HEART RATE DYNAMICS IN SUBJECTS WITH DIFFERENT HYPNOTIZABILITY

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ABSTRACT

Spectral analysis has been the principal technique used for investigating hypnotizability-related differences in heart rate variability. In contrast to this classical approach, the present study is based on recurrence quantification analysis (RQA), a non-linear method able to describe different features of heart rate dynamics. RQA was used to analyse heart rate data taken from 17 not hypnotized, highly hypnotizable (*highs*) and 17 low hypnotizable subjects (*lows*). The data were recorded while the subjects were paying attention to a non-emotional movie. Results showed higher absorption scores (TAS) in *highs* than in *lows*, only among males, higher attention to the movie in females, and no correlation between TAS and reported attention. Traditional spectral analysis was able only to reveal gender, but not hypnotizability-related differences in these data. RQA indices also detected gender, but not hypnotizability-related differences in the predictability of heart rate dynamics, and confirmed the parasympathetic prevalence observed in females through spectral analysis. Moreover, some RQA indices were modulated by present attention and not by absorption, changes that were not detected using spectral analysis. Thus, RQA of heart rate dynamics appears to be a useful tool for characterizing individual cognitive states.

Key words: hypnotizability, heart rate dynamics, attention

INTRODUCTION

The cognitive trait of hypnotizability is attracting increasing interest in physiology, to explain part of the variability of the general population (Carli et al., 2008; Santarcangelo, 2011; Menzocchi et al., 2010, 2012; Castellani et al., 2011), while in medicine it is increasingly seen as a powerful instrument to control stress, pain, and biological parameters (Weisberg, 2008).

Spectral analysis of the tachogram (that is the sequence of distances between consecutive R waves of the electro-cardiogram) has been widely used to study heart rate variability in subjects with different hypnotizability in resting conditions (Santarcangelo et al., 1992; De Benedittis et al., 1994; Hippel et al., 2001; Diamond et al., 2008; Aubert et al., 2009; Sebastiani et al., 2005; Yüksel et al., 2013) as well as during physical (Santarcangelo et al., 2008; Yüksel et al., 2013) and cognitive stimulation (Santarcangelo & Sebastiani 2004; Gemignani et al., 2006;

Ray et al., 2000; Jorgensen & Zachariae, 2002; Zachariae et al., 2000; Sebastiani et al., 2007). In particular, it has recently been shown (Santarcangelo et al., 2012a) that, during simple relaxation, highly hypnotizable individuals (*highs*) display higher parasympathetic tone than low hypnotizable persons (*lows)*. This was revealed by a higher normalized high frequency (HFn) component and lower low frequency (LFn) and very low frequency components (VLFn) in the power spectrum of the tachogram (Santarcangelo et al., 2012a). Moreover, in the ordinary state of consciousness and in the absence of suggestions, *highs* exhibit no vascular effect of acute stress (Jambrik et al., 2004a, b) and lower effects of nociceptive stimulation (Jambrik et al., 2005) with respect to low hypnotizable persons (*lows*). Overall, these findings suggest that *highs* may be protected against cardiovascular events (Santarcangelo & Sebastiani, 2004), since low scores on these variables are predictive of cardiac health. Strong support for this view of a natural protection of *highs* against cardiac hazard comes from the positive correlation found in the general population (Pinter et al., 2012) between vagally mediated heart rate variability and endothelial function.

Nevertheless, the differences in heart rate variability observed between *highs* and *lows* in the resting state disappear when subjects are asked to pay attention to a relaxing movie (Santarcangelo et al., 2012b). In these individuals, spectral analysis does not reveal any difference between *highs* and *low*s. In contrast, some gender differences remain across the two conditions. Thus, gender differences consisting of significantly higher HFn, and lower LFn, and LF/HF in females than in males are present in both simple relaxation and low attentional tasks (Santarcangelo et al., 2012a, b).

