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Statistical Examination of Specific Spectral Intensity-Ratio Zone (SIRZ) to Characterize Alcohol Intake

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***Abstract*- The authors already proposed an advanced and reliable alcoholic-intake detection method by analysing the photoplethysmogram (PPG) signals, where the specific spectral-intensity ratio zone (specific SIRZ) to characterize the alcohol intake was demonstrated. However, the zone definition is not ensured from the point of view of statistics. This paper statistically examines the reliability of specific SIRZ definition.**

Keywords*- *Photoplethysmogram; Alcohol Intake Detection; Specific Spectral-Intensity Ratio; Statistical Examination

I. INTRODUCTION

In trying to noninvasively detect alcohol intake, many studies have focused on optical analysis of the photoplethysmogram (PPG) signal [1-6]. This approach is attracting more attention from the viewpoint of its many medical applications [2, 7]. The studies referenced attempted to suppress the uncertainty inherent in the raw data representing the PPG signals including the information of blood-pulse wave, which is due to diverse factors including body posture and age [8, 9].

This paper investigates how the alcohol-intake-oriented spectra of the PPG signal can be extracted from the original PPG signal. This paper studies the impact of smoking on the PPG signal [10]. Our approach is to convert the PPG signal into the frequency-domain by fast-Fourier-transformation (FFT) processing [8, 9, 11, 12]. Based on statistical analysis, this paper demonstrates the importance of observing the respiratory spectrum of the PPG signal [13]. We also demonstrate the viability of the specific 'spectral intensity ratio zone (SIRZ)' [13] in detecting alcohol intake.

II. EXPERIMENTAL METHOD AND SETUP

Measurement system and experimental conditions are shown in Fig. 1. This is identical to those described in the previous paper [12]. The PPG signal is converted into the frequency domain by FFT processing after the source signal is linearly amplified by an operational amplifier. Since the intensity of the original spectra is so large, the following analysis considers square-root values. PPG signals were measured with various LEDs as the optical source; the primary wavelength is in the range of ~ 935 nm for "infrared", ~ 660 nm for "red", ~ 470 nm for "blue", and ~ 525 nm for "green". However, we will stress the advantages of green-LED-based photoplethysmography in the following discussion because of its superior performance [6, 12].

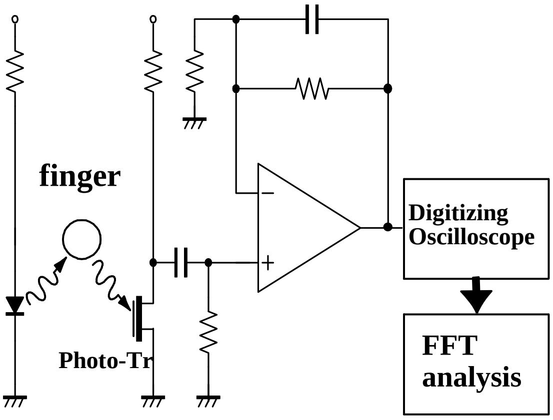

Fig. 1 Experimental setup

III. RESULT AND DISCUSSION

A. *Aspects of FFT spectra with alcohol intake and/or smoking for smokers*

Various FFT spectra of PPG signals with the green LED are shown in Fig. 2; Fig. 2(a) shows the spectral intensity profile

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of a smoker with and without alcohol intake, but without smoking, Fig. 2(b) shows the spectral intensity profile of a smoker with and without smoking, but with alcohol intake, and Fig. 2(c) shows the spectral intensity profile of a smoker with alcohol intake and smoking, or without alcohol intake and smoking. Figure 2(a) reveals that alcohol intake makes high-frequency shifts of the spectra without smoking, but that it does not alter the intensity of the primary spectrum; this is an important characteristic for smokers. Fig. 2(b) clearly shows that the smoking also yields the blue shift, but that it drastically reduces the spectral intensities of the primary and the 2nd harmonics without alcohol intake. Fig. 2(c) shows an important result; smoking with alcohol intake blue shifts the spectra, but the spectral intensities of the primary and the 2nd harmonics are drastically reduced [10]. The smoking overwhelms the influence of alcohol intake on the PPG spectra.

