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An Entropy Measure of Emotional Arousal via Skin Conductance Response

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Abstract

Whether different affective states have specific physiological activation patterns still does not have an exact interpretation and clear validation. Skin Conductance Response (SCR) is under strict control of the autonomic nervous system, providing an efficient way to measure the emotional reactions. Since the emotional SCR signals are always short and noisy, it is of great value to study the methods suitable for short-term SCR analysis. According to the characteristic of SCR signal, we proposed a symbolic method and the symbolic information entropy, further, applied the method to analyse emotional SCR signals. Experiment results show that the symbolic information entropy of SCR is in accordance with the arousal level of emotions, and SCR is more sensitive to the variations of emotional arousal rather than to valence. Symbolic information entropy is less influenced by noise and non-stationary, providing an effective method in analyzing SCR signals or other complex physiological signals.

Keywords: Skin Conductance Response; Affective Computing; Symbolization; Information Entropy

1 Introduction

Researches on emotion have shown that autonomic responses vary according to reports of affective valence (i.e. pleasant or unpleasant) and arousal (i.e. calming or stimulating), which are two motivational determinants of emotions [1]. Skin Conductance Response (SCR) provides readily accessible autonomic indices, since SCR is under strict control of the sympathetic branch of the nervous system. SCR reflects the change in skin conductance caused by rapid fluctuations in eccrine sweat gland activity, which is the result of the liberation of acetylcholine by the sympathetic nervous system [2]. Many researchers have demonstrated [3-5] a tight relationship between emotional reactions and SCR. When an emotion-inducing events occurs, sympathetic nerve activity will rise to dominance, which is reflected in the increase of sweat gland secretion. By calming down the emotion, sympathetic tension decreased, and parasympathetic activity increased, thereby the sweat gland secretion decreased. This regulation process is very complex and differs in different affective states. Moreover, other factors, cognition activities, for instance, also have noticeable functions to

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SCR. Although we know that emotional events may raise the physiological arousal and organ's activation, however, whether different affective states have specific physiological activation patterns still does not have an exact interpretation and clear validation. In this study, we wanted to observe whether different emotions could induce specific SCR patterns, both on valence and arousal states.

Since SCR is nonlinear and non-stationary, more intensive analysis should be done to get a better understanding of the underlying dynamic condition. In addition to conventional linear methods, many nonlinear dynamical methods and complexity measures have been used in analyzing the SCR. These studies are helpful in revealing the potential law and physical nature of the emotional and cognitive activities. Common methods include Lyapunov exponent, correlation dimension, multi-fractal spectrum, and entropy measures as well [6-9]. Entropy first appeared in macroscopic thermodynamics, and Boltzmann makes entropy has a microscopic meaning of the molecular level. Although Shannon entropy was proposed for information theory, it has a general meaning. In a broader sense, Boltzmann entropy in thermodynamics is a special case of Shannon information entropy. Entropy is no longer confined to the thermodynamic and molecular thermal motion, but the nature of uncertain events. Information entropy and its variants are widely used to describe the irregularity of various signals [10-13]. Among them, approximate entropy (ApEn) and sample entropy (SampEn) are most commonly used in measuring the complexity of biological data [14, 15]. ApEn measures the "likelihood that runs of patterns that are close remain close on next incremental comparisons", and has been suggested to measure the complexity of short data sets [16, 17]. Richman and Moorman [15] discussed some shortcomings of ApEn, and they pointed out that ApEn includes a bias towards regularity inherently, as it will count a self-match of vectors. SampEn was recommended as an algorithm to counteract the shortcomings of ApEn [15]. Increase in SampEn is often associated in increases in complexity. However, Luiz et al. [18] showed the strong limitation of SampEn as a complexity metric. They found that a shuffled version of the Heart Rate Variability (HRV) series is often assigned with higher values of SampEn than the original HRV series, quite the opposite expected from a complexity measurement, for the SampEn values of HRV series of healthy subjects are often lower than that of the atrial fibrillation ones. In addition, Yentes et al. [14] demonstrated that both ApEn and SampEn are extremely sensitive to parameter choices, especially for very short data sets, $N \leq 200$. In stead of analyzing the complexity of original time series, symbolic information entropy measures the complexity of symbol sequence of SCR signals. Symbolization is an important means of dynamical system analysis. Its significance lies in coarse-graining off part of the details, while retaining the interesting part [19]. Guzzetti et al. [20] transformed HRV series into a symbol sequence of six symbols and found that the rates of occurrence of the patterns of three successive symbols are useful in describing the short-time fluctuations. Appropriate coarse graining helps to obtain more rigorous conclusions. The greatest advantage of symbolization is less sensitivity to the noise, and the key part of the application is how to differentiate right symbol area to properly coarse grain the signal.

The emotional SCR signals are always short and noisy, so in order to observe the SCR patterns induced by different emotional events, we proposed a dynamic symbolic method of time series and the symbolic information entropy, which are applicable in the short-term SCR analysis. Firstly used four symbols to portray the SCR fluctuations, further used symbolic information entropy to indicate the complexity of SCR symbolic sequences. The study found that emotional events induce skin conductance responses varying according to arousal, but not to valance. Thus, SCR measurement may offer a way to perceive the intensity of personal emotional feelings, but it is hard to know whether the emotion is positive or negative by SCR alone.