The lack of hypnotizability-related differences in heart rate variability during attentional tasks contrasts with the well-documented greater proneness of *highs* to become deeply engaged in cognitive tasks (Tellegen & Atkinson, 1974; Green & Lynn, 2011). This suggests that we may expect the requirement to pay attention to a non-demanding movie (without any unpleasant/fearful/stressful content) (Santarcangelo et al., 2013) to be performed with lower cognitive effort by *highs* than by *lows*, and thus with lower autonomic cost. Nonetheless, we could hypothesize that the low attentional demand of the task may have prevented the occurrence of autonomic differences between *highs* and *lows* and/or that spectral analysis was not sufficiently sensitive to detect them. In fact, heart rate dynamics may contain features that remain undetected by spectral analysis; after all, it is the case that different RR dynamics can be associated with similar RR power spectra, which are the characteristics revealed by this form of analysis. Among the techniques available for the analysis of systems dynamics, the recurrence quantification analysis (RQA) is one of the methods most often used to detect the structure of any kind of data (Zbilut et al., 2002) and has been used widely in studies involving humans (Javorka et al., 2009; Sabelli & Lawandow, 2010; González et al., 2013).

Thus, the aim of the present study was to characterize by RQA the RR dynamics of the *highs* and *lows* (of both genders) who had paid prolonged attention to the above cited movie, and to study the possibly different sensitivities of RQA and spectral indices to trait (hypnotizability, absorption) and state (reported attention) characteristics.

METHODS

Participants were recruited from 280 students of the University of Pisa attending classes on the physiological correlates of hypnotizability. They signed an informed consent, completed

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the Tellegen Absorption Scale (TAS) and underwent hypnotic assessment through the Stanford Hypnotic Susceptibility Scale, form C (De Pascalis et al., 2000). Seventeen *highs* (mean ± sd; SHSS score: 10.2 ± 1.7; age 22 ± 2.4, 9 females) and 17 *lows* (SHSS score: 1.6 ± 0.9; age: 23.01 ± 2.1, 9 females) were included in the present re-evaluation of the cardiac function monitored during an experimental session consisting of watching a movie presenting a sequence of images showing landscapes in various seasons, without animals or humans, for 30 minutes (Santarcangelo et al., 2012b). The instruction administered to participants was to relax and pay attention only to the images. At the end of the movie, subjects were interviewed about the level of attention paid to the movie (range 1 (minimum)–10 (maximum)) and other subjective experiences described elsewhere .

SIGNAL ACQUISITION

ECG was recorded through Red Dot™ Ag/AgCl disposable electrodes placed according to the standard D1 lead. The beat-to-beat time intervals (RR) series was obtained using a QRS complex detector using a threshold based on a derivative signal (Taddei et al., 1984). An initialization phase, performed on a 20s signal interval, was used to automatically estimate the detection threshold and the sign of the maximum derivative. The detector parameters were beat-to-beat recursively updated in order to track signal changes. Abnormal RR intervals due to false negatives or coming from the detection of events not originating from the sinus node (ectopic beats, spikes) were removed through a predictive filter with an adaptive threshold on prediction error (Varanini et al., 1993).

SPECTRAL ANALYSIS

The spectral analysis of the RR-interval time series was performed according to Welch's averaged periodogram method, using an effective frequency resolution of 0.0084Hz with Hamming windowing, zero padding and subinterval overlapping of 50%; the number of subintervals was automatically adjusted and ranged from 13 to 15. The spectral indexes considered for HRV were: VLF, spectral power in the very low frequency band (0.00–0.04Hz); LF, spectral power in the low frequency band (0.04–0.15Hz); HF, spectral power in the high frequency band (0.15–0.4Hz) and the LF/HF ratio (Task Force, 1996). Spectral analysis indices were estimated over 30 minutes, in contrast to an earlier evaluation (Santarcangelo et al., 2012b) which was performed on two consecutive 15-minute blocks. The normalized spectral powers (VLFn, LFn, HFn) were obtained by dividing each component by the sum of all of them (VLF + LF + HF). The ratio between LF and HF (LF/HF) was also computed.

