Short communication

The Hurst exponent of cardiac response to positive and negative emotional film stimuli using wavelet

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ABSTRACT

We examined the Hurst exponent of heart rate time series and its relation with the subjective measures of valence and arousal in two groups of subjects. The electrocardiogram (ECG) and the subjective valence and arousal were measured during the administration of emotional film stimuli (happiness, sadness, anger and fear). The results showed that there is a difference in the Hurst exponent for the happiness and sadness conditions but not between the negative emotion conditions (sadness, anger and fear). This seems to indicate that the Hurst exponent is an indicator of subjective valence.

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1. Introduction

Several contemporary studies have provided evidence supporting the hypothesis of the autonomic specificity of emotions such as fear, anger, disgust, happiness and sadness (Ekman et al., 1983; Levenson et al., 1990; Levenson, 1992; Roberts and Weerts, 1982; Schwartz et al., 1981; Christie and Friedman, 2004; Rainville et al., 2006). Another approach to the differentiation of emotions that has received considerable empirical support is based on a dimensional model of subjective emotional experience (Russell, 1980). According to this model, the emotional space can be described by two dimensions. The first dimension, valence (positive and negative), refers to the subjective feeling of pleasantness or unpleasantness. The second dimension, arousal (high and low), refers to the subjective feelings of activation or deactivation of the body. However, this large body of literature has not yet led to consistent conclusions regarding the existence of specific peripheral activities related to the emotions (Cacioppo et al., 2000).

Several different computational techniques have been developed to characterize the cardiovascular activity by means of heart rate variability (HRV) to study the emotions and the relationship between mental and physiological processes (Malik and Camm, 1995; Huikuri et al., 1990; Yeragani et al., 1991; Rainville et al., 2006).

These methods are useful and promising, but suffer from a basic drawback: they cannot properly manage the irregularities present in most of the signals; they simply ignore the irregularities or deemed them as originating from a random external source. One approach to investigate these irregularities is fractal analysis. Fractality refers to the feature of some stochastic time series that present temporal self-similarity (González and Pereda, 2004).

In order to observe fractal self-similar behaviour, several tools have been developed such as power law spectrum in log frequency vs. log power plots, detrended fluctuation analysis and the Coarse-Graining Spectral Analysis technique (Mandelbrot, 1982; Goldberger and West, 1987; Katz, 1988; Glenny et al., 1991; Pincus et al., 1991; Yeragani et al., 1993, 2000; Plamen et al., 1999; Kobayashi and Musha, 1982; Saul et al., 1987; Yamamoto and Hughson, 1991).

Another powerful method of fractal analysis that could be used without any assumption about the stationarity of the signal and that could reveal the irregular characteristic of the signals is the wavelet transform (Mallat, 1998).

The aim of the study is to investigate the Hurst exponent of the cardiac response to emotional and neutral film stimuli using the wavelet transform and to explore whether there are emotion-specific characterizations of the Hurst exponent in the cardiac signal. The prediction is that if there are emotion-specific characterizations we will find different Hurst exponent values for the different emotional states.

2. Methods

2.1. Participants

Sixty right-handed volunteers (30 male, 30 female; mean age = 27.6, SD = 5.35) took part in the study. All subjects had no personal history of neurological or psychiatric illness, no drug or alcohol abuse, no current

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medication, and had normal or corrected-to-normal vision. Handedness was assessed with the "measurement of Handedness" questionnaire (Chapman and Chapman, 1987). All subjects were informed about the scope and design of the study and gave their written consent for participation. The Ethics Committee of the Department of Psychology of the University of Turin approved the study.

2.2. Film clips

One hundred film clips with neutral, positive, and negative emotional content of happiness, sadness, anger and fear were selected from commercial movies which, in our judgment, were likely to elicit these specific emotional states (expected emotions). The stimuli obtained were tested on a sample of judges ($N = 30$), who labelled the emotion experienced during the vision of films and rated the valence and the arousal on a Likert scale ranging from 0 to 10. There was high concordance between the expected and the self-reported emotions (k-Cohen = .89, $p < .001$). Each stimulus lasted 128 s.

2.3. Questionnaires

The questionnaire was based on the method applied by Gross and Levenson (1995). Participants rate the strongest emotion that was experienced during the film.