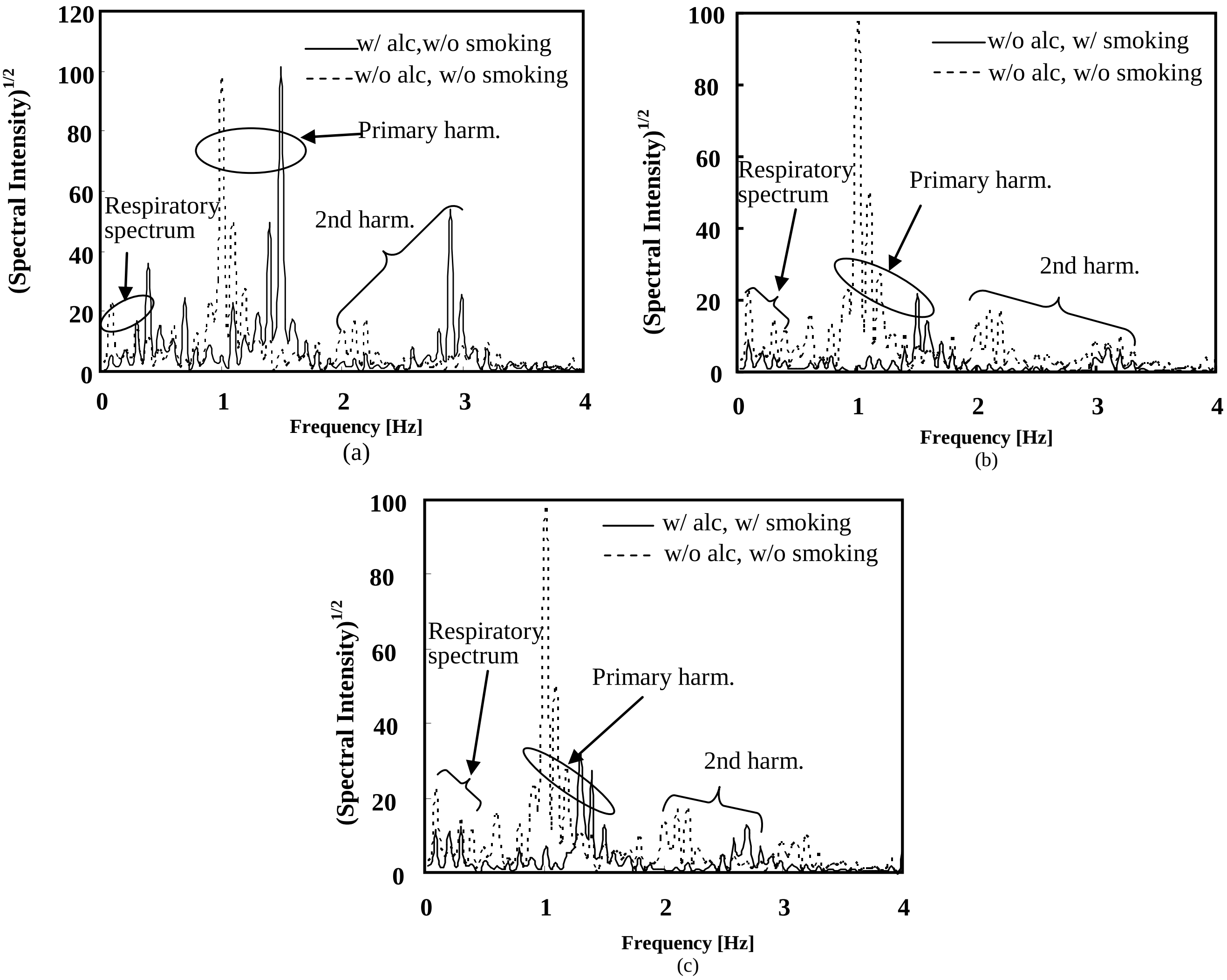

Fig. 2 Spectral intensities of PPG signal with the green LED (a) Spectra of PPG signal (smoker), (b) Spectra of PPG signal (smoker), (c) Spectra of PPG signal (smoker).The source data were obtained from two 22-year old subjects (male).

