Title: Anxiety, Heart Rate Variability and Performance in a Tennis Match

Running Head: Anxiety, HRV and Performance in Tennis

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Abstract

Pre-competitive anxiety may have an impact on performance in a tennis match during real life competition. Heart rate variability (HRV) is a relevant biomarker reflecting cardiac modulation by sympathetic and vagal components of the autonomic nervous system (ANS). This study will analyse, with non-invasive tools, the influence of competition and pre-competitive anxiety on psychophysiological activation, as well as its impact on performance outcomes. A sample of 30 players between 14-18 years will be monitored during two firsts round matches and a training day (simulating a match play). RMSSD and High frequency (HF)-HRV (often referred to as respiratory sinus arrhythmia), Revised Competitive State Anxiety Inventory-2 (CSAI-2R) and score-match (outcome of good or bad performance) will be assessed before the tennis match and during the match breaks. According to the literature review, we expect that "losers" will show lower resting HRV and will score higher in anxiety compared to "winners". Based on our findings, an individualized training program will be implemented in order to improve performance in tennis competition.

Keywords: Anxiety, HRV, Performance, Sport competition, Tennis

1. **Introduction**

Anxiety is an emotional state characterized by experiential (e.g., fear), behavioral (e.g., avoidance), and physiological (e.g., tachycardia) components that can be experienced in varying degrees of intensity, frequency, and duration. Anxiety is adaptive and necessary for everyday life (Mallorquí-Bagué et al., 2015). Stress and anxiety tend to be used as synonyms in sports competition but scientific approaches consider that stress refers to the condition or feeling experienced when a person perceives that demands exceed the personal and social resources the individual is able to mobilize, whereas anxiety would appear before a situation that is perceived as threatening or dangerous (King et al., 1976; Lazarus and Folkman 1984). According to the Spanish Society for the Study of Anxiety and Stress (SEAS), both stress and anxiety share symptoms and can occur at the same time, and stress can lead to anxiety. One of the differences is that anxiety can be cognitively generated by the person without having to be exposed to a stressful situation, being an anticipatory response to a situation that is assessed as threatening.

In tennis competition, the player's own thoughts can cause anxiety before starting a match. Fernandez-Abascal et al. (2003, pp. 281) concludes that "anxiety is a system of processing threatening information that allows mobilization in advance as preventive actions". But anxiety does not have its own and exclusive cognitive trigger processing, nor is its uniquely facial expression or physiological activation. The sport context is an environment where this emotion is frequently experienced, receiving a lot of interest both from research and applied professional interventions (Checa 2012). A theoretical approach about anxiety that had importance at the conceptual and applied level has been the Spielberger's *Theory of State and Trait Anxiety* (1985). According to this theory, *trait anxiety* would be linked to personality characteristics or predisposition to react anxiously to aversive stimuli, whereas *state- anxiety* would be associated with a particular moment –being characterized by physiological activation, especially the autonomic nervous system (ANS), and feelings of apprehension, fear and tension. These two types of anxiety can occur at the same time in a person but are also independent of each other and may not be correlated.

Some theories such as the *Processing Efficiency Theory* (Eysenck & Calvo, 1992) point out that individual differences in trait anxiety with fluctuations in state anxiety and attention mechanisms interact to influence performance. Based on the *Multidimensional Theory of Sport Anxiety* proposed by Endler (1997), cognitive anxiety is the mental component of anxiety caused by negative expectations about success or by negative self-evaluation, whereas somatic anxiety is the physiological and affective elements of the anxiety experience that develop directly from autonomic arousal, and self-confidence is the individual difference factor (Craft et al., 2003). According to the *Attentional Control Theory of Anxiety* by Eysenck and colleagues (2007), anxious apprehension as well as worrying about performance outcome can disrupt the efficient exercise of attentional control, leading to increased distractibility by task irrelevant stimuli and reducing processing efficiency (Ducrocq et al., 2016).

