ratio between SD2 and SD1 (SD2/SD1), which measures the autonomic balance and is correlated with the LF:HF ratio (Laborde et al., 2017; Shaffer and Ginsberg, 2017).

HRV has been investigated in individual and team sports (Garrido et al., 2011; Edmonds et al., 2015; Hernández-Cruz et al., 2017) to assess athletes' "fatigue" state under rest condition, during physical exercise and during the post-exercise recovery phase, as per respective standard procedures (Bourdillon et al., 2017). Besides, some studies have analysed HRV before and after a physical exercise in different exercise modes in order to know the influence of physical activity on the change of HRV and showed a decrease in the SDNN and RMSSD after finishing exercise, compared to pre-exercise values (Bisschoff et al., 2016; Edmonds et al., 2013; Esco et al., 2018; Hernández-Cruz et al., 2017). Nevertheless, no study has reported that information in table tennis participants, so there is a lack of knowledge in scientific literature about the response of HRV after table tennis matches. Thus, the analysis of HRV in table tennis could be useful to quantify "fatigue" generated in training sessions and matches, in order to apply adequate the training loads to the state of the player (Buchheit, 2014; Nakamura et al., 2016), facilitating the complicated training process of this sport.

Therefore, the aim of the present study was to compare HRV indices before and after playing a table tennis simulated competitive match. As a hypothesis, based on previous findings in other sports (Garrido et al., 2011), it was expected that HRV indices would decrease after a simulated table tennis match.

Methods

Participants

Twenty-one table tennis players (21.86 ± 8.34 yr, 1.73 ± 0.08 m, 64.09 ± 13.39 kg and 21.46 ± 4.38 kg·m^{-2}), who were competing during the study period in the 2nd national league or in the Basque honor division, participated in this study. Inclusion criteria were as follows: (i) at least two years of competitive experience at either a regional or national level, and (ii) be training on a weekly basis (at least twice a week). Exclusion criteria were: (i) previous injuries that might interfere with the study, and (ii) taking medications. Written informed consent was obtained from the players and the club prior to the commencement of the study after a detailed written and oral explanation of the potential risks and benefits resulting from their participation. Written informed parental consent and player assent were obtained when players were under 18 years of age. Ethical approval was granted by the Ethics Committee for Research on Humans (CEISH, Nº 2080310018-INB0059) and the study was conducted in accordance with the Declaration of Helsinki (2013).

Measures

Perceived match load: After taking HRV measurements, participants perceived match loads (RPEML) were quantified using the rating of perceived exertion (RPE) method, based on the modified Borg CR-10 scale and duration (minutes) of the match (Williams et al., 2017).

Heart rate variability (HRV) analysis: A portable HR monitor (Polar V800, Kempele, Finland) was used to record HRV data. The data obtained were transferred to the computer via Polar Software (Polar Flow, Kempele, Finland) and exported for HRV analyses using specific software (Kubios v3.0. Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland). The following variables in the time domain were obtained: i) the mean of RR intervals of the records (Mean RR); ii) the standard deviation of N-N intervals (SDNN) which is influenced by the sympathetic and parasympathetic system; iii) the mean HR of the records (Mean HR); iv) the standard deviation of heartbeats (STD HR); v) the minimum HR of the records (Min HR); vi) the maximum HR of the records (Max HR) vii) the natural logarithm transform of the root mean square of successive differences in the R-R intervals (LnRMSSD) and viii) the relative number of successive R-R interval pairs that differed more than 50 ms (pNN50) which is correlated with parasympathetic nervous activity (Shaffer and Ginsberg, 2017).

From the frequency domain variables, the contribution of both the sympathetic and parasympathetic nervous system in the power peak band i) between 0.04-0.15 Hz (Low Frequency (LF)), ii) between 0.15-0.40 Hz (High Frequency (HF)), and iii) the ratio between LF and HF (LF/HF) that reflects the autonomic balance, were recorded. These variables analyze the frequency at which the length of the R-R interval changes (Djaoui et al., 2017) being measured in three different units: i) absolute power (ms^2); ii) log power (log), and iii) absolute power (n.u.).

The Poincaré plot standard deviation 1 (SD1) which measures short-term HRV and correlates with baroreflex sensitivity (Shaffer and Ginsberg, 2017), the Poincaré plot standard deviation 2 (SD2) which measures long-term HRV and correlates with LF power and baroreflex sensitivity (Shaffer and Ginsberg, 2017), and the ratio of SD2 to SD1 (SD2/SD1) which is used to measure the autonomic balance and the unpredictability of the RR time series (Shaffer and Ginsberg, 2017) from the non-linear variables, were measured.