B. Statistical verification of universality of specific SIRZ to exclude smoking impact

We defined two harmonic ratios as

$$I_{PP} / I_{BP} = \frac{[\text{Primary harmonic spectral intensity of pulsation}]^{1/2}}{[\text{Respiratory spectral intensity}]^{1/2}}, \tag{1}$$

$$I_{BP} / I_{SP} = \frac{[\text{Respiratory spectral intensity}]^{1/2}}{[\text{Second harmonic spectral intensity of pulsation}]^{1/2}}, \tag{2}$$

and examined the correlation between these harmonic ratios of pulsation and respiratory spectrum from the data of 8 subjects (5 smokers and 3 non-smokers) as shown in Fig. 3(a). Note that most values of the two harmonic ratios with alcohol intake lie in the specific SIRZ (the broken line box). Fig. 3(a) reveals that the concept of specific SIRZ is viable in detecting alcohol intake regardless of smoking. Here, we reviewed all the data plotted in Fig. 3(a) because we must reconsider the statistical reliability of the specific SIRZ defined above. We averaged the spectral intensity ratio of the 8 each subjects over 2

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hours and extracted the variance of data. In Fig. 3(b), the averaged data points are replotted and the standard deviations are indicated by the horizontal and vertical bars. In Fig. 3(c), we averaged that of 8 all subjects and replotted. It is seen that all the averaged points with symbols of closed circles and closed triangles are inside the specific SIRZ. However, a couple of the standard-deviation bars for the closed circles and closed triangles lie out of the zone, and a couple of the standard-deviation bars for the open triangles are inside the zone. This suggests that the specific SIRZ is still incomplete. It is suggested that the incompleteness of the specific SIRZ is due to some unknown impact of smoking. In other words, we must utilize the behaviour of respiratory signal. Since the respiratory signal is also influenced by the physical exercise, we have to take account of features of impact of physical exercise on the respiratory spectrum.