Participants were asked to complete an 8-item emotion self-report inventory. The first six items (based on the discrete emotion model) were the label of the following discrete emotions: anger, fear, happiness, disgust, sadness and surprise. The last two items (based on the dimensional model) were label of the valence and the arousal. The subjects indicate on a 9-point Likert (0–8) scale the greatest amount of each emotion he experienced while watching the film clip. On this scale, for the discrete emotions 0 means "you did not feel even the slightest bit of emotion" and 8 means "the most you ever felt" and for the dimensional items the participants have to rate the feeling from unpleasant (0) and pleasant (8) and the valence from negative (0) to positive (8).

We also allow participants to rate any other emotion they may have felt during the film by suggesting the option "other emotion". We also ask whether they looked away during the film and in this case the subjects were not considered in subsequent analyses.

2.4. Apparatus

The electrocardiogram (ECG) was recorded in a LEAD II configuration. All signals were amplified by a bio-signal amplifier (band pass 0.3–70 Hz) and A/D converted at 256 Hz per channel with 12-bit resolution and 1/8–2 µV/bit accuracy.

2.5. Procedure

Subjects were seated in comfortable chairs in a temperature-controlled, dimly lit room during electrode attachment and throughout the recording. Upon obtaining informed consent, subjects were told that the study concerned media communications and they were to watch a number of film clips paying close attention and avoiding any distraction and movements. At the beginning, heart rate was recorded at rest for 5 min in front of the blank screen. Subjects were tested individually and randomly assigned to two groups, balanced between male and female, who were subjected to different experimental conditions.

The reason for using two separate groups of subjects is that by examining two pairs of emotions separately, it is possible to avoid interference effects and overlap phenomena among successively induced different emotions, and the experimental sessions were not too long. Therefore it was possible to reduce the effects of changes in attention or motivation.

Both groups watched three clips. The first group watched the neutral clip, the happiness clip, and the sadness clip. The second group watched the neutral clip, the fear clip, and the anger clip. The neutral clip was always presented as the first. The order of presentation of the two emotional clips was randomised within each group. The questionnaire was completed after each stimulus to assess the subjective emotional responses during the film clip presentations. Each question was displayed on the screen and the subjects were told to type their answer on a keyboard placed in front of them. After completion of the self-report, there followed a rest period ranging from 30 s to 1 min to allow the heart rate to return to the baseline level. All the stimuli were presented without sound on a 21 in. CRT screen positioned 2 m in front of the subject.

2.6. Data reduction

A peak detection algorithm determined the temporal position of the R-waves. The presence of artefacts was checked manually, although no abnormalities were found in any subject. The R–R intervals were then calculated as the time interval between two consecutive R-waves. Then the R–R interval data were re-sampled at 4 Hz using Berger's method (Berger et al., 1986). The wavelet transform of cardiac signals and the Hurst Exponent were calculated for each subject and condition. The Hurst exponent of each experimental condition was corrected for the baseline value of each subject, in order to obtain the Hurst change score occurring during the vision of stimuli compared to rest (condition minus baseline).

3. Results

The results of the analysis of the questionnaires showed that the emotional states induced in the subjects correspond to the expected emotions. Target emotions were correctly identified (happiness clips = 93.1%, sadness clips = 79.2%, anger clips = 70.0%, fear clips = 90.5%) with high concordance between expected and the self-reported emotions (k-Cohen = .77, $p < .001$).

Repeated measures ANOVA with subjective valence and arousal as dependent variables were performed in film clips (neutral, happiness, sadness, anger and fear) within-subjects factor ($\alpha = 0.05$). When the assumption of sphericity was not met, unadjusted degrees of freedom and Greenhouse–Geisser adjustment and adjusted p-value were reported in the omnibus tests.

The analysis revealed a main effect of the film clip for the valence and the arousal level [$F(1.7, 39.2) = 204.3$; $p < .001$; $\eta^2 = .9$]. The post-hoc analysis showed that the happiness clips and the sadness clips were significantly different for valence (happiness mean = 7.38, SD = 1.24; sadness mean = 1.17, SD = .59; $t(29) = 26.8$, $p < .001$), whereas the fear clips and anger clips were significantly different for arousal (fear mean = 5.48, SD = 1.76; anger mean = 7.36, SD = 1.96; $t(27) = 5.2$, $p = .000$). All the emotional clips were significantly different with respect to the neutral clips. It was confirmed that the happiness clips and the sadness clips differ in their levels of pleasantness, whereas the anger clips and fear clips in the arousal level.

