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Heart-rate variability and precompetitive anxiety in swimmers

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The aim of this study was to test the utility of heart-rate variability (HRV) analyses as a noninvasive means of quantifying cardiac autonomic regulation during precompetitive anxiety situations in swimmers. Psychophysiological state evaluation of 10 volunteer «master» swimmers (6 women and 4 men) was obtained by comparing baseline training condition (TC) with competition condition (CC). Self-evaluation of precompetitive somatic anxiety measured by CSAI-2 showed significant increase from the TC to CC. Analysis showed that during higher precompetitive anxiety level, a significant reduction in the timing (RMSSD), frequency (HFms^2 and HFnu) and Poincaré plot (SD1) of heart-rate variability was observed, and a significant increase in the low frequency to high frequency ratio (LF/HF %). The results indicate a shift towards sympathetic predominance as a result of parasympathetic withdrawal. Our results provide an HRV analysis in a valid, useful and non-invasive way to evaluate the change of sympathovagal balance in presence of precompetitive stress.

Variabilidad de la frecuencia cardiaca y ansiedad precompetitiva en nadadores. El objetivo de este estudio fue valorar la utilidad del análisis de la variabilidad de la frecuencia cardiaca (VFC) como un medio no invasivo para cuantificar la regulación autonómica cardiaca en nadadores durante situaciones de ansiedad precompetitiva. Se evaluó el estado psicofisiológico de 10 nadadores «master» voluntarios (6 mujeres y 4 hombres) comparando la condición de línea base en un entrenamiento (simulación de competición) (TC) frente a la condición real de competición (CC). La ansiedad somática precompetitiva evaluada mediante el CSAI_2 mostró un incremento significativo de la TC a la CC. Cuando los niveles de ansiedad precompetitiva eran más elevados se observó una reducción significativa en los parámetros de la VFC en el dominio del tiempo (RMSSD), en el dominio de la frecuencia (HFms^2 y HFnu) y en el gráfico de Poincaré (SD1); y también se observó un incremento significativo en la proporción de bajas frecuencias sobre altas frecuencias (LF/HF %). Los resultados indican un cambio hacia el predominio simpático como resultado del descenso de la actividad parasimpática. Estos resultados sugieren la utilidad del análisis de la VFC como un método válido, práctico y no invasivo para evaluar los cambios en el equilibrio simpático-parasimpático en presencia de estrés competitivo.

Heart rate variability (HRV) is a well-established non-invasive tool which can be used to study the effect of mental stress on autonomic control of the heart rate (HR) (Akselrod, Gordon, Ubel, Shannon, Barger, & Cohen, 1981; Acharya, Joseph, Kannathal, Lim, & Suri, 2006; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). There is clinical evidence about the specificity and sensitivity of the HRV parameters to asses the reduction in parasympathetic activity related to several anxiety forms (Friedman, 2007). Although in the sport competitive field the relationship between HRV and emotions have been less studied, the reduction in parasympathetic cardiac control has been found in chess players in real situation (Schwarz, Schachinger, Adler, & Goetz, 2003).

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Heart rate variability (HRV) has been defined as the capacity of the heart to change the interval between beats when faced with different situations, where these variations are modulated mainly by the autonomous nervous system (ANS) (Sztajzel, 2004). Electrocardiogram (ECG) QRS complex detection allows the RR time series analysis. The more common RR intervals analysis methods are defined in the time domain (satistical and geometrical parameters), in the frequency domain (spectral parameters) and in the nonlinear analysis (Poincaré plot).

Various lines of research into HRV analysis have supported their use in the area of sports. In the area of health it has proven to be an effective tool for measuring the benefits of physical exercise objectively (Buchheit, Simon, Viola, Doutreleav, Piquard, & Brandderberger, 2004; Carter, Banister, & Blaber, 2003) or the positive effects of stretching (Mueck-Weymann, Janshoff, & Mueck, 2004). Specifically in competition sports, the interest has focused mainly on the adaptation to training loads, the diagnosis and prevention of overtraining, and the evaluation of the state of physical fitness (Aubert, Seps, & Beckers, 2003; Cotting, Durbin, & Papelier, 2004; Earnest, Jurca, Church, Chicharro, Hoyos, & Lucie, 2003; Iellamo, Pigozzi, Di Salvo, Vago, Norbiato, Lucini, & Pagani, 2003; Leicht, Allen, & Hoey, 2003; Mourot, Buhaddi, Perrey, Cappelle, Henriet, Wolf, Rovillon, & Regnard, 2004).