RECURRENCE QUANTIFICATION ANALYSIS

Repeating patterns are found in most dynamical systems and the degree of recurrences in time contains a large part of information on the system's characteristics. Recurrence quantification analysis (RQA) is a technique based on the construction of the recurrence plot (RP) (Eckmann, et al., 1987; Zbilut & Webber, 1992; Zbilut et al., 2002), which is particularly suitable for the analysis of complex dynamics, non-linear and non-stationary data. RP contains features that can be easily quantified. The RQA indices usually extracted are: REC (recurrence rate), corresponding to the probability that a specific state will recur; DET (determinism), related to

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the periodicities and predictability of the system; Lmax (length of the longest diagonal line), which is a measure of the process robustness to perturbation; LAM (laminarity), related to the percentage of laminar phases, that is the states in which the dynamics remains constant; Vmax (length of the longest vertical line), representing the maximal duration of laminar states; TT (trapping time), indicating the average time in which the system remains in a laminar state; ENT (entropy), related to the complexity of periodic structures present in the RP; RTE (recurrence time entropy, or recurrence period density entropy), which is an expression of the 'regularity' of the system dynamics. In our study we used the MATLAB crp toolbox (Marwan et al., 2002)

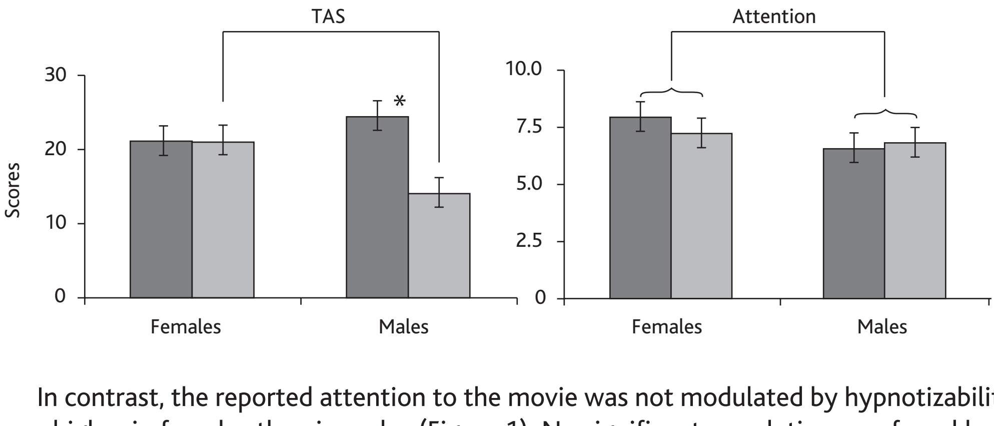
STATISTICAL ANALYSIS

Hypnotizability and gender were the *between* subjects factors in all analyses, which were performed through the statistical package SPSS15. Univariate ANOVAs were performed on the reported attention and TAS scores. Multivariate ANOVAs were performed on the entire session spectral and RQA indices. Finally, MANCOVAs were performed on both spectral and RQA indices controlling for the reported attention and TAS, separately. The Pearson correlation coefficient was computed between subjective (TAS, reported attention) and RQA/spectral indices. Significance was set at $p<0.05$.

RESULTS

ANOVA revealed a significant hypnotizability × gender interaction for TAS scores, which were similar in *highs* and l*ows* among females, and higher in *highs* than in *lows* among males (Figure 1).

Figure 1. Subjective experience. TAS scores and reported attention (mean, SE) in highs (dark bars) and lows (light bars). Asterisk indicates significant difference between highs and lows; lines, significant differences between females and males.



In contrast, the reported attention to the movie was not modulated by hypnotizability and was higher in females than in males (Figure 1). No significant correlation was found between TAS and reported attention scores

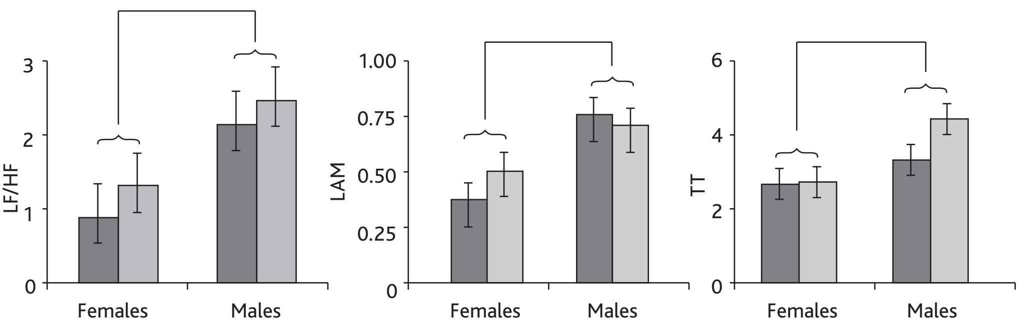
Multivariate ANOVA on spectral variables (Table 1) showed significantly higher HFn and lower LF/HF in females than in males, independently of hypnotizability (Table 2, Figure 2);

MANOVA on RQA indices (Table 1) revealed significantly lower values of LAM and TT in females than in males (Table 2, Figure 2).