A large body of work establishes *Hanin's IZOF model* as a starting point for relating performance and anxiety in sport (Cervantes et al., 2009). Hanin (2003) proposes the IZOF model as an intra-individual framework that allows to describe, predict, explain, and control the athlete's subjective experiences (optimal or dysfunctional), related to the successful or low individual performance. Thus, it allows the conceptualization of the functional impact of the emotion on the performance. The "in and out of zone" principle of the IZOF model refers to the fact that each athlete has his or her own level of anxiety, activation and individual zone of intensity. Furthermore, the hypothesis that the best performances are associated with the intensities of cognitive and somatic anxiety that fall within the individual zone of optimal functioning has been empirically confirmed (Kamata, Tenenbaum and Hanin, 2002).

Individual sport athletes depend completely on their own skills and training, which can increase their sense of accountability and intense feelings of shame or guilt after losing (Pluhar et al., 2019). In this vein, the *Revised Competitive State Anxiety Inventory-2* (CSAI-2R) (Cox et al., 2003) has been used in numerous works for measuring competitive state anxiety in athletes.

In addition, psychological stress might play an important role during tennis competition. Some studies on stress responses to competition have suggested the important psychophysiological demands of actual play as reflected on psychological and physiological responses (Fernandez-Fernandez et al., 2014). In tennis, prior research providing measurements such as heart rate (HR) along with anxiety and/or performance is scarce. Some authors have measured pre-competitive anxiety alongside cortisol and HR (Fernandez-Fernandez et al., 2014). However, none have yet measured heart rate variability (HRV) in relation to performance, bearing in mind that pre-competition stress or anxiety could affect it. According to Nakamura et al. (2015), there are a close relationship between HRV and sports performance, and the athletes with improved performance show increased parasympathetic modulation and increased HRV. Other researchers like Mateo et al., (2012) suggest that pre-competitive stress can lead to an increased disturbance in the ANS, resulting in impaired HRV. In sports competition, high levels of stress tend to increase pre-competitive anxiety and likely influence performance during competition (Fortes et al., 2016). As mentioned above, Fernandez-Fernandez et al., (2014) compared anxiety and HR among match winners and losers in tennis. So far HRV impact on the performance of tennis players has not been explored but in other sports –such as the elite Canarian wrestlers– HRV has been shown as an effective tool to detect functional cardiac patterns related to performance (de Saa et al., 2009).

HRV is a relevant biomarker reflecting cardiac modulation by sympathetic and vagal components of the ANS (Dong et al., 2016), defined as the variation over time between consecutive heartbeats periods. HRV is thought to reflect the heart's ability to adapt to changing circumstances by detecting and quickly responding to unpredictable stimuli. HRV analysis has been used to assess overall cardiac health and the ANS state responsible for regulating cardiac activity (Rajendra et al., 2006). Sympathetic stimulation, occurring in response to stress, exercise and heart disease, causes an increase in HR by increasing the firing rate of pacemaker cells in the heart's sino-atrial node[1]. Parasympathetic activity, primarily resulting from the function of internal organs, trauma, allergic reactions and the inhalation of irritants, decreases the firing rate of pacemaker cells and the HR, providing a regulatory balance in physiological autonomic function. The separate rhythmic contributions from sympathetic and parasympathetic autonomic activity modulate the heart rate (RR) intervals of the QRS complex in the electrocardiogram (ECG), at distinct frequencies[2]. Sympathetic activity is associated with the low frequency range (0.04–0.15 Hz) while parasympathetic activity is associated with the higher frequency range (0.15–0.4 Hz) of modulation frequencies of the HR. This difference in frequency ranges allows HRV analysis to separate sympathetic and parasympathetic contributions. This should enable preventive intervention at an early stage when it is most beneficial (Rajendra et al., 2006). HRV has been used to evaluate and compare hemodynamic parameters and cardiovascular autonomic modulation in tennis players in order to explore whether playing tennis induced cardiac benefits (Nista-Piccolo et al., 2019).

