PARADOXICAL RESPONSE TO AN
EMOTIONAL TASK:
Trait Characteristics and Heart-Rate Dynamics

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Abstract: The present study evaluated the heart-rate dynamics of
subjects reporting decreased (responders) or paradoxically increased
relaxation (nonresponders) at the end of a threatening movie.
Heart-rate dynamics were characterized by indices extracted through
recurrence quantification analysis (RQA) and detrended fluctuation
analysis (DFA). These indices were studied as a function of a few
individual characteristics: hypnotizability, gender, absorption, anxiety,
and the activity of the behavioral inhibition and activation systems
(BIS/BAS). Results showed that (a) the subjective experience of respon-
siveness is associated with the activity of the behavioral inhibition
system and (b) a few RQA and DFA indices are able to capture the
influence of cognitive-emotional traits, including hypnotizability, on
the responsiveness to the threatening task.

Subjectively reported emotion has been classically associated with the
modulation of heart-rate variability (HRV) studied through spectral
analysis (Kop et al., 2011; Rajendra, Natharaian, Min, & Suri, 2006; Task

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Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). This correlation was challenged by findings obtained in an experiment requiring subjects to pay attention to a threatening movie (Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012). In that study, about 40% of the healthy participants paradoxically reported increased relaxation (nonresponders), and the spectral analysis of HRV did not reveal significant differences between these subjects and the participants reporting decreased relaxation (responders). The study had been undertaken in search of possible differences between individuals with high (highs) and low (lows) hypnotizability in the cardiovascular response to a threatening task. In fact, in a previous study, both highs and lows, who display significant differences in HRV in resting conditions (Santarcangelo, Paoletti, Balocchi, Carli, et al., 2012) as well as during physical stimulation—upright stance (Santarcangelo et al., 2008)—had shown the ability to buffer the autonomic effects of unpleasant imagery, although through different mechanisms (Sebastiani, Simoni, Gemignani, Ghelarducci, & Santarcangelo, 2003).

Becoming a responder or nonresponder was independent of hypnotizability and the two subsamples (including females and males) exhibited the same scores of anxiety (assessed by the State–Trait Anxiety Inventory [STAI]) and the ability of absorption in cognitive activities (measured through the Tellegen Absorption Scale [TAS]). Thus, we reasoned that factors other than hypnotizability, gender, absorption, and anxiety should be involved in the above-cited unexpected results. A candidate trait could be the activity of the behavioral inhibition/activation system (BIS/BAS; Fowles, 1988; Gray & McNaughton, 1996), measured by BIS/BAS scales (Carver & White, 1994). The behavioral inhibition system is based in septo-hippocampus networks receiving information from the prefrontal cortex and projecting to the locus coeruleus and to the raphe and modulates sensitivity to impending unpleasant and/or stressful situations. Recently, however, it has been associated with a conflict-detection system rather than with a predisposition for avoidance (for review, see De Pascalis, Cozzuto, Caprara, & Alessandri, 2013). The behavioral activation system, based in the septal area and in the lateral hypothalamus, is sensitive to potential rewards and influences the drive toward novel and/or pleasant experiences. Indeed, it was recently observed that the BIS/BAS modulates the efficacy of emotionally unpleasant imagery, preventing an efficient pain imagery but not an efficient neutral imagery in highs, who have great imagery abilities, assessed through the Betts questionnaire (Santarcangelo et al., 2013).

In addition to the classic linear approach of spectral analysis to the study of the HRV oscillatory content (Task Force of the European Society of Cardiology and the North American Society of Pacing and
Electrophysiology, 1996), other techniques are available to capture different characteristics of heart activity. In the present study, we applied two different methods of nonlinear analysis—recurrence quantification analysis (RQA) and detrended fluctuation analysis (DFA)—to describe the dynamic features of heart rate. These methods characterize the fluctuation properties of a time series.