Table 1. Spectral and RQA indices

		Females		Males	
		Mean	SD	Mean	SD
Spectral indices	VLFn	0.29	0.09	0.35	0.12
	LFn	0.35	0.12	0.41	0.11
	HFn	0.42	0.24	0.23	0.12
	LF/HF	1.10	0.90	2.27	1.25
RQA indices	DET	0.67	0.10	0.69	0.11
	Lmax	120.40	174.20	186.10	230.60
	ENT	2.48	0.31	2.53	0.27
	LAM	0.43	0.33	0.71	0.30
	TT	2.64	0.99	3.76	1.60
	Vmax	34.35	41.30	48.06	31.78
	RTE	0.04	0.02	0.05	0 .02

Figure 2. Spectral and recurrence plot indices. Highs (dark bars) and lows (light bars). LF/HF, ratio between low and high frequency component of the heart rate variability; LAM, percentage of laminar states in the recurrence plot; TT, duration of laminar states. Lines indicate significant gender differences.



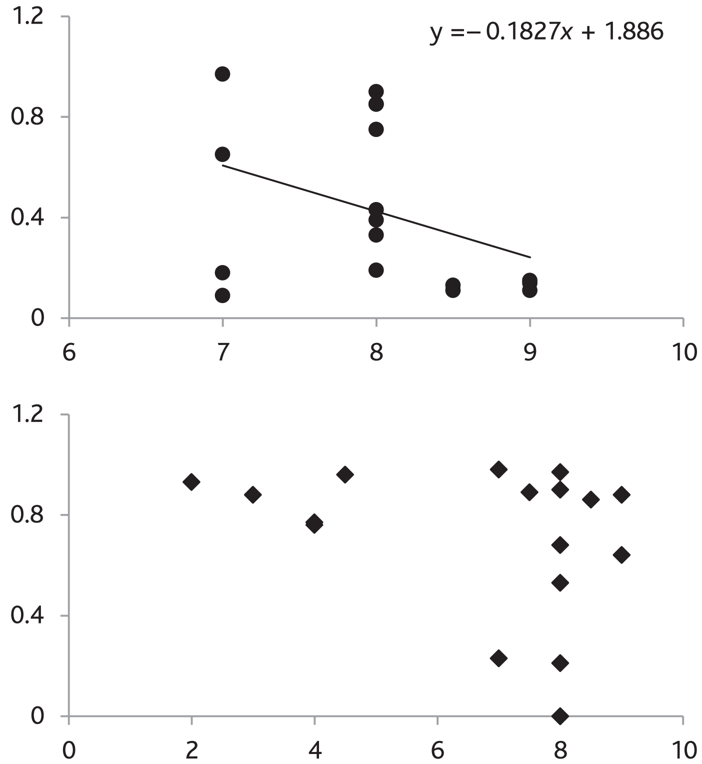
Controlling for the TAS scores (MANCOVA) did not change the significant gender differences observed in HFn, LF/HF, LAM and TT, while controlling for the reported attention abolished the gender differences in the RQA indices LAM and TT, but not in spectral indexes (Table 2).

A significant negative correlation was observed between the reported attention and LAM (R = –0.406, $p < 0.019$) indicating that the higher the attention the lower the laminarity and thus, the regularity of the recurrence plot. Splitting by gender (Figure 3) the correlation survived only in females (R = –0.502, $p < 0.048$) who, indeed, reported higher attention than males.

Table 2. Summary of significant subjective and physiological results.