A usual HRV measure in athletes is Polar portables instruments because they allow measurements of R-R intervals while practicing sport. By exposing a patient to physical stress, short laboratory measurements (2-5 minutes) can be made that allow HRV comparison before and after exposure to ANS stimulation. In general, sympathetic stimulation increases HR and decreases HRV although this modulation is not linear. The predominance of the parasympathetic in the resting state favours coronary irrigation since it allows the diastole to be longer and the left ventricle to be subjected to shorter periods of hypoxia (Korcick et al., 2011; Haga et al., 2012). HR and HRV are inversely proportional, being influenced by different factors such as age, gender, temperature, time of day, activity status (active or at rest), workload, alcohol or tobacco consumption, among many others (Font et al., 2008; Veloza et al., 2019; Rajendra et al., 2006).

Based on the literature revision, our study aimed at exploring whether players with higher resting HRV before the competition will score lower in pre-competitive anxiety (measured with the CSAI-2R self-report questionnaire) and will show a better performance during the tennis match. According to prior studies, we expect that all players will present higher pre-competitive anxiety scores on match days compared to training days. In addition, we predict that players scoring lower in state anxiety will show higher HRV during the match and will get better performance results, as indexed by the scoreboards during the match (i.e., scores at the moment of the R-R measurement). Unfortunately, this study could not be carried out due to the health crisis and the confinement special measures derived from the COVID-19 pandemic. Our intention is to implement the experimental protocol described in this manuscript when the tennis competitions are re-established, always applying safe protocols to the participants and following the preventive sanitary measures that could be established at that time.

2. Method

2.1. Participants

The planned experimental sample is 30 adolescent tennis players (15 females, 15 males), all participants corresponding to the high national rank, and age range between 14 and 18 years. A brief questionnaire to recruit sociodemographic data and relevant information about anthropometric data and sport experience in tennis competitions will be administered at the beginning of their enrolment in this study (see Table 1). The estimated average training experience of players will be 10 years (± 2y), the estimated average training per day will be approximately 4 hours (± 2h), and the average training per week will be 20 hours ± 4h. The estimated average competition experience is 8 years (± 2y). Table 1 show as descriptive data (mean ± SD) of anthropometric characteristics and experience in tennis of participants will be presented.

Participants who regularly drink caffeine before playing a tennis match will not be included unless they avoid intake coffee at least 24 hours prior to data acquisition. They must not be regular users of alcohol or any other drugs, at least in the last week before data acquisition. All participants will sign the informed consent form and the personal data will be traded anonymously. This study will be performed in accordance with the Helsinki declaration and with the permission of the research ethics committee at Universitat Jaume I.

2.2. Materials and design

2.2.1. Self-reported measures

Competitive State Anxiety Inventory-Revised [CSAI-2R] (Cox et al., 2003); Spanish version validated by Andrade et al., 2007): This questionnaire will be used to evaluate the pre-competitive state anxiety of tennis players. The CSAI-2R consists of 16-items that measure three hypothesised dimensions of anxiety: *somatic anxiety* (SA, 6 items), *cognitive anxiety* (CA, 5 items), and *self-confidence* (SC, 5 items), using a four-point Likert scale where the options range from 1 (‘‘not at all’’) to 4 (‘‘very much so’’). Therefore, scores in each of the three subscales may range as follows: SA (from 6 to 32), CA (from 5 to 20), SC (from 5 to 20), with higher scores meaning higher levels of state anxiety. The Spanish adaptation showed a good fit of the data to the model (CFI = .95, NNFI = .94, RMSEA = .054), suggesting that the CSAI-2R could be used for measuring competitive state anxiety in athletes. Cronbach alpha coefficients for the factors ranged from .79 to .83. Andrade et al. (2007) concluded that the Spanish adaptation shows adequate properties, in terms of its dimensionality and internal consistency.

2.2.2. Experimental design

Participants will arrive at their usual training sport centre in the morning without having breakfast. Day 1 will be the *Baseline* (or *Control Day)* and will take place one week before competition. After five minutes resting period, ECG will be continuously recorded 10 minutes using two instruments, a portable system (MP36R) and a cardiac monitor (Polar RS800). The same protocol will be applied in the training and competition days (T, C1 and C2) but only using the cardiac monitor RS800 in order to record resting HRV (rT, rC1, rC2).