Two repeated measures ANOVA with Hurst score as dependent variables were performed in which film clips (neutral, happiness, sadness) for the first experimental group and (neutral, anger and fear) for the second experimental group were considered as within-subjects factor ($\alpha = 0.05$). (see Fig. 1). The Mauchly test confirmed the assumption of sphericity. Results of univariate effects were significant for the happiness and sadness clips ($F(2; 58) = 10,46$; $p < .001$; $\eta^2 = .26$). The same analysis performed on the Hurst change score for the experiment of anger and fear did not turn out to be significant ($F(1.7, 52.7) = .65$; $p < .5$). A post-hoc analysis with Bonferroni correction for multiple comparisons showed a difference between neutral and happiness (mean difference = $-.051$; $p < .001$), and between happiness and sadness (mean difference = .031; $p < .05$), with the happiness
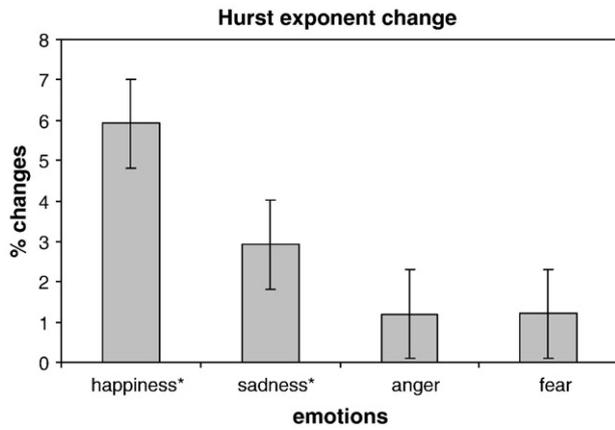
Hurst exponent change

Fig. 1. Mean of Hurst exponent change for each of the four emotional conditions. Emotions sharing an asterisk are significantly different from each other according to planned pairwise contrasts ($p < .05$). Note: error bars are standard error of the mean.

response exhibiting a higher value. In order to check whether the subjects of the two groups tended to react differently to stimuli, the two groups were compared performing a t-test for independent samples on the Hurst change score of the response to the neutral film clips: results did not show a significant difference ($p < .01$), confirming that the variation of response was comparable between groups.

4. Discussion and conclusion

This study provides evidence that happiness and sadness films are associated with different Hurst exponents. Negative emotional states do not differ in the Hurst exponent and the different emotions (happiness, sadness, fear and anger) were distinguished from the neutral control condition. This result seems to indicate that the structural changes in physiological signals were related to the subjective valence of the emotional experiences. The results support the hypothesis that the structural organization of cardiac signals is a discrete feature that switches between negative and positive emotions. Specifically, an increase in the fractal dimension seems to be a marker of positive emotions, whereas the other negative emotions all exhibited a lower Hurst change score. These results are consistent with a model describing emotions as a circumplex model (Larsen and Diener, 1992; Russel, 1980). According to this model, fear and anger are characterized by a similar measure of valence (negative), whereas happiness and sadness have different measures of valence. This finding is also consistent with the results obtained by Barrett and Russel (1998), who showed that valence was independent of arousal. Further, Barrett (2006) showed that valence is a basic, invariant building block of emotional life deriving from the human mind's capacity to engage in the process of valuation or judging whether something is helpful or harmful.

These results suggest that autonomic processes can contribute to the encoding and probably the experience of the emotional stimuli. In this research we did not try to find an invariant relationship between emotional experience and physiological response, but rather for what conditions and emotions differential physiological activity is observed. The results are clear: the Hurst exponent discriminates between negative and positive emotions and showed the existence of a valence-specific physiological pattern as in the meta-analysis of Cacioppo et al. (2000).

Further, the measure of subjective arousal and valence judgment on emotional response to stimuli confirmed that participants experienced the emotions and identified them according to expectations (happiness, sadness, fear, anger, neutral), hence the validity of the film clip as an induction method was confirmed.

The present study provides data in support of the application of non-stationary analyses of cardiac signals. The measure adopted here

was the Hurst exponent, which apparently is able to detect the variations occurring in emotional processes with different valences. Thus, the Hurst exponent seems to be a robust estimator of the relationship between cardiac activity and emotional experiences. This suggests that there should be more investigations of physiological signals in emotional states, using new methods of analysis like the one proposed here. In conclusion, this study shows that the investigation of the Hurst exponent by wavelet transform method was able to reveal the specific properties of cardiac signals related to the valence of emotional responses.

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