From a psychophysiological point of view, authors like Lane, Adock & Burnett (1992) and Berntson, Bigger, Eckberg, Grossman, Kautman, Malik, Nagaraja, et al. (1994) agree that HRV is sensitive to changes in emotional state, and they propose its use as an evaluation technique for identifying the interaction between the heart and the brain. It seems that cardiac control and the response to different stressors could be explained by variations in the activity of the parasympathetic nervous system (PNS) (Friedman, 2007; Grossman & Edwin, 2007; Porges, 2007) and/or by activation of the sympathetic nervous system (SNS) (Berntson & Cacioppo, 2002). In this sense, there is evidence that shows the decrease in HRV parameter values related to the vagal activity when faced with stressfull conditions (Dishman, Nakamura, García, Thompson, Dunn, & Blair, 2000; Hasegawa, Uolumi, & Ono, 2004; Hjortskov, Rissen, Blangsted, Falletin, Lundberg, & Sogaard, 2004; Ruediger, Seibt, Scheuch, Krause, & Alam, 2004) and during championship chess games (Schwarz, Schachinger, Adler, & Goetz, 2003). Other works have found the influence of sympathetic activity when faced with mental stress by means of the increase in LF/HF % parameter values (Seong, Lee, Shin, Kim, &Yoon, 2004).

Several studies have shown that analysis of the heart rate variability is gaining acceptance as a tool to measure the cardiac parasympathetic activity and its relation to anxiety. Friedman (2007) and Cohen & Benjamin (2006) concluded that the reduction of HRV implies in the increase of anxiety and that different forms of anxiety should be studied particularly because specific patterns of autonomic response can be observed.

The moments prior to sports competition and their influence on performance have been always of great interest for sports psychologists. For example, Gimeno, Buceta & Pérez-Llantada (2007) conducted a research study to observe the influence of perception of stress control on sports performance. In a pioneer study into pre-competitive anxiety, Burton (1988) analysed the importance of the intensity of somatic anxiety in swimmers using Marten's multidimensional anxiety theory (1977). More recently, in the same line, various authors have used Hanin's IZOF model (2000, 2003) to explain the relationship between pre-competitive psycho-biosocial state and performance (Davis & Cox, 2002; Hagtvet & Hanin, 2007; Kamata, Tenenbaum, & Hanin, 2002). From the methodological point of view, the development of the CSAI_2 (Competitive State Anxiety Inventory 2) by Martens, Vealey & Burton (1990) has been of great relevance in measuring the precompetitive anxiety state in a multidimensional way, distinguishing between cognitive anxiety, somatic anxiety and self-confidence. The precompetitive anxiety state was defined by Martens et al. (1990) as an immediate emotional state, characterised by feelings of apprehension and tension associated with the activation of the organism in situations of competition. This activation was related to the activation of the ANS, and specifically, of the SNS.

The impact of the components of anxiety on performance is different in resistance sports (long duration) than in technical sports (short duration), where any error can seriously impair the result. For example, according to Kleine (1990), the negative effect of anxiety is higher in anaerobic activities than in aerobic ones. Parfitt & Pates (1999) affirms that somatic anxiety can act positively on performance in sports where anaerobic demands come into play. For their part, Hanton, Jones & Mullen (2000) in a study with rifle marksmen and women, concludes that somatic anxiety has a high impact on performance in sports of short duration and considered as relying on motor ability. These studies suggest that, when analysing the relationship between anxiety and performance, the influence of aspects such as the type and the characteristics of the sports being practised has to be taken into account (Raglin, 1992). In this line, Kirby & Liu (1999) in a study with chinese athletes, found that the athletes that participated individually presented higher somatic anxiety scores than those athletes that practiced team sports. For their part, Wilson & Raglin (1997) also recorded high values of anxiety in young track and field athletes, which related to better performances, in contrast to that shown in other sports.

The main objective of this study was to test the utility of heart rate variability (HRV) parameters to examine how the autonomic nervous system (ANS) regulates the heart during precompetitive anxiety in swimmers. In this sense, we tested the hypothesis that higher precompetitive somatic anxiety levels will provoke an increasement of sympathetic activity HRV values and a decreasement of the parasympathetic activity HRV values.

Method

Participants

The initial sample of this study included 25 «Master» swimmers, members of the «Master» swimming team of a Spanish private club. After a briefing, only 10 swimmers were invited to participate in our research, since they were the only ones that met the following inclusion criteria: a) they had to be 50 meters swimmers specialist; b) they had to participate in national competitions; and c) they had to be trained at least three days per week. All 10 swimmers (6 women, 4 men), with an average age of 47 years (DT= 6.81) and 8 years participating in national competitions (DT= 2.07), participated voluntarily in the two phases of the study. After they were informed about the procedures and the objectives of the study, a written consent was signed. None of these 10 swimmers was discarded due to missing data on questionnaires or due to errors in physiological records.