RQA is one of the most employed and promising nonlinear techniques for signal analysis because of its wide applicability (short recordings, noisy and nonstationary signals) and the multiplicity of indices supplied, useful to characterize a system in its manifold features (Webber & Zbilut, 1994; Zbilut, Thomasson, & Webber, 2002). It has been applied in many different fields and provided reliable findings in studies on human heart-rate dynamics (Arcentales, Giraldo, Caminal, Benito, & Voss, 2011; Gonzales, Infante, Perez Grovas, Jose, & Lerma, 2013; Javorka, Turianikova, Tonhajzerova, Javorka, & Baumert, 2009; Marwan, Wessel, Meyerfeldt, Schirdewan, & Kurths, 2002; Mohebbi & Ghassemian, 2011; Y. Peng & Sun, 2011; Trzebski, Smietanowski, & Zebrorski, 2001). The characterization of the heart-rate dynamics by RQA in provoking experimental conditions allowed researchers to associate specific differences in RQA indices with sympathetic and/or parasympathetic prevalence (Gonzales et al., 2013; Javorka et al., 2009).

DFA has been widely employed to study the long-term memory properties of time-series fluctuations by the computation of indices related to the degree of its autocorrelation. It is an extension of the fluctuation analysis to nonstationary time series by operating an appropriate local detrending of the time series (Eke, Herman, Kocsis, & Kozak, 2002; C. K. Peng et al., 1994; C. K. Peng, Havlin, Stanley, & Goldberg, 1995). DFA has been useful in characterizing physiological conditions such as sleep (Yeh et al., 2013), supine rest, sitting, exercising (Castiglioni & Di Rienzo, 2010), and cardiac diseases (Makikallio, Hoiber, et al., 1999; Makikallio, Koistinen, et al., 1999; Tapanainen et al., 2002). In particular, $\alpha_1$ seems to yield prognostic information on postinfarction and cardiac arrhythmias and to be a risk marker in elderly people (Goldberger et al., 2002; Iyengar, Peng, Morin, Goldberger, & Lipsitz, 1996). However, DFA is closely related to standard spectral analysis, and its $\alpha_1$ and $\alpha_2$ indices—relative to short- and long-term fluctuation, respectively—have been associated with the normalized low and very low frequency band of the heart-rate spectral variability (Willson & Francis, 2003).

The aim of the present study was to investigate whether (a) heart-rate dynamics, as described by RQA and DFA indices, are different in responders and nonresponders to the above-cited threatening task and (b) absorption, anxiety, the ability of absorption in mental activities, and the activity of the BIS/BAS influence the indices extracted through RQA and DFA.
METHOD

Subjects and Experimental Procedure

As described in a previous article (Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012), 34 healthy, drug-free students of the University of Pisa (age 19–30, 17 females), volunteered for a study performed in accordance with the Declaration of Helsinki and completed questionnaires on trait anxiety (STAI-Y2) and on the ability of absorption in cognitive tasks (TAS). At least 2 months after hypnotic assessment, they participated in an experimental session consisting of watching a threatening movie none had seen before. At the end of the movie, 21 subjects reported decreased relaxation (responders, 12 women), whereas the remaining 13 subjects declared increased relaxation (non-responders, 5 women). STAI and TAS scores were similar in responders and nonresponders. On the occasion of the present reevaluation of their autonomic activity through RQA and DFA, performed 1 month after the experimental session, participants were asked to complete BIS/BAS scales (Carver & White, 1994). Since the latter evaluates trait differences, it is unlikely that the short time interval between heart-rate monitoring and the BIS/BAS scale completion biased the relation between subjective and cardiac variables. The reported changes in relaxation have been published elsewhere (Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012). They will be reconsidered in the following description of results in relation to BIS/BAS scales and to the indices of cardiac dynamics.

Signal Acquisition

An electrocardiogram (ECG) was recorded through Red DotTM 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 based on threshold on derivative signal (Taddei, Marchesi, & Landucci, 1984). An initialization phase, performed on a 20-second 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 originated by the sinus node (ectopic beats, spikes) were removed through a predictive filter with an adaptive threshold on prediction error (Varanini et al., 1993).

RQA Method

Recurrence Quantification Analysis (RQA) is a technique particularly suitable for the analysis of nonlinear and nonstationary data of almost any length, originally based on the visual inspection of the recurrence plot (RP; Eckmann, Kamphorst, & Ruelle, 1987) and successively made
quantitative by Webber and Zbilut (1994; Zbilut et al., 2002). In our analysis, RQA was applied to the RR series extracted from the ECG signals (for details, see Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012) using the Matrix Laboratory (MATLAB) Creating Recurrence Plots (CRP) toolbox (Marwan et al., 2002). Among the RQA indices extracted (see Appendix), we considered the recurrence rate (REC), determinism (DET), entropy (ENT), percentage of laminar states (LAM), and trapping time (TT).