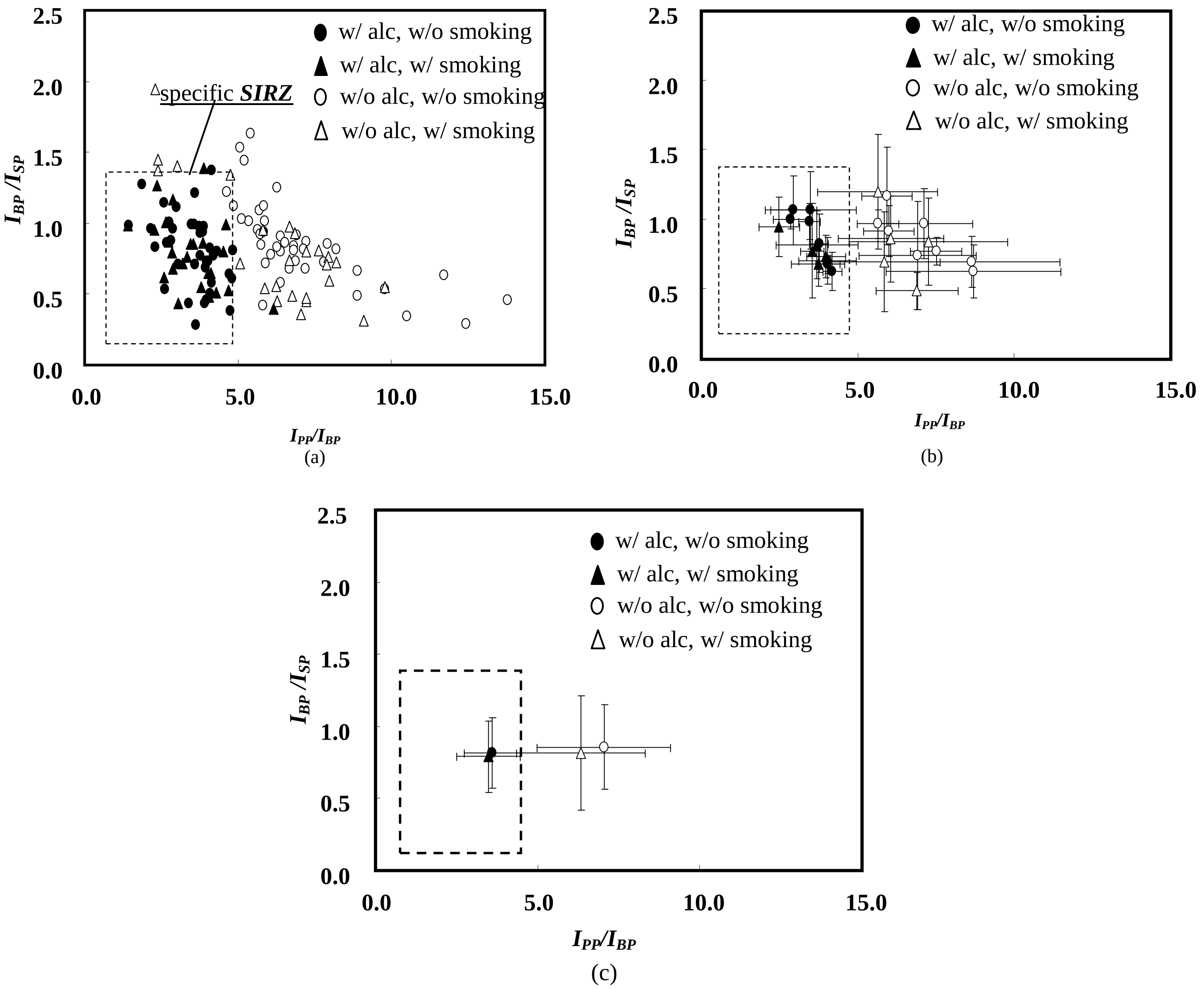

Fig. 3 Correlation between spectral intensity ratios (5 smokers and 3 nonsmokers, green LED) (a) Correlation between raw data of spectral intensity ratios (b) Statistical point of view of spectral intensity ratios. All data are taken from Fig. 3(a) (c) Statistical assessment of new parameters defined with eqs. (1) and (2). All data are taken from Fig. 3 (a).

C. Advanced SIRZ to exclude influence of physical exercise

To take account of the influence of physical exercise, we redefined two deferent harmonic ratio using oxygen saturation level (SpO_2) in artery [14, 15] as

$$RS_{PB}\left(\frac{I_{PP}}{I_{SP}}\right)=\frac{[\text{Primary harmonic spectral intensity}]^{1/2}}{[\text{2nd harmonic spectral intensity}]^{1/2}[\text{Respiratory spectral intensity}]^{1/2}[\text{SpO}_2]^6}, \tag{3}$$

$$RS_{BS}\left(\frac{I_{PP}}{I_{SP}}\right)=\frac{[\text{Primary harmonic spectral intensity}]^{1/2}[\text{Respiratory spectral intensity}]^{1/2}}{[\text{2nd harmonic spectral intensity}]^{1/2}[\text{SpO}_2]^6}. \tag{4}$$

We examined the correlation between $RS_{PB}/(I_{SP}/I_{PP})$ values and $RS_{BS}/(I_{SP}/I_{PP})$ values extracted from the data of 8 volunteers (5 smokers and 3 non-smokers) as shown in Fig. 4(a). Fig. 4(a) reveals that the advanced ratio data with