Instruments

The Competitive State Anxiety Inventory-2 (CSAI-2) (Martens et al.,1990) was used to measure preperformance cognitive anxiety, somatic anxiety, and selfconfidence of the participants. The CSAI-2 comprises 27 items, with nine items in each subscale. Examples of cognitive anxiety items include 'I am concerned about this competition'' and 'I am concerned about performing poorly', whilst somatic anxiety items include 'I feel nervous' and 'My body feels tense'. Self-confidence items included 'I feel at ease' and 'I am confident about performing well'. The response scale had participants rate the intensity of each symptom on a scale of 1 (not at all) to 4 (very much so), resulting in scores ranging from 9 to 36 for each subscale. The three intensity subscales with the present sample showed adequate internal consistency with Cronbach's alpha coefficients between 0,79 and 0,90, which was similar to those noted by Martens and his colleagues (1990).

A Polar S810i heart rate recorder was used with a Polar T61 elastic electrode belt (*Polar Electro Oy*), validated in the study by Gamelin, Berthoin & Bosquet (2006). This allows the RR interval to be recorded with a maximum capacity of 30,000 beats and a sampling frequency of 1000 Hz. The 10 minute recordings of the RR intervals were transferred to a personal computer using Polar Precision Performance Software (Version 4.03.041, Polar Electro, Finland). After correcting for possible recording errors, the RR intervals were exported to the HRV Analysis Software (Version 1.1 SP1, University of Kuopio, Finland) to analyse the HRV using the parameters summarised below.

Procedure

The first contact was made with the club's manager and trainer, to whom the objective and the general contents of the study were explained. This was followed by a second explanation to the swimmers in the master swimming team taking part in the study. The data was recorded during the period of competition, specifically in the «tapering» micro-cycle, within a 13 micro-cycles training plan. Information was obtained from the same group of swimmers by comparing two different situations: a) Baseline Training Condition (TC), on the third day of the competitive «tapering» micro-cycle, when it was created a simulated competition, during training, designed to proportionate a stressful situation; and the Competition Condition (real competition) (CC), on the tenth day of the competitive «tapering» micro-cycle, which coincided with the National Master Swimming Championships.

In each condition, the data from the psychological and physiological variables were obtained 30 min. before the swimming trial. Once each swimmer had carried out their warm-up, they went to a previously prepared area where: They first completed the CSAI_2 questionnaire (somatic anxiety was included as control measure of the stress level); and then they were asked to wear the elastic electrode belt (placed with conductive gel), attached by the researcher. The participants were asked to remain quiet, without speaking or making any movements for 10 minutes in a supine position. The HRV data were obtained on the resting position, using the HR monitor (Polar S810i), which was placed and set to start by the researcher.

HRV analysis

It was selected the last segment of 300 s within the total 600 s of the supine corrected Polar recording. The data obtained was analyzed in: **1) time domain methods**; the mean RR interval, the standard deviation of all RR intervals (SDNN), the root mean square of differences (RMSSD) of successive RR intervals, differences between adjacent RR intervals of more than 50 ms (pNN50), and the proportion of differences between adjacent RR intervals of more than 50 ms (pNN50) were computed. The triangular interpolation of RR interval histogram is the baseline width of the distribution measured as a base of a triangle, approximating the RR interval distribution (the minimum square differences are used to find such a triangle; TINN) (Task Force, 1996); **2) frequency domain methods**; spectral analysis was performed using an autoregressive model estimation (parametric method), resulting in a continuous smooth spectrum activity (Sztajzel, 2004), to quantify the power spectral density of the very low frequency (VLF; 0.00-0.04 Hz), the low frequency (LF; 0.04-0.15 Hz), and the high frequency (HF; 0.15-0.40 Hz) bands. Additional calculations included the LF/HF ratio, LF, and HF values expressed in normalised units (nu). The LF/HF ratio is generally used as a measurement of the sympathetic-parasympathetic balance. The increase in this parameter indicates a greater influence of the sympathetic activity, a decrease of the parasympathetic activity or a combination of both of these. Kamath, Fallen, Dixon, McCartney, Mishker & Reilly (1991) have demonstrated that this index is more useful in short-term recordings; and **3) the Poincaré plot**; this nonlinear analysis method quantifies separately the instantaneous beat-to-beat variability (SD1) and the long term beat-to-beat variability (SD2) of the plot (Mourot et al., 2004; Brennan, 2001).