**DFA Method**

DFA is aimed at characterizing the autocorrelation properties of a time series (see Appendix for more details). DFA produces one or more indices, called exponents, strictly related to the dynamics of the process that generates the series fluctuations. In cardiology studies, it was first applied to heart-rate time series derived from 24-hour electrocardiogram (ECG) recordings (ECG Holter monitoring). These studies demonstrated that the (HRV) can be characterized by unique dynamics along all the scales investigated or by the presence of a crossover separating two different dynamics, one for small scales up to about 11 cardiac beats (short-term dynamics) and a second for the remaining scales (long-term dynamics) expressed by the $\alpha_1$ and $\alpha_2$ exponents, respectively. In our study, DFA has been applied to the 30-minute intervals of the RR series and computed through ad hoc software (CNR, Institute of Clinical Physiology, Pisa).

**Statistical Analysis**

The SPSS.15 package was used to apply multivariate analysis of variance (MANOVA) to RQA (DET, ENT, REC, LAM, TT) and DFA ($\alpha_1$, $\alpha_2$) indices and to questionnaire scores (BIS and BAS$_{tot}$, which represents the sum of the BAS subscales scores), separately. Responsiveness to the threatening movie (responders, nonresponders), Hypnotizability (h highs, lows), and Gender (females, males) were between-subjects factors. Multinomial logistic regression was also performed on questionnaire scores to evaluate possible psychological predictors of Responsiveness. Pearson coefficients were computed between reported relaxation, questionnaire scores, and the cardiac indices showing responsiveness and/or hypnotizability and/or gender differences. Level of significance was set at $p < .05$.

**Results**

**Questionnaires**

TAS and STAI scores did not differ between responders and nonresponders; TAS scores were significantly higher in highs (Santarcangelo,
Figure 1. Behavioral Inhibition System and responsiveness: (a) significantly higher BIS scores in responders (black bar) than in nonresponders (white bar); (b) negative correlation between BIS scores and changes in relaxation (Δ rel). Four responders out of 20 are not well classified. Numbers in the figure area indicate superimposed subjects.

Paoletti, Balocchi, Scattina, et al., 2012. BIS scores (see Figure 1a) were significantly higher in responders than in nonresponders, F(1, 33) = 4.155, p < .05, and BAS_tot was similar in the two groups. BIS (see Figure 1b) exhibited a weak but significant negative correlation with the changes in relaxation (R = −.388, p < .023). As shown in Figure 1b, responders and nonresponders are well classified according to BIS scores (multinomial logistic regression analysis: B = 0.57, p < .043, exp(B) = 1.77). Mean values and standard deviations of questionnaire scores are reported in Table 1.

RQA and DFA Indices

Two subjects were excluded from the analysis of cardiac indices for their RQA outlier values.

Mean values and standard deviations of all indices are reported in Table 1. No significant effect was found for responsiveness and hypnotizability, but effect size was quite low (η² < .1). A trend toward significantly higher values of LAM in males than in females was observed, F(1, 31) = 4.163, p < .053, η² = .15.