The *Training Day* (T) will be an ordinary training day, in which a simulated competition match will be performed to create a stressful situation (c.f., Mateo et al., 2012). In addition, two *Competition Days* will be included in our experimental design (C1, C2). For each of the three testing days (T, C1, C2), 15 minutes before the simulated (aT) and real competition (aC1, aC2), the cardiac monitor RS800 and the belt (pulsometer) will be attached and synchronized individually in time for accurately recording HR according to each person clock, taking into account the differences in the match breaks between games. Then HR will be registered for 10 minutes and immediately after participants will fill out the CSAI-2R questionnaire. During the match break, data will be registered individually in their resting chairs. In all cases, subjects will be seated and informed to remain silent and without disruptive movements.

The precompetitive routine of the athletes is particularly important, so HR will be registered seated for trying not to interfere (Mateo et al., 2012). Each subject response will be individualized in relation to their resting values. During the match breaks, resting's HRV will be registered 1 minute meanwhile the player will be sitting (every two games, the players rest for 90 seconds), as well as the match scores (i.e., outcomes of good performance) at this moment will be also recorded. Figure 1 presents a schematic overview of the experimental protocol.

2.3. Psychophysiological data acquisition and reduction

Physiological data acquisition at the control day (*Baseline*) will be accomplished using Biopac MP36R. The software used for data acquisition and pre-processing will be Acqknowledge 4.4 and Kubios HRV Premium. Electrocardiogram (ECG) will be recorded at Lead II (positive electrode on the left ankle, a neutral electrode on the right ankle and a negative electrode on the right wrist) using Ag/AgCl electrodes with electrolyte paste (8 mm in diameter). A band-pass filter of 0.5–35 Hz and a sampling rate of 1000 Hz will be used. HRV signal will be obtained from the ECG based on the QRS-signal waveform (IBI). This technique shows graphically each of the R-waves that are generated with each beat, allowing the analysis of time in milliseconds between the R-R intervals and the small variations that can be detected between consecutive intervals (Veloza et al., 2019). The IBI's will be calculated and checked for artifacts. Occasional ectopic beats (irregularity of the heart rhythm involving extra or skipped heart beats) will be visually identified and manually replaced with interpolated adjacent IBI values (Elliot et al., 2011, Tarvainen et al., 2014). Artifact beats will be identified as RR values deviating more than 0.25 s from baseline (Mateo et al., 2012).

We will use 8 units of Polar RS800 HR monitor set to R-R mode (Polar Electro, Kempele, Finland) together with an electrode transmitter belt (T61), after application of conductive gel. HRV will be measured with this cardiac monitor either the control day (*baseline*), the resting in the morning before competition (rT, rC1 and rC2), 15 minutes before the match (aT, aC1 and aC2) and during the match breaks. Although this instrument has been previously validated for the accurate measurement of R-R intervals and for analysing HRV (Mateo et al., 2012), we will additionally record ECG at the control day in order to check that the measurements with the pulsometers work properly. RS800 data will be transferred to Polar Pro Trainer 5 software and will be further analysed using Kubios HRV Premium.

