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Differences in photoplethysmography morphological features and feature time series between two opposite emotions: Happiness and sadness

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Abstract It has been well established that change in emotion state is associated with the change in physiological signals. This paper aimed to investigate the differences of finger photoplethysmography (PPG) morphological features and feature time series between happiness and sadness emotion states. Fifty-three volunteers were enrolled. Finger PPG signals were recorded under two emotion states with a random measurement order (first happiness emotion measurement then sadness or reverse). Seven morphological features were extracted, including three temporal features (T, T_1 and T_2), three area features (A, A_1 and A_2) and one amplitude feature (Amp). Five variability indices from the 5-min feature time series were calculated, including two time-domain indices (SDNN and RMSSD) and three frequency-domain indices (LFn, HFn and LF/HF). Results showed that temporal features T_2 and T were critical features for identifying the two emotion states since not only they themselves but also their three frequency-domain variability indices had significant differences between the two emotion states. For area features, only two frequency-domain variability indices of LFn and HFn for A_1 feature time series reported significant differences. Amplitude feature Amp itself, as well as its variability indices, did not had significant differences between the two emotion states. These results indicated that temporal features were more sensitive to response to emotion change than area and amplitude features. Moreover, compared with time-domain variability indices, frequency-domain variability indices were more suitable for short-term 5-min time series analysis for exploring the inherent but slight change due to the emotion effect.

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Introduction

Emotion recognition plays an important role in human-to-human and human-to-computer interaction. For example, it can alert sleepy drivers and pilots with low vigilance based on the predicted user's emotional states.[1] Emotions are involved various responses of multi channels such as facial expressions, tone of voices and mental thoughts expressed by words.[2–4] Emotions are also accompanied by changes of physiological signals. Moreover, physiological signal-based emotion evaluation has many advantages, such as the measurement is simple and insensitive to social and cultural differences since physiological responses are involuntary and can't be easily induced by conscious controls.[5] A strong correlations exist between emotion states and physiological signals.[6] Previous researches also proved that physiological signal-based emotion recognition has the similar accuracy compared with the emotion recognition using audio or visual measures extracted from facial and vocal expressions.[7,8]

Currently, a variety of physiological signals are used for emotion recognition studies, to identify or classify different emotion states, such as happiness, sadness, fear, anger, *etc*.[9–11] Typical signals include electrocardiography (ECG), electroencephalography (EEG), photoplethysmography (PPG), respiration, galvanic skin resistance (GSR), skin temperature (SKT), blood volume pressure (BVP), heart rate (HR), electromyogram (EMG), *etc*.[12] Employed classification algorithms usually include support vector machine (SVM),[13,14] linear discriminant analysis (LDA),[15,16] random forests,[16] *etc*. Chang et al. collected ECG, GSR, BVP, respiration and pulse signals and used SVM to classify three emotions (sadness, fear and pleasure), achieving a recognition rate of 89.2%.[17] Park et al. analyzed SKT and PPG signals, and obtained the classification accuracy of 92.41% for classifying happiness and sadness emotions by using SVM.[18] In addition, physiological changes under different emotions were also explored to find out the features with significant differences among different emotion states.[19] Quintana et al. suggested that increased HRV may provide a novel marker to recognize emotions.[20] Lee et al. used PPG instead of ECG or EEG signal, which also verified the change of HRV was related to the change of emotion states.[21]

PPG signals have been widely used in clinical measurement since they are easy and convenient to be collected. Although many PPG features, as well as many variability indices from the PPG feature time series, have been studied in the past decades, their usefulness in emotion identification is still not deeply explored. In this study, we aimed to compare the finger PPG morphological features, as well as the variability indices of the feature time series, between two opposite emotion states: happiness and sadness, to test the discernibility of these features and variability indices for differentiating the happiness and sadness emotion states.

Methods

Subjects

Fifty-three healthy volunteers (27 females and 26 males) were recruited in this study. None of them was reported having any cardiovascular history, mental illness, or alcohol record, according to the Hospital medical report. All subjects signed the informed consents before the experiment. The study received ethical permission from Shandong University and the Second Affiliated Hospital of Jining Medical College in China by the Ethical Affairs Committee. Table 1 depicts the basic information for all involved 53 subjects.

Emotion stimulating materials

Two videos (each about 7 min) were selected to evoke two opposite emotion states for the subjects: happiness and sadness. The video for stimulating happiness emotion is 'Joyous Comedy Person (a happy sketch)', and the video for stimulating sadness emotion is 'I Want a Family (a touching movie)'. Compared with the stimulating materials from images and sounds, videos are more suitable and easier for evoking subjects' emotions since video stimuli have the desirable properties of being readily standardized, involving no deception, and being dynamic rather than static.[22] Video stimuli also have a relatively high degree of ecological validity.[22]

Data collection

PPG signals were recorded using RM6240B system (Chengdu Instrument Factory, Chengdu, China) with a sample rate of 1000 Hz. During the experiment, the subjects sat in a reclining chair with their hands placed comfortably at their sides. The experimental protocol is depicted in Fig. 1 and is summarized as follows:

First, subjects were asked to rest quietly about 10 min. Then they were attached by PPG sensors to the index finger of the right hand. Subjects were asked to remain relaxation during the experiment. In the emotion-stimulating period, subjects watched the two videos. At the same time, the equipment recorded the PPG signals for 5 min for each emotion state. The order of playing the two videos was random. In order to avoid the interaction, there was a gap for at least 5 min between the two videos playing.

Data preprocessing and features extraction

High-frequency interference and baseline drift in PPG signal were filtered by a sym8 wavelet filter.[23] PPG feet and

Table 1 Basic information of all 53 subjects.

Variables	Value
No.	53
Female/Male	27/26
Age (year)	24 ± 1
Height (cm)	168 ± 8
Weight (kg)	59 ± 11
Body mass index (kg/m^2)	21 ± 2
Heat Rate (beats/min)	71 ± 9
Systolic blood pressure (mmHg)	119 ± 15
Diastolic blood pressure (mmHg)	71 ± 10

Note: data are expressed as numbers or mean ± standard deviation (SD).