Significant Responsiveness × Hypnotizability × Gender interactions concerned the following: REC, F(1, 31) = 5.411, p < .029, η² = .19; DET, F(1, 31) = 4.701, p < .041, η² = .17; ENT, F(1, 31) = 6.051, p < .022, η² = .21; LAM, F(1, 31) = 10.391, p < .004, η² = .31; and TT, F(1, 31) = 4.662, p < .042, η² = .17. Their decomposition revealed significantly lower values of REC, F(1, 6) = 10.051, p < .034, LAM, F(1, 6) = 22.357, p < .009, and TT, F(1, 6) = 7.169, p = .052, in females than in males among the highs of the nonresponders group (see Figure 2).
Table 1
*Questionnaires, RQA, and DFA Indices*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Responsiveness</th>
<th>Mean</th>
<th>SD</th>
<th>Gender</th>
<th>Mean</th>
<th>SD</th>
</tr>
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<tbody>
<tr>
<td>Questionnaires</td>
<td>TAS</td>
<td>R</td>
<td>20.95</td>
<td>6.18</td>
<td>F</td>
<td>21.80</td>
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<tr>
<td>(N = 34)</td>
<td>Non R</td>
<td>19.62</td>
<td>7.71</td>
<td>M</td>
<td>19.28</td>
<td>7.39</td>
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<tr>
<td></td>
<td>STAI</td>
<td>R</td>
<td>45.55</td>
<td>3.33</td>
<td>F</td>
<td>46.27</td>
</tr>
<tr>
<td></td>
<td>Non R</td>
<td>46.08</td>
<td>4.50</td>
<td>M</td>
<td>45.33</td>
<td>3.65</td>
</tr>
<tr>
<td></td>
<td>BIS</td>
<td>R</td>
<td>16.00</td>
<td>1.86</td>
<td>F</td>
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<tr>
<td></td>
<td>Non R</td>
<td>14.77</td>
<td>1.79</td>
<td>M</td>
<td>15.83</td>
<td>1.79</td>
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<tr>
<td></td>
<td>BAS_{tot}</td>
<td>R</td>
<td>22.65</td>
<td>8.74</td>
<td>F</td>
<td>23.87</td>
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<tr>
<td></td>
<td>Non R</td>
<td>25.23</td>
<td>4.78</td>
<td>M</td>
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<td>7.58</td>
</tr>
<tr>
<td>RQA</td>
<td>REC</td>
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<td>0.03</td>
<td>F</td>
<td>0.05</td>
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<td>(N = 32)</td>
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<td>0.02</td>
<td>M</td>
<td>0.05</td>
<td>0.02</td>
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<tr>
<td></td>
<td>DET</td>
<td>Non R</td>
<td>0.66</td>
<td>0.09</td>
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<td>0.66</td>
</tr>
<tr>
<td></td>
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<td>M</td>
<td>0.66</td>
<td>0.10</td>
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<tr>
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<td></td>
<td>R</td>
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<td>0.24</td>
<td>M</td>
<td>2.41</td>
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</tr>
<tr>
<td></td>
<td>LAM</td>
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<td>0.30</td>
<td>F</td>
<td>0.48</td>
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<td></td>
<td>R</td>
<td>0.56</td>
<td>0.37</td>
<td>M</td>
<td>0.66</td>
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<tr>
<td></td>
<td>TT</td>
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<td>2.88</td>
<td>0.81</td>
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</tr>
<tr>
<td></td>
<td>R</td>
<td>2.89</td>
<td>0.75</td>
<td>M</td>
<td>3.11</td>
<td>0.71</td>
</tr>
<tr>
<td>DFA</td>
<td>$\alpha_1$</td>
<td>R</td>
<td>1.10</td>
<td>0.26</td>
<td>F</td>
<td>1.06</td>
</tr>
<tr>
<td>(N = 32)</td>
<td>Non R</td>
<td>1.13</td>
<td>0.19</td>
<td>M</td>
<td>1.16</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>$\alpha_2$</td>
<td>R</td>
<td>0.93</td>
<td>0.11</td>
<td>F</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Non R</td>
<td>0.90</td>
<td>0.07</td>
<td>M</td>
<td>0.92</td>
<td>0.10</td>
</tr>
</tbody>
</table>

*Note.* R = responders; Non R = nonresponders.

Decomposition of the interactions for DET and ENT revealed significant Gender $\times$ Hypnotizability interactions among nonresponders, but subsequent analysis could not be performed owing to the very small number of subjects in each subsample of females and males. No significant effect was found for the DFA indices $\alpha_1$ ($\eta^2 < .1$) and $\alpha_2$ ($\eta^2 = .1$) (see Table 1). Controlling for TAS, STAI, BIS, and BAS, both separately and together, did not disclose further differences.

No significant correlation between questionnaire scores and cardiac indices were found in the entire sample as well as in responders and nonresponders. In contrast, after splitting responders and nonresponders by hypnotizability, we found different correlations in the four subsamples (see Figure 3). Among responders, correlations were present only in lows: TAS correlated significantly with LAM ($R = -.667$, $p < .50$), BIS with DET ($R = .743$, $p < .042$), and ENT ($R = .731$, $p < .025$), and BAS_{tot} with ENT ($R = .675$, $p < .046$). Among nonresponders, BAS_{tot} correlated positively with REC in highs ($R = .827$, $p < .042$) and with $\alpha_1$ in lows ($R = -.836$, $p < .038$).
Figure 2. Responsiveness \times Hypnotizability interaction. Mean values and SE of recurrence rate (REC), laminarity (LAM), and trapping time (TT) in responders (black bars) and nonresponders (white bars) of both genders (F, females; M, males) belonging to the highs and lows groups.