The whole pre-processing of HR/HRV signal will be carried out by the same researcher to ensure consistency (Mateo et al., 2012; Martinez-Navarro et al., 2018). The parameters obtained in the *time domain* will be the mean RR interval (RRi), the standard deviation of normal RRi (SDNN), the successive percentage of R-R interval differences greater than 50 ms (pNN50) and the root-square difference of successive normal RRi (RMSSD), which will be converted by logarithmic transformation (InRMSSD) to avoid outliers and simplify the analyses (Nakamura et al., 2015; Panissa et al., 2016). The SDNN and InRMSSD values will be presented in milliseconds (ms) and frequencies to establish the spectral power (ms2/Hz) (Tarvainen et al., 2014; Ravé and Fortrat, 2016; Fortes et al., 2017). In the *frequency domain*, R-R intervals will be detrended and resampled at 4 Hz, and the Fast Fourier Transform will be calculated using Welch's periodogram method. The spectral analyses of resting HRV is limited to 0.5 Hz and can be broken down into bands that are universally accepted by the scientific community: VLF (very low frequency) 0.0033-0.04 Hz (cycle length > 25 sec); LF (low frequency) 0.04-0.15 Hz (cycle length > 6 sec); HF (high frequency) 0.15- 0.40 Hz (cycle length 2.5 to 6.0 sec). The HF component is proportional to the parasympathetic activity and at depth of breath that is manifested by inspiratory tachycardia secondary to vagal inhibition and contrary expiratory behaviour. This relationship between the respiratory and cardiac systems shows sinus respiratory arrhythmia (SRA). The LF component was initially related to sympathetic stimulation, although some researchers questioned this hypothesis (Reyes del Paso et al., 2013). Although all the previously described HRV parameters will be obtained during the pre-processing of the ECG and R-R signal, only the RMSSD and HF will be statistically analysed in this study as these are the most explored and recommended parameters according to literature (Reyes del Paso et al., 2013).

2.4. Procedure

The control day (baseline), sensors for ECG recording will be attached to participants in the morning (before breakfast), while reclining in a comfortable armchair located in a darkened, sound-attenuating room at their tennis clubs. Then, resting HRV will be continuously recorded during10 minutes. Participants will be informed to sit quietly with their hands on their thighs without speaking or moving. The same procedure will be applied for resting HRV acquisition during the training and competition days (rT, rC1 and rC2). Participants will remain in the tennis club and the diet before the competition will remain the same for all of them. Approximately 15 minutes before the competition, HRV will be recorded during 10 minutes at the training and control days (aT, aC1 and aC2) in conditions as similar as possible to resting HRV. Afterwards, the CSAI-2R questionnaire will be administered in paper and pencil format, trying to maintain the immediacy for assessing pre-competitive anxiety, as recommended by Cox et al. (2003) and Andrade et al., (2007). Once in the game, at each break between games, the time and the scores will be registered without interacting with the players. After finishing the 4 sessions, participants will be debriefed and thanked for their collaboration. Each session will last approximately 2 hours, depending on the duration of the matches.

2.5. Statistical analyses

In order to compare resting HRV during training and competition days, separate one-way repeated measures ANOVAs will be performed on RMSSD and HF values as dependent variables, and *Time* as a within-subjects factor. In addition, separate one-way repeated measures ANOVAs will be calculated to compare pre-competitive anxiety CSAI-2R (on one side) and match scores (on the other side) during T (*training*) and C1, C2 (*competition*) days.

In addition, Pearson's correlations would be performed in order to explore plausible associations between scores in CSAI-2R (pre-competitive mean anxiety) resting HRV (both RMSSD and HF) and match scores (as a measure of good performance), considering the magnitude of the relationship as follows: large ($p > 0.5$), moderate (0.3-0.5), small (0.1-0.3). For all analyses, the significance level will be set at $p < 0.05$.

Further analyses will be performed in which participants will be classified into two groups according to the 50th percentile of the CSAI-2R scores: Low pre-competitive anxiety (< 28.00) and High pre-competitive anxiety (> 28.00) (see Fortes et al., 2017). Similarly, the sample will be additionally divided into "losers" and "winners" players based on their scores at the match breaks. In both cases, group differences in resting HRV measurements will be explored by calculating Student's t-test for independent samples (separately for each R-R measurement) and Two-way repeated measures ANOVAs, with the within-subjects factor *Time* (T, C1, C2) and the Group (High vs. Low, Losers vs. Winners) as a factor.