Statistical analysis

Normal distribution was tested by means of the Kolmogorov–Smirnov test. Due to the assumption of normal distribution was violated for some variables and due to the small sample size (n= 10), we performed nonparametric Wilcoxon signed rank test for paired samples to compare the two phases of the study. Data results will be expressed in terms of mean (M) and standard deviation (SD). All calculations were performed by using the SPSS statistical package for Windows (v.16.0).

Results

Pre-competitive anxiety analysis. Results showed that the CC scores (M= 13,14; SD= 5,47) were significantly higher than TC scores (M= 8,56; SD= 6,71) for the somatic anxiety component of CSAI_2 (p= 0,009). Concerning the cognitive anxiety and self-confidence, scores showed non-significant differences between TC and CC.

Time domain HRV analysis. The comparison between the two conditions of the study for the time domain HRV parameters are shown in Table 1. Concerning the RMSSD parameter, a significant decrease in the CC was noticed (p= 0,047). Whereas the Mean RR, STDRR, STDHR, NN50, TINN, ND.TRI and pNN50 indexes did not differ significantly among the two conditions.

Nonlinear HRV analysis. The comparison between the two conditions of the study for Poincaré plot parameters are shown in Table 1. Comparing SD1 during TC and CC conditions revealed that SD1 it was significantly lower (p= 0,047) during CC for the swimmers. Concerning the SD2, no differences were noticed among two conditions.

Frequency domain HRV analysis. Table 2 show the comparison between the two conditions of the study for frequency domain parameters. Significant differences for sympathetic activity related parameters were only found in terms of the increase of the LF/HF %, which expresses the proportion between low frequencies and high frequencies (p= 0,005). In the band of low normalised frequencies (LFnu) an increase with a tendency towards significance (p= 0,074) was observed, whereas the VLF (% and ms^2), LF (% and ms^2) did not differ significantly among the two conditions. On the other hand, in terms of the parameters related to parasympathetic activity, a significant decrease was found in the HF ms^2 (p= 0,017) and HF nu (p= 0,013) values, and a decrease with a tendency towards significance in the HF % parameter (p= 0,059).

Table 1
Comparison between the two conditions of the study for the HRV time domain and the Non Lineal Analysis (Poincaré Plot) scores. (n= 10)

	Training condition		Competition condition	
HRV	**Mean**	**SD**	**Mean**	**SD**
Time Domain				
Mean RR (ms)	0,741	0,084	0,712	0,084
STDRR (ms)	0,032	0,011	0,033	0,016
HR (ms)	82,10	7,91	85,58	10,08
STDHR (ms)	3,56	1,52	3,90	1,18
RMSSD (ms) *	37,69	27,19	21,79	22,47
NN50	5,60	6,04	7,10	9,10
pNN50 (%)	1,41	1,51	1,85	2,59
IND.TRI	0,056	0,018	0,060	0,021
TINN (ms)	346,00	228,21	199,00	0,021
No Lineal Analysis (Poincaré Plot)				
SD1 ms *	27,50	20,01	15,73	16,23
SD2 ms	60,92	29,43	62,45	23,51

** p<0,05. Wilcoxon signed rank test for paired samples*

Table 2
Comparison between the two conditions of the study for the HRV frequency domain scores (n= 10)

	Training condition		Competition condition	
HRV	**Mean**	**SD**	**Mean**	**SD**
Frecuency Domain				
VLF %	20,03	32,69	26,11	25,34
LF %	60,02	27,61	64,78	22,41
HF %	21,03	13,25	9,11	9,36
LF/HF % **	7,45	14,92	16,74	17,55
VLF ms^2	49,60	65,49	131,40	153,98
LF ms^2	525,60	531,78	378,50	328,02
HF ms^2 *	209,20	250,05	87,20	328,02
LF nu.	59,19	21,54	76,43	14,94
HF nu. *	19,45	8,31	9,77	8,52

** p<0,05; ** p<0,01. Wilcoxon signed rank test for paired samples*

Discussion

The anxiety responses of athletes could be modulated by the specifics requirements of the task demands of the sport (Martens et al., 1990). In our study the participants showed greater pre-competitive somatic anxiety levels in CC than in TC, whereas no differences in cognitive anxiety and self-confidence scores were reported. The results obtained in the studies of somatic anxiety in short-duration trials and in individual sports made by Burton (1988), Hanton et al. (2000) and Parfitt & Pates (1999), were similar to our findings. Once the difference of stress level was confirmed, the next step was to analyze the HRV parameters between two conditions.