**DISCUSSION**

The RQA recurrence rate, indicating the percentage of recurrent points, is usually higher in a system with periodic than aperiodic dynamics; laminarity and trapping time reflect the percentage of laminar phases (that is, states in which the dynamics remains constant) and their mean duration. An increase of the above-mentioned RQA indices is expected at the increase of the system stability.

It has been shown that the heart-rate laminarity increases with parasympathetic withdrawal and with increased sympathetic tone, for instance, during upright stance (Javorka et al., 2009; Gonzales et al., 2013). Moreover, in both healthy subjects and chronic heart failure patients, increased sympathetic predominance is associated with higher HR laminarity (Gonzales et al., 2013).
Figure 3. Correlations of questionnaire scores and cardiac indices in the highs and lows subsamples of responders and nonresponders: Upper panels: abscissae, BIS scores; ordinate, RQA determinism (DET). Lower panels: abscissae, BAS scores; ordinate, RQA recurrence rate (REC, left) and DFA short-term fluctuation index ($\alpha_1$, right).

Responsiveness

Our findings do not explain the dissociation between subjective experience and cardiac dynamics during the threatening task because we did not find clear-cut significant differences between responders and nonresponders in cardiac indices, as already observed for the RR oscillatory variability (Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012). However, the low effect size of many comparisons may account for the few differences found. In contrast, for other comparisons, we have detected significant interactions in spite of low effect size, which indicates that the observed differences are highly reliable. Indeed, a few RQA indices—recurrence rate, laminarity, and trapping time—are able to characterize responsiveness as a function of hypnotizability and gender. In contrast, the indices extracted through detrended fluctuation analysis are not modulated by states (reported emotion) and only the activity of the BAS negatively correlates with the DFA short-term index of fluctuation.

Owing to the physiological processes that have been associated with a few RQA indices (Javorka et al., 2009; Gonzales et al., 2013), we suggest that the sympathetic activity developing during the threatening task is higher in highs among responders and in lows among nonresponders. The former finding can be accounted for by the greater
absorption in mental activities reported by the highs enrolled in the study (Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012) and generally observed in highs with respect to lows (Council & Green, 2004; Lichtenberg, Bachner-Melman, Ebstein, & Crawford, 2004; Tellegen & Atkinson, 1974). In contrast, the lows’ higher sympathetic involvement among nonresponders could be a consequence of the cognitive load experienced in the attempt to buffer the subjective negative experience potentially induced by the task. Finally, the lower sympathetic involvement of the highs in nonresponders could be accounted for by dissociation abilities (Dienes et al., 2009) present in at least part of the highly hypnotizable individuals (Terhune, Cardeña, & Lindgren, 2011) and allowing these subjects to escape from the unpleasant consequences of paying attention to the threatening task.

Finally, the lower laminarity observed in females with respect to males is in line with the widely described lower sympathetic tone in females (see Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012).

Correlational Analysis

Only the activity of the BIS predicts subjective responsiveness in that the higher the BIS score the lower the increase (nonresponders) or higher the decrease (responders) in relaxation.

In lows, high regularity (LAM) of the recurrence plot correlates negatively with absorption (TAS) and positively (DET, ENT) with the tendency to avoid potentially stressful situations (BIS) and the drive toward potential rewards and novel/pleasant experiences (BAStot) among responders, whereas no correlation between traits and cardiac indices was found in highs. Thus, the highs’ control over heart-rate dynamics could be more complex, and not efficaciously characterized by the studied psychological traits, or more independent of them. Among nonresponders, high regularity was associated with high activity of the BIS in highs, whereas high activity of the renin angiotensin system (related to α1) was associated with low activity of the BAS in lows.

In general, we wish to point out that heart dynamics are more influenced by psychological traits in nonresponders than in responders. Maybe in the latter the threatening content of the task buffered any potential cognitive-related control on the cardiac function.