Statistical analyses will be performed using IBM SPSS 22.0 software for Windows. Normality distribution of the variables will be evaluated calculating Kolgomorov-Smirnov normality test. When due to the small number of participants the criteria for normality were not met, non-parametric statistics would be used. Friedman's ANOVA and Wilcoxon's test would then be applied to explore see differences between the two comparisons (i.e., related measures). To analyse the differences at a given time, we would calculate Kruskal Wallis with a Bonferroni test. The correlation would be calculated with Spearman's Rho. Both statistical analyses approaches have been observed in prior studies when reviewing the literature on the subject.

3. Results and Discussion

This study aimed at exploring relationships between resting HRV parameters before the competition (RMSSD and HF), pre-competitive anxiety (CSAI-2R scores), and performance (scores at the moment of the R-R measurement) during the tennis match. Although this study was not able to be implemented due to global COVID-19 pandemic, the expected results have been described and discussed according to the findings of prior works .In this vein, we have not found previous studies in tennis competition (neither in PubMed nor in Web of Science) including simultaneous measurements of HRV, pre-competitive anxiety or performance outcomes. Only past works conducted with similar individual sports like badminton, or even different individual or team sports, were available to provide support information concerning these two performance-related variables.

HRV is a non-invasive method used in laboratory settings to obtain valuable data concerning physiological changes that occur in the response to physical activity. Accordingly, HRV parameters might be relevant to explore stress and anxiety experienced by the body during training in sport competition. Regarding athletes, changes in their ANS patterns reflected by variations in resting HRV may serve as useful parameters for managing their physical fatigue and establishing their exercise intensity (Dong et al., 2016). Differences in resting HRV between training day (simulated competition) and real competition results might be due to pre-competitive anxiety. Indeed, during the tennis match, a positive correlation is expected between stable HR rhythms and players' scores in state anxiety.

3.1. Empirical findings in sport competition

In tennis competition, Fernandez-Fernandez et al., (2014) found significant differences between the tennis training day and the tennis match day in both pre-somatic and cognitive state measures for all subjects, significantly higher during competitions, using the CSAI-2R questionnaire. For the self-confidence parameter, pre-competition values on the match day were significantly lower than on training day. Regarding differences between winners and losers, there were significant differences for pre- and post-competition values for somatic and cognitive state anxiety, with higher scores for losers the pre-match day for somatic state anxiety, and between pre- and post-match day and post-training day for cognitive state anxiety. Winners also scored significantly higher for self-confidence at the pre- and post-match day and the post-training day. In addition, losers exhibited higher salivary cortisol levels compared to winners at all points in time on the match day but only in the post competition on the training day. Both winners and losers showed significantly lower salivary cortisol levels on the training day compared to the match day, except for winners at 8:00p.m. Also, significant correlations were found between psychological and physiological responses at different points in time on match and training days. HR and rate of perceived exertion were only related to CSAI-2R scores on the match day. According to the authors, this was the first study comparing the psychophysiological stress responses during a real competitive match and a training session (i.e., simulated tennis match play) in young elite female tennis players.

In addition, also with tennis players in real competition, Filaire et al. (2009) reported that somatic anxiety was significantly higher (+23%: $p < .05$) in females compared to males, whereas self-confidence was significantly higher in males (+34%: $p < .05$). Males reported greater interpretations of cognitive and somatic anxiety symptoms when compared with those in females. Somatic and cognitive anxiety scores were significantly higher in the losers ($p < .05$, +42%, and +26%, respectively), but self-confidence was significantly higher in winners than in losers ($p < .05$, +59%).

Similarly, Mateo et al., (2012) showed in BMX athletes, that anxiety scores were higher on both days of competition compared to the training day either for cognitive or somatic anxiety subscales of CSAI-2R questionnaire ($p < 0.005$ between C1 and T; $p < 0.05$ between C2 and T); being d lower for shelf confidence ($p < 0.05$).

In elite Canarian competitive wrestlers, the high-level group showed lower HRV (total power 498.00 ± 384.07 ms2 vs. 1,626.00 ± 584.57 ms2) compared to the lower level group. In both cases, the weight of the frequency spectrum was found in the high frequency (HF) band (higher: 53.30% ± 19.00; lower: 60.33% ± 14,53). The higher body weight of wrestlers, the higher respiratory demand (even at rest) and the usual deficiency of the oxygen supply system (low VO2max) that these athletes normally present may be the cause of the high weight of the frequency spectrum in the HF band (de Saa et al., 2009).