Procedures

In this study, 21 recordings were made, before and after a table tennis match, to the best of 5 sets, played by participants of this study, during the off-season period, simulating a competitive match, with an opponent with a similar ranking during the season. Before each match, a standardized warm-up was performed consisting of 2 min of forehand and backhand rallies, as well as forehand and backhand topspin rallies, just like in an official match. HRV was recorded during the 3 min PRE and POST match in a lying supine position on the floor (Bourdillon et al., 2017). PRE match analysis was recorded before the 2 min warm-up and the POST match analysis was recorded right after the cessation of the match. Participants were instructed not to exercise vigorously 48 h before the test to avoid any fatigue effects on the results.

Statistical analysis

The results are presented as means ±

standard deviation (SD). Data normality was evaluated with a Shapiro-Wilk test, which determined that the assumption of normality was violated for the HRV variables ($p < 0.05$). The Wilcoxon signed-rank test was used to determine the differences between PRE match and POST match values. The difference in percentage ($\Delta.$ %) was calculated using the formula: $\Delta.$ (%) = [(mean POST – mean PRE) / mean PRE] x 100. The effect size (*ES*) was calculated using the method proposed by Cohen (1988). Effects sizes lower than 0.2, between 0.2 and 0.5, between 0.5 and 0.8 and higher than 0.8 were considered trivial, small, moderate and large, respectively. Pearson product-moment correlation coefficients (r) with 90% confidence limits were calculated to determine relationships between LnRMSSD, RMSSD or RPEML and the differences in percentage ($\Delta.$ %) of HRV variables. To interpret the results, the threshold values employed for Pearson product were low (r<0.3), moderate (0.3<r<0.7) to high (r>0.7) (Salaj and Markovic,

2011). Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS Inc, version 23.0 Chicago, IL, U.S.A.). The upper limit for statistical significance was set at $p < 0.05$.

Results

Matches had average duration of 15.33 ± 3.89 min, RPE of 4.97 ± 1.53 and RPEML of 79.45 ± 35.21 AU. Table 1 shows mean values for PRE and POST match HRV time domain variables. Mean RR, SDNN, LnRMSSD and pNN50 POST values were significantly lower than PRE values ($\Delta.$ (%) = -9.86 to -36.79, ES = -0.63 to -2.14, moderate to large, $p < 0.01$ or $p < 0.05$), while Mean HR, Min HR and Max HR values were higher in POST than in PRE ($\Delta.$ (%) = 26.16 to 43,47, ES = 1.66 to 1.74, large, $p < 0.01$). No significant differences were obtained in STD HR ($\Delta.$ (%) = 17.39, ES = 0.24, small, $p > 0.05$) values between PRE and POST analysis.

Table 1

Heart rate variability (HRV) changes in the time domain before (PRE) and after (POST) playing a match.

	PRE	POST	Δ. (%)	ES	p
Mean RR (ms)	781.24 ± 91.47	592.47 ± 88.22	-23.74	-2.14	0.000
SDNN (ms)	39.64 ± 15.14	30.23 ± 14.91	-18.73	-0.63	0.020
Mean HR (beats/min)	78.11 ± 7.76	103.99 ± 15.09	34.01	1.72	0.000
STD HR (beats/min)	5.01 ± 1.39	5.54 ± 2.21	17.39	0.24	0.345
Min HR (beats/min)	67.37 ± 5.95	84.79 ± 10.51	26.16	1.66	0.000
Max HR (beats/min)	93.87 ± 11.3	133.52 ± 22.84	43.47	1.74	0.000
LnRMSSD (ms)	3.42 ± 0.46	3.06 ± 0.57	-9.87	-0.63	0.008
pNN50 (%)	12.92 ± 14.98	5.49 ± 8.03	-36.69	-0.93	0.008

Mean RR = mean of RR intervals. SDNN = standard deviation of NN intervals. Mean HR = mean heart rate. STD HR = standard deviation of heart rate. Min HR = minimum heart rate. = Max HR = maximum heart rate. LnRMSSD = The natural logarithm transform of the root mean square of successive differences between normal heartbeats. pNN50 = Relative number of successive RR interval pairs that differ more than 50 ms. ES = Effect size

Table 2

Heart rate variability (HRV) changes in the frequency domain before (PRE)
and after (POST) playing a match

	PRE	POST	Δ. (%)	ES	*p* value
LF					
Power (ms²)	892.83 ± 811.14	859.99 ± 1472.16	54.17	-0.02	0.929
Power (log)	6.38 ± 0.81	5.73 ± 1.11	-9.29	-0.59	0.027
Power (n.u.)	63.62 ± 10.89	72.97 ± 14.76	17.52	0.63	0.180
HF					
Power (ms²)	581.83 ± 778.65	416.89 ± 577.78	4.14	-0.29	0.177
Power (log)	5.76 ± 0.92	4.57 ± 1.48	-20.33	-0.80	0.001
Power (n.u.)	36.28 ± 10.83	26.89 ± 14.66	-22.38	-0.64	0.017
LF/HF					
Power (ms²)	2.42 ± 1.38	4.58 ± 3.15	153.34	0.69	0.009