A limitation of the study is the absence of medium hypnotizable participants. They were not included because in the present study we reevaluated a previously studied sample not including medium hypnotizables. The evaluation of other individual traits potentially interacting with the studied ones, such as optimism and locus of control (De Pascalis et al., 2013), and the assessment of the brain correlates of the heart dynamics would have greatly enhanced the relevance of the
results. At the moment, however, we can conclude that the subjective experience of responsiveness is associated with high activity of the BIS and that the regularity of heart dynamics, as measured by a few indices extracted by the Recurrence Quantification Analysis and by detrended fluctuation analysis, is influenced by cognitive-emotional traits, including hypnotizability.

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REFERENCES


APPENDIX

Recurrence Quantification Analysis (RQA)

RQA is a technique based on recurrence plot (RP) initially introduced as a purely qualitative technique by Eckmann, Kamphorst, and Ruelle (1987) and, successively, rendered quantitative by Charles Webber and Joseph Zbilut (1994). This technique is particularly suitable for the analysis of the complex dynamics of nonlinear and nonstationary data. RP
construction is a simple procedure, performed according to the tools of nonlinear dynamics. Nonlinear data analysis generally starts with the construction of the different states of the system (Phase Space) under consideration. Usually, in real world processes, not all the state variables are known or can be measured and often only a single representation of the process is known, that is, a monodimensional time series. However, using the Takens’s time delay embedding theorem (Takens, 1981), a Phase Space can be reconstructed starting from the monodimensional representation. The embedding procedure is performed as follows. The monodimensional time series \( \{x_i\} \) is embedded into an appropriate higher \( d \)-dimensional space where the system geometry can become completely unfolded. The generic \( d \)-dimensional point of the Phase Space is a vector of the following type:

\[
X_i = (x_i, x_{i+\tau}, \ldots, x_{i+(d-1)\tau}),
\]

where \( d \) is the dimension of the embedding space and \( \tau \) is a selected delay.

As the state of the system changes in time, the vector in the phase space describes a trajectory representing the time evolution of the system. The RP construction is then accomplished by checking the phase space to identify points that move close together, maintaining their distance below a cutoff value; if the \( d \)-dimensional point \( X_i \) is close to the \( d \)-dimensional point \( X_j \), a dot is placed in a square matrix at the position \( (i,j) \). Even though visual inspection of RP can, by itself, give some information on the dynamics of the series under investigation, it also contains features that can be easily quantified. According to the results obtained using the false near neighborhood technique (Kantz & Schreiber, 1998) and mutual information (Fraser & Swinney, 1986) to estimate suitable embedding dimension and time delay, respectively, we constructed the RR Phase Space using the values \( d = 10 \) and \( \tau = 1 \). In our analysis, RQA was applied to the RR series extracted from the ECG signals previously recorded (for details, see Santarcangelo, Paoletti, Balocchi, Scattina, et al., 2012) using the Matrix Laboratory (MATLAB) Creating Recurrence Plots (CRP) toolbox (Marwan et al., 2002). The RQA indices extracted from RP were the following: REC (Recurrence rate), corresponding to the probability that a specific state of the system will recur; DET (Determinism), related to the periodicities and predictability of the system; LAM (laminarity), related to the percentage of laminar phases, that is, states in which the dynamics remains constant; TT (trapping time), indicating the average time in which the system remains in a laminar state; ENT (entropy), strictly related to the complexity of periodic structures present in the RP.
**Detrended Fluctuation Analysis**

*DFA* is a technique aimed at investigating the long-range autocorrelation properties of fluctuating time series (self-similar-like time series) and is especially suitable when classical correlation analysis cannot be correctly applied (for instance, in highly nonstationary data). The degree to which the series shows correlation properties is measured by the DFA scaling exponent \(\alpha\). The DFA can be accomplished according to the steps briefly described below. The time series \(\{X_t, t = 1, 2, \ldots, n\}\) is first integrated and then divided into equal, nonoverlapping windows of length \(n\). Next, the least squares linear regression line, which represents the local trend, is computed in each window. The integrated series is detrended by subtracting this local linear trend. The detrended fluctuation \(F(n)\) is then defined as the root mean square of the locally detrended series. This procedure is repeated for increasing window sizes to obtain a relationship between the function \(F(n)\) and the window size \(n\). For self-similar-like signals, a power law relation exists between \(F(n)\) and \(n\), that is, \(F(n) < n^\alpha\) or, in other words, a linear relation exists such that \(\log(F(n)) < \alpha n\). The value \(\alpha\), computed with this simple logarithmic operation, ranges in the interval \(0 < \alpha \leq 1.5\) and characterizes different kinds of autocorrelation. A value of \(\alpha = 0.5\) indicates completely uncorrelated dynamics (i.e., white noise). When \(\alpha < 0.5\), the correlation is said *antipersistent*, that is, high values alternate with low values, while *persistence*, where high values are likely to be followed by still higher values, is present when \(0.5 < \alpha < 1\). The value \(\alpha = 1\) corresponds to the special case of \(1/f\) power law behavior present in a great variety of physical processes. Values ranging between \(1 < \alpha < 1.5\) characterize fractional Brownian motion while a value \(\alpha = 1.5\) is obtained for Brownian motion.