Comparing HRV indexes in TC vs. CC it was confirmed the effect of the mental stress on the HRV. The RMSSD parameter showed the expected change, since the significant decrease in the competition condition suggests it is related to the inhibition of the parasympathetic activity in stress situations, in our case, under the impact of the competitive situation. This parameter has been proposed due to its sensitivity in rapidly quantifying the variations of the RR interval as one of the most reliable parameters in the HRV short-term recordings (Bornas, Llabrés, Noguera, Tortella, Fullana, Montoya, Gelabert, & Vila, 2006), such as the 300 s periods analysed in our study. Therefore, in terms of time domain parameters, RMSSD seems to be the most valid one as an indicator of emotional state in competition situations. The results with regard to the frequency domain of the HRV analysis confirm the autonomic control in competition situations, increasing the sympathetic activity and at the same time inhibiting the parasympathetic activity. The parameters that increased its value significantly, and that are related to sympathetic activity, are LF/HF % (ratio between low frequencies and high frequencies) and LFnu (band of low normalised frequencies with a tendency towards significance). The actual results are in the line with those obtained for phobic anxiety (Kawachi, Sparrow, Vokonas, & Weiss (1995) and according to level of anxiety (Piccirillo, Elvira, Bucca, Viola, Cacciafesta, & Marigliano (1997). Anxiety was related to increased low frequency (LF) and sympathetic predominance (LF/HF %), therefore, anxiety was associated with sympathetic hyper-activity. The parameters that decreased its value significantly in our study, and that are related to parasympathetic activity, are HF (strength of low frequencies in ms^2) and HFnu (band of low normalised frequencies), and HF% (percentage of the band of high frequencies). This in conforms with a large number of studies that reported a decrease in vagal activity with anxiety disorders (Cohen & Benjamin, 2006; Friedman, 2007; McCraty, Atkinson, Tomasino, & Stuppy, 2001; Yeragani, Pohl, Berger, Balon, Ramesh, Glitz, Srinivasan, & Weinberg, 1993). In the same direction, Schwarz et al. (2003) found a reduction of the values of HF (ms^2) parameter in chess players during competition, by interpreting a decrease of the vagal activity in relation to the affective negative states. Reviewing all the results, the analysis of the LF/HF % parameter is suggested for evaluating the balance of the SNA modulation during pre-competition periods. In agreement with other authors, a predominance of sympathetic activity over parasympathetic activity is expected to be found in stress situations like sports competitions (Iellamo, Pigozzi, Spataro, Lucini, & Pagani, 2004; Kamath et al., 1991).

Nonlinear analysis of the HRV using a Poincaré plot can reflect the impact of stress situations on short-duration records based on the SD1 parameter (Mourot et al., 2004). Our results indicate a significant inhibition of the parasympathetic activity in a competition situation, as the SD1 parameter is significantly lower than in the training situation. The comparison between SD1 and RMSSD parameters seems to be redundant, because the significance of both parameters in this study, are exactly the same (p= 0,047).

Several studies focused on abnormalities of HRV and anxiety disorders (Friedman 2007) while this study assessed the relationship of HRV to precompetitive state anxiety. No cross-sectional studies have investigated the effects precompetitive anxiety on HRV in real conditions. However, Hjortskov et al. (2004) have reported a conversion from vagal to sympathetic dominance during mental workload, a reduction in the HF parameter of HRV and an increase in LF/HF % were observed in the stress situation compared to the control session. It may be interesting also from an applied point of view. «…anxiety in its phasic, tonic and pathologic forms is marked by aberrant ANS cardiac control. A range of HRV indices converge to implicate low vagal and elevated sympathetic activity in anxiety» (Friedman, 2007, p. 195) this conclusion is in conformity with the results obtained in this study.

In terms of HRV recording devices, the cardiac frequency monitor Polar S810i is considered a valid, reliable and low-cost portable system (Gamelin et al., 2006) that allows the continuous analysis of heartbeats using RR intervals. For use in field research it is a non-invasive, easy to handle apparatus that permits the application of different methods of HRV analysis (Kingsley, Lewis, & Marson, 2005). The validity of analysing short-term recordings (e.g., of 300 s long) has been confirmed in various studies relating to the influence of emotions (McCraty, Atkinson, Tiller, Rein, &Watkins, 1995).

In conclusion, our findings provide information about the change of sympathovagal balance in presence of precompetitive stress higher levels**.** Our results suggest that the use of the Polar monitor in a supine position in the swimmers' pre-competitive routine, and after correcting the data, provides a HRV analysis in a valid, useful, non- invasive and inexpensive way to evaluate the pre-competitive anxiety state. Short-term HRV analysis (300 s.) is proposed as a technique for complementing the evaluation of the precompetitive psychophysiological state and for enabling strategies to be applied to optimize the impact of precompetitive anxiety on the performance of swimmers.

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