Variable		Effect		ANOVA-MANOVA	ANCOVA-MANCOVA	
					Controlling for attention	Controlling for TAS
TAS		Hypn		$F(1,33)=9.090$, $p<0.005$		
		Hypn × Gender		$F(1,33)=5.406$, $p<0.027$		
			females: ns			
			males: *highs* > *lows*			
				$F(1,16)= 16.183$, $p<0.0001$		
			highs: ns			
			lows: females>males			
				$F(1,16)=5.596$, $p<0.032$		
Attention		Gender		$F(1,33)=4.424$, $p<0.044$		$F(1,33)=5.278$, $p<0.029$
				females > males		
Spectral indices	HFn	Gender		$F(1,33)=7.597$, $p<0.010$	$F(1,33)=8.750$, $p<0.006$	$F(1,33)=6.701$, $p<0.015$
				females > males		
	LF/HF	Gender		$F(1,33)=9.834$, $p<0.004$	$F(1,33)=8.121$, $p<0.008$	$F(1,33)=8.545$, $p<0.007$
				females < males		
RQA indices	LAM	Gender		$F(1,33)=6.687$, $p<0.015$	ns	$F(1,33)=6.088$, $p<0.020$
				females < males		
	TT	Gender		$F(1,33)=6.554$, $p<0.016$	ns	$F(1,33)=6.714$, $p<0.015$
				females < males		

Figure 3. Scatter plot of LAM values as a function of attention. Upper panel, females; lower panel, males.



DISCUSSION

The present analysis reveals three main points. First, the absorption was higher in *highs* than in *lows* only among males and there was no correlation between TAS and attention scores, that is between the self-reported proneness to be involved in cognitive tasks and the subjective report of attention to the present task. Second, both spectral analysis and RQA revealed only gender differences; third, spectral indices were not influenced by either trait (TAS) or state (reported attention) subjective characteristics, while RQA indices maintained the gender differences after controlling for TAS, but not after controlling for the reported attention. This indicates that the RQA reveals characteristics of the present cognitive state not detected by spectral analysis.

Gender and hypnotizability differences in absorption have been widely described (Tellegen & Atkinson, 1974; Crawford, 1982; Hoyt et al., 1989; Green & Lynn, 2011), while to our knowledge this is the first report on an interaction between the two factors. We believe that it may be important to account for the several interactions observed at the behavioural level. Gender differences restricted to *lows* have been found elsewhere: in degree of veering during blindfolded locomotion (Menzocchi et al., 2010) and in the visual reproduction of haptically

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explored angles (Menzocchi et al., 2012). In two studies similarities in the behaviour of the male *highs* and female *lows* have been reported: in the postural control of subjects standing on a see-saw platform (Caratelli et al., 2010) and in the visual recognition of unfamiliar objects after uni- and bimanual exploration (Castellani et al., 2011; 2012). We argue that gender and hypnotizability-related characteristics may interact depending on the nature of the task.

The absence, in this study, of any correlation between the proneness to absorption and the attention actually paid to the movie indicates that great caution should be used whenever experimental hypotheses are formulated on the basis of trait characteristics (Tellegen, 1981). This result is in line with recent evidence showing that the *highs*' greater imagery abilities are not sufficient to let them obtain a better pain imagery with respect to *lows*, as other factors such as the activity of the behavioural inhibition/activation system (Gray, 1990) may interact with them and prevent the occurrence of the expected imagery-triggered pain experience (Santarcangelo et al., 2013).

Recurrence quantification analysis did not reveal hypnotizability, but only gender-related differences in heart rate dynamics. It showed higher values of LAM and TT in males, whose heart dynamics are thus more regular than those of females. It is known that higher values of LAM and TT are observed during upright stance with respect to the supine position; this suggests an association between higher LAM/TT and higher sympathetic/lower parasympathetic activity (Javorka et al., 2009; González et al., 2013). Thus, in the present study, lower LAM and TT values in females imply a lower sympathetic/higher parasympathetic tone and confirm the findings obtained through spectral analysis (present study; Santarcangelo et al., 2012b).

Finally, we wish to remark that RQA indices appear useful in the assessment of the specific role of trait and state cognitive features in the cardiac control. In fact, TAS scores did not account for the variability of both spectral and RQA indices, whereas LAM and TT (indicating the percentage of laminar states and their duration in the recurrence plot) were modulated by the attention paid to the movie and not influenced by TAS scores. Thus, RQA provides a deeper insight in the physiology of the brain–heart axis, as it reveals heart rate variability characteristics associated with individual cognitive states. In particular, the greater the attention paid to the task the more irregular the heart rate dynamics.

In conclusion, although the cognitive–emotional control of heart rate as a function of hypnotizability is far from being completely assessed, innovative methods of analysis and holistic approaches to the brain–heart axis can provide novel information and perspectives.

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