**Paradoxe Antwort auf eine emotionale Herausforderung: Eigenschaften und Herzfrequenz-Dynamiken**

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**Abstrakt:** Die aktuelle Studie evaluierte die Herzfrequenzdynamiken von Personen, die am Ende eines bedrohlichen Films weniger (responder) oder paradoxerweise erhöhte Entspannung (nonresponders) angaben. Die Herzfrequenzdynamiken wurden durch Meßwerte gekennzeichnet, die durch recurrence quantification analysis (RQA) und detrended fluctuation analysis (DFA) erhoben wurden. Diese Meßwerte wurden als Funktion einiger individueller Merkmale untersucht: Hypnotisierbarkeit, Geschlecht, Aufnahmepotential, Ängstlichkeit und der Aktivität der behavioral inhibition and activation systems (BIS/BAS). Die Ergebnisse zeigten, daß: (a) die subjektive Erfahrung der Antwortsfähigkeit mit der
Aktivität des behavioral inhibition Systems assoziiert ist und (b), daß einige RQA und DFA Messwerte den Einfluß von kognitiv-emotionalen Merkmalen bezüglich der Reaktion auf eine bedrohliche Situation, einschließlich der Hypnotisierbarkeit, aufzeigen können.

Stephanie Reigel, MD

Réaction paradoxe à une tâche émotionnelle: traits caractéristiques et dynamique de la fréquence cardiaque

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Résumé: La présente étude a évalué la dynamique de la fréquence cardiaque de sujets signalant une relaxation diminuée (sujets répondants) ou une relaxation paradoxalement accrue (sujets non-répondants) à la fin d’un film d’épouvanter. La dynamique des fréquences cardiaques a été caractérisée par des index extraits au moyen d’une analyse de quantification de récurrence (RQA) et d’une analyse de fluctuation détendue (DFA). Ces index ont été étudiés en fonction de quelques facteurs particuliers: hypnotisabilité, sexe, absorption, anxiété et activité des systèmes d’activation et d’inhibition comportementaux (BIS/BAS). Les résultats ont montré que: (a) l’expérience subjective de la réceptivité est associée à l’activité du système d’inhibition comportemental; et (b) certains indices RQA et DFA sont capables de saisir l’influence des traits cognitifs-affectifs, y compris l’hypnotisabilité, sur la réceptivité à une tâche menaçante.

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Respuesta paradójica a una tarea emocional: Características de rasgo y dinámicas del ritmo cardíaco

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Resumen: El presente estudio evaluó las dinámicas del ritmo cardíaco en sujetos que reportaron una disminución (respondientes) o paradójicamente mayor relajación (no respondientes) al final de una película amenazante. Las dinámicas del ritmo cardíaco se caracterizaron a través de índices obtenidos a partir del Análisis de Cuantificación de Recurrencia (RQA) y el Análisis de Fluctuación Sin Tendencia (DFA). Estos índices fueron estudiados como una función de pocas características individuales: hipnotizabilidad, género, absorción, ansiedad, y la actividad de los sistemas de inhibición y activación conductual (BIS/BAS). Los resultados muestran que: (a) la experiencia subjetiva de respuesta se asocia con la actividad del sistema de inhibición conductal; y (b) unos cuantos índices RQA y DFA son capaces de capturar la influencia de rasgos cognitivo-emocionales, incluyendo hipnotizabilidad, sobre las respuestas ante una tarea amenazante.

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