In similar study conducted with competitive swimmers (Fortes et al., 2017), a significant relationship was found between HRV and cognitive anxiety ($p = 0.001$), as well as between HRV and somatic anxiety ($p = 0.001$), but no relationship between self-confidence and HRV ($p = 0.27$). Statistically significant differences were found for all HRV indicators (SDNN, pNN50, InRMSSD, LFnu, HFnu and LF/HF), with greater values for the low anxiety group (sll $ps < 0.01$), indicating a negative relationship between competitive anxiety and HRV. Although Mateo et al., (2012) did not report a relationship between competitive anxiety and HRV, the findings by Fortes et al. (2017) would support our hypothesis in this regard.

Similar results with master swimmers were also found (Cervantes et al., 2009), with a higher level of pre-competitive anxiety, and HFms2 and HFnu. parameters being significantly related with parasympathetic activity decrease, and LF/HF% parameters being significantly related with sympathetic activity increase. Some other works such as those carried out by Nakamura et al., (2015) showed that athletes with higher HRV were superior in competition performance, which may partly explain their lower anxiety scores.

Finally, a study conducted with judo athletes (Morales et al., 2013) reported that international-standard judo athletes showed higher confidence, mean RR interval, standard deviation of RR, square root of the mean squared difference of successive RR intervals, number of consecutive RR that differ by more than 5 ms, short-term variability, long-term variability, long range scaling exponents and short-range scaling exponent, as compared to national-standard judo athletes. According to the authors, the former athletes showed less pre-competitive anxiety than the latter athletes, suggesting that HRV is sensitive to changes in pre-competitive anxiety.

Therefore, we hope to contribute to the prior literature with our planned empirical study by adding information regarding associations between HRV, anxiety and performance at the tennis court that might help to shed light in this area of knowledge.

3.2. Methodological limitations and future outcomes

Since this is the first study exploring the results of the HRV besides pre-competitive anxiety and performance during a tennis match in real competition, we decided to simplify the statistical analysis in this pilot work. The main limitations of the study are due to the difficulty of control the conditions of measurements during the ongoing tennis match, as there can be delays in the competition schedule and variations in the climatic conditions across players.

In addition, we have not initially considered to explore statistical differences between boys and girls, neither in anxiety nor HRV, although we tried to compensate the sample in terms of male/female in order to facilitate further analysis including a gender perspective. To this extent, gender and age differences might affect both HR and HRV during adolescence. In a recent review, Koenig et al. (2020) suggest that in absence of sufficient empirical evidence from longitudinal studies on HRV development in early life stages, mean HR continuously decreases after a peak at 1 month of age and until the age of 18. Because HR and vagally-mediated HRV are typically negatively correlated (given that HR is a product of both sympathetic and parasympathetic activity), and based on the cross-sectional studies reviewed above, we can assume that vagal activity steadily increases during adolescence. In addition, there are considerable sex differences in these trajectories. Koenig and colleagues (2020) showed that women have greater HRV and HR, and that HRV is decreased and HR increased in girls compared to boys, finding previous evidence that these sex-related differences in ANS function emerge during adolescence (de Zambotti et al., 2017).

Similarly, regarding resting HRV parameters that could be obtained based on the planned measurements, we decided to initially focus only on RMSSD and HF for this exploratory pilot study in order to simplify the preliminary findings. However, future empirical works should take into account additional parameters, both in the time and frequency domains, to further investigate the relationship between vagal HRV and both anxiety and performance in an ongoing tennis match in real competition.