LF = low frequency. HF = high frequency. LF/HF = ratio between LF and HF. Power (m·s2) =
absolute power. Power (log) = Log power. Power (n.u.) = Normalised power. ES = Effect size

Table 3

Heart rate variability (HRV) changes in non-linear before (PRE) and after (POST) playing a match

	PRE	POST	Δ. (%)	ES	*p* value
SD1 (ms)	24.48 ± 15.14	17.67 ± 10.66	-27.82	-0.64	0.022
SD2 (ms)	49.79 ± 16.77	38.42 ± 18.67	-22.84	-0.61	0.026
SD2/SD1	2.36 ± 0.61	2.51 ± 0.67	6.36	0.22	0.302

SD1 = Standard deviation of short-term variability. SD2 = Standard deviation long term
variability. SD2/SD1 = SD2 and SD1 ratio. ES = Effect size.

Table 2 shows mean values for PRE and POST match frequency domain variables of HRV. LF Power (log), HF Power (log) and HF Power (n.u.) POST values were significantly lower than PRE values (Δ. (%) = -9.29 to -22.38, ES = -0.59 to -0.80, moderate to large, $p < 0.01$ or $p < 0.05$). In contrast, LF/HF (ms2) value was higher in POST than in PRE (Δ. (%) = 153.34, ES = 0.69, moderate, $p < 0.01$). No significant differences were observed in LF Power (ms²), LF Power (n.u.) and HF Power (m²) values between POST and PRE analysis (Δ. (%) = 4.14 to 54.17, ES = -0.02 to 0.63, trivial to moderate, $p > 0.05$).

Table 3 shows mean values for PRE and

POST match HRV non-linear variables. SD1 and SD2 POST values were significantly lower than PRE values (Δ. (%) = -22.84 to -27.82, ES = -0.61 to -0.64, moderate, *p* < 0.05). In contrast, in SD2/SD1 value significant differences were not found between POST and PRE analysis (Δ. (%) = 6.36, ES = 0.22, small, *p* > 0.05).

LnRMSSD PRE correlated significantly only with Δ. (%) Mean HR (r = 0.46 ± 0.3 CL, *p* < 0.05, moderate) and Δ. (%) SD2/SD1 (r = 0.46 ± 0.3 CL, *p* < 0.05, moderate). Regarding the associations between the RPEML and Δ. (%) of HRV values, only significant correlations were found between RPEML and Δ. (%) Min HR (r = 0.52 ± 0.28 CL, *p* < 0.05, moderate).

Discussion

The purpose of this study was to compare the HRV behavior before and after a table tennis match. HRV has been previously analyzed in competition comparing PRE- and POST-match values in some sports (Edmonds et al., 2013; Esco et al., 2018; Hernández-Cruz et al., 2017) in order to determine changes in sympathetic and parasympathetic modulation, providing information on athletes' physical performance (Hernández-Cruz et al., 2017). However, in racket sports, although this PRE- and POST-match HRV analysis could be interesting, as we know, there are only studies in badminton (Bisschoff et al., 2016; Garrido et al., 2011). Nevertheless, until now, no study has determined the influence of a table tennis match on HRV values in table tennis players. We found that HRV values decreased after a match, in comparison with rest conditions, using time domain, frequency domain and non-linear indices. Therefore, playing a table tennis match produces acute changes in HRV, reducing parasympathetic activity, while increasing sympathetic activity.

The HRV time domain indices have been used in other racket modalities such as badminton (Bisschoff et al., 2016; Garrido et al., 2011) to determine players' "fatigue" after a match. Athletes in an overtraining state may show a significant decrease in LnRMSSD and SDNN (Dong, 2016), while the increment of the HR is associated to "fatigue" (Djaoui et al., 2017). The results of this study showed a decrease in Mean RR, SDNN, LnRMSSD and pNN50 comparing POST with PRE match values in table tennis

players, while Mean HR, Min HR and Max HR values were higher in POST compared with PRE match values. These results are in accordance with other sport modalities (Esco et al., 2018; Hernández-Cruz et al., 2017; Luft et al., 2009) and with another racket sport such as badminton (Bisschoff et al., 2016; Garrido et al., 2011). Bisschoff et al. (2016) found a decrease in Mean RR, SDNN, LnRMSSD and pNN50 after playing a badminton match. In the same way, Garrido et al. (2011) found a decrease in Mean RR, SDNN, LnRMSSD and pNN50 and an increase in Mean HR after playing a badminton match, compared to rest values. This decrease in HRV time domain indices shows a parasympathetic withdrawal, leading to sympathetic predominance in the ANS (Garrido et al., 2011) induced by accumulated fatigue generated by the table tennis match.

On the other hand, HRV frequency domain analysis decomposes any signal into its sinusoidal components, showing ANS status (Aubert et al., 2003). During exercise, the sympathetic and parasympathetic branch of the ANS play a pivotal role (Aubert et al., 2003) and the analysis of the ANS through HRV measures can indicate recovery status (Bisschoff et al., 2016), possible overtraining status (Mourot et al., 2004) or "fatigue" (Schmitt et al., 2015), being useful for some sports, including table tennis. The results of this study show a decrease in LF and HF while the LF/HF ratio increases, comparing POST with PRE match values. Previous studies found similar results to this study (Bisschoff et al., 2016; Edmonds et al., 2013; Esco et al., 2018; Luft et al., 2009). Specifically, Esco et al. (2018) found a decrease in LF and HF values (49.16% and 71.43%, respectively), and an increase in the LF/HF ratio, with basketball and soccer players after performing a maximal gradual exercise test. Also, Bisschof et al. (2016) found a decrease in HF value (11.11%) and an increase in the LF/HF ratio (23.91%), after badminton official matches, while Luft et al. (2009) found an increase in LF/HF value (385.71%) with track and field athletes after performing an incremental exercise test. Meanwhile, Edmonds et al. (2013) found a decrease in LF and HF values (1.79% and 59.52%, respectively) in rugby players after a competitive game, showing a withdrawal of the parasympathetic system and a sympathetic predominance. Both LF and HF are depressed, but

the increment of the LF/HF ratio during post-exercise time points suggests that greater magnitude of decline occurred in HF compared to LF values (Esco et al., 2018). Considering the obtained results, playing a table tennis match causes an activation of the sympathetic system, while the parasympathetic system is deactivated, showing at the same time an increase in the HR mean POST-match.

Another aspect analyzed in the scientific literature regarding HRV includes non-linear indices. Through the Poincaré plot, R-R intervals are plotted as a function of the previous one, giving a visual representation of the HRV behavior, where the transverse diameter is represented by SD1 variable and the longitudinal diameter is represented by SD2 variable (Garrido et al., 2011). The results of this study show a decrease in SD1 and SD2 when comparing POST with PRE match values, meaning a reduction in parasympathetic influence and an increase in sympathetic control, respectively (Garrido et al., 2011). This result agrees with other racket sports such as badminton (Garrido et al., 2011; Bisschoff et al., 2016). Garrido et al. (2011) and Bisschoff et al. (2016) found a decrease in SD1 and SD2 variables comparing POST- with PRE-match values, reporting a reduction in both diameters in the Poincaré plot, in badminton players aged between 18 and 23 years. These results show a HRV decrease after a table tennis match, meaning an activation of the sympathetic system, while simultaneously the parasympathetic system is withdrawn.

The aim of the present study was to analyze HRV behavior, comparing the HRV indices before and after playing a table tennis simulated match, through time domain, frequency domain and non-linear variables. By analyzing the obtained results, as conclusion, table tennis matches can acutely cause an increase in the sympathetic influence and a reduction in the parasympathetic influence, due to the cardiac autonomic function perturbation generated by the match. This analysis could be useful in order to quantify the "fatigue" generated, in order to optimize the recovery times, avoid overtraining or detect non expected responses to training (Djaoui et al., 2017; Dong, 2016; Nakamura et al., 2016).

The main limitation of the study was that there were no studies in table tennis that analyzed HRV, making it difficult to compare the obtained results with similar sports, such as badminton. The design of the study only analyzed the differences in HRV before and after the match, but it did not analyze the mechanisms of HRV variations, apart from the impact of physical exercise. Also, the results were obtained through simulated matches, with a low sample size, thus it is possible that official matches will produce different results due to competitive stress that could affect HRV (Ngo et al., 2017), being both potentially influenced by the competitive level (Proietti et al., 2017). Therefore, future studies should analyze HRV in competitive matches and analyze the reasons of HRV variations, such as the match result, level of anxiety or physical and psychological load. The analysis of the aforementioned variables could be useful in order to obtain appropriate measures to analyze HRV variation and to adapt workouts. In addition, it could be interesting to analyze HRV day-to-day fluctuations until total recovery compared to PRE values, since this information could provide a helpful tool for monitoring player workloads to maximize training and match performance.

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