Finally, we would like to highlight the applied outcomes of the current research. To this extent, players with higher scores in state anxiety are currently advised to train breathing control strategies in the moments before the match and to analyse in more detail the intensity and duration of pre-competitive anxiety. In order to achieve greater HRV stability during the match –which would be theoretically associated with low state pre-competitive anxiety–, participants could perform individualized training routines during the breaks of the tennis match, thus improving their breath control strategies on throughout biofeedback techniques based on an HR monitor, coping therefore in a more suitable way the stress that could arise during the game.

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FOOTNOTES

1. Such sympathetic stimulation of adrenergic receptors β1, β2, and β3, which are generally more sensitive to adrenaline and slightly less sensitive to noradrenaline, generates increases the concentration of intracellular cyclic adenosine monophosphate that leads to different effects. β1 in the heart increases cardiac output by activating heterotrimeric G-protein and stimulating adenylate-cyclase, which antagonizes the effects of muscarinic receptors and increases intracellular Ca++ in the cytosol, mainly through cAMP-dependent protein kinase, which triggers the phosphorylation of voltage-dependent L-type Ca2++ channels (ICa++L), thus increasing the Ca2++ induced response. Some antagonistic substances β1 are useful antihypertensives. In turn, β2 are in high concentrations in the bronchial muscle and β3 in the adipocytes. The receptors α1 predominate in the blood vessels and the α2 in the presynaptic terminals and are more sensitive to noradrenaline than to adrenaline. Stimulation of adrenergic α1 receptors generates stimulation of G-protein and effects of activated α subunits, which in turn stimulate phospholipase C, an enzyme that converts PIP2 to inositol triphosphate (IP3) and diacylglycerol (DAG), both of which generate vasoconstriction secondary to the stimulation of IP3 receptors in the sarcoplasmic reticulum allowing effective output of Ca2++, while DAG activates phosphokinase C (PKC).

2. The adrenal medulla also influences inotropism and chronotropism as it is a special adaptation of sympathetic division, homologous to the postganglionic sympathetic neuron that releases adrenaline into the bloodstream. This neuroendocrine component of the sympathetic output enhances the ability of the sympathetic division to spread its message and decreases the variability of heart rate. The PNS, unlike the SNS, decreases the heart rate and blocks the sympathetic effects on the heart (Miller et al., 1994). Acetylcholine (ACh) is a

neurotransmitter secreted by branches of the vagus nerve, which stimulates ACh-sensitive muscarinic receptors M1, M2, M3 and M5, which in turn are coupled to Gs proteins. Stimulation of cardiac M2 blocks the sympathetic action by decreasing the concentration of [ccAmp]i and additionally stimulates potassium output causing repolarization through rectified acetylcholine-dependent potassium receptors (IKACh), which are compatible with negative inotropic and chronotropic actions, which tend to increase HRV by increasing the time of slow depolarization in stage four of the slow response action potential.

FIGURES AND TABLES

Day 1 **Control Day (Baseline)** Previous week Training Day	***Day 2*** **Training Day (T)** Previous Competition week	***Day 3*** **Competition 1 (C1)** First round	***Day 4*** **Competition 2 (C2)** First round
HRV 10 min Biopac MP36R Polar RS800	HRV Resting (rT) 10 min Polar RS800	HRV Resting (rC1) 10 min Polar RS800	HRV Resting (rC2) 10 min Polar RS800
	15 min before match - Placement Polar RS800 Sync up time Polar RS800 with clock register person		
	HRV Anxiety (aT) 10 min CSAI-2R	HRV Anxiety (aC1) 10 min CSAI-2R	HRV Anxiety (aC2) 10 min CSAI-2R
	Match: Recorder time (clock) and scores (performance) (resting periods between games)		

Figure 1. Schematic overview of the experimental protocol (adapted from Mateo et. al., 2012)

Table 1. Descriptive data of anthropometric characteristics and experience in tennis competition.

Anthropometric characteristics	
Age (years)	
Weight (kg)	
Height (cm)	
Fat-free mass (kg)	
Fat mass (%)	
Body Mass Index (kg/m2)	
Experience in tennis competition	
Age of beginning sport practice	
Years of sport practice	
Age of start in competition	
Years of competition	
Hours per week of training	