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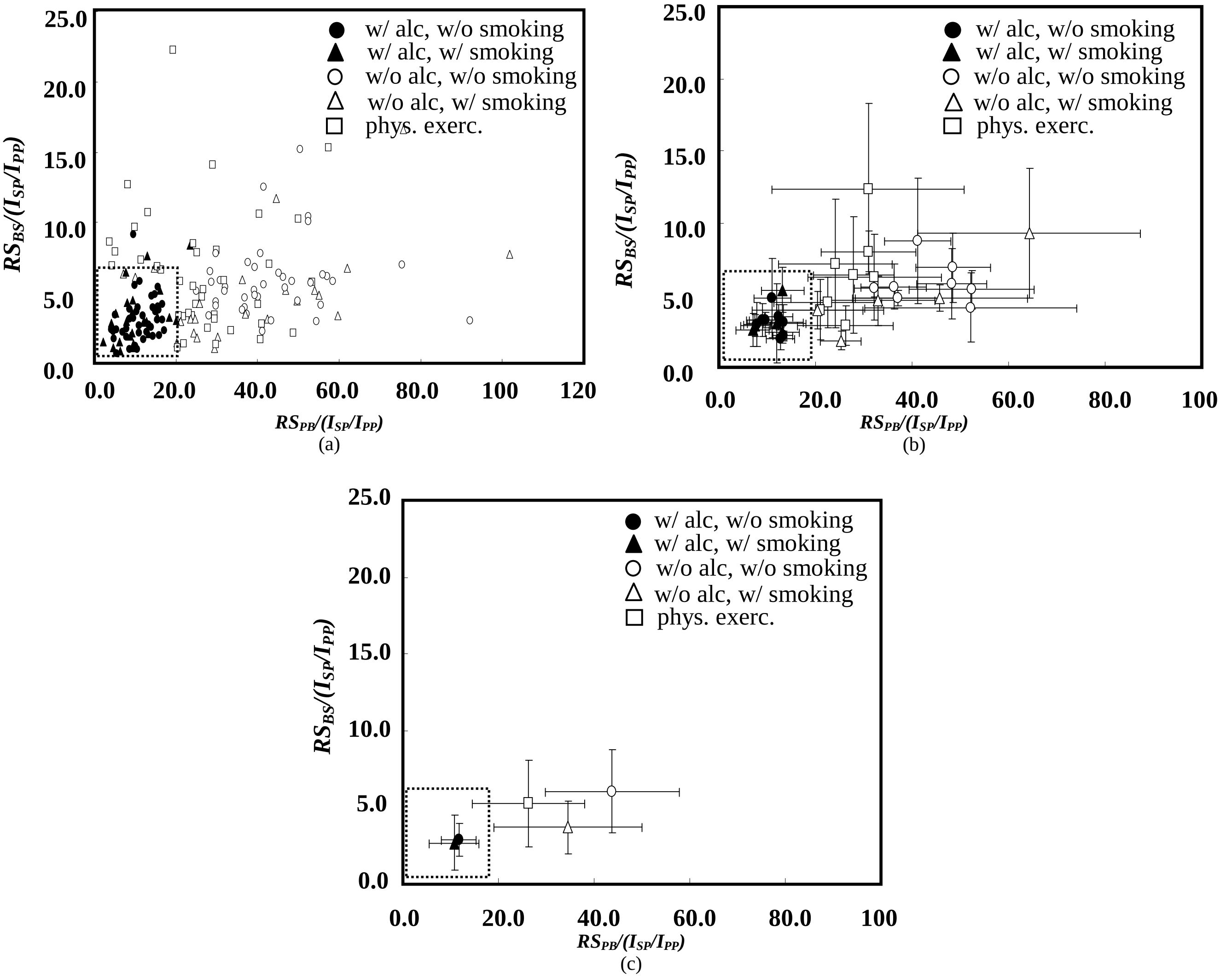

Fig. 4 Correlation between spectral intensity ratios and statistical consideration (5 smokers and 3 nonsmokers, green LED) (a) Correlation between raw data of spectral intensity ratio, (b) Statistical point of view of spectral intensity ratios All data are taken from Fig. 4(a), (c) Statistical assessment of new parameters defined with eqs. (3) and (4). All data are taken from Fig. 4(a)

Alcohol intake lie only in the specific SIRZ (see the broken line box), which demonstrates that the technique proposed here has great potential in detecting alcohol intake with regardless of smoking and/or physical exercise. Finally we also statistically examined the data plotted in Figs. 4(b) and 4(c) in the same manner as those in Figs. 3(b) and 3(c). Note that a couple of the standard deviation bars for the closed square and closed triangles lie out of the zone, and a couple of the standard-deviation bars for the open triangles and squares are inside the zone. This is because the harmonic ratios change unexpectedly by smoking or physical exercise and their standard deviation is also influenced by such behaviour of pulsation and breathing. Such unknown factors must be analysed in detail in the future.

IV. CONCLUSION

This paper examined the correlation between harmonic ratios of PPG signal based on statistical analysis to validate the reliability of the alcohol intake detection method using specific SIRZ. To achieve noninvasive alcohol-intake detection regardless of smoker and non-smoker, we discovered that specific SIRZ is critical. However as observed in Figs. 3(b) and 4(b), raw data of smoking and physical exercise still suggest a drawback of this method from statistical point of view. Individual deference, for example, their tolerance of alcohol intake and their ability to exercise, should be considered with BMI values to demonstrate more reliable method [16]. The great advantage of the new algorithm proposed here is also demonstrated statistically though the number of subjects is still small. We have to challenge this method with more volunteers in order to examine its reliability. In addition, it is anticipated that the PPG signal of pulsation is distorted by noise and body motion, so we will apply independent component analysis (ICA) to digital signal processing algorithms to obtain low-noise PPG signals [15]. Generally speaking, it is known that young subjects have a larger second harmonic spectrum than old subjects [9]; this suggests that the present algorithm to separate the data after alcohol intake should be slightly altered. Since the volunteers are 22-23-year-old in this study, we will obtain PPG signal data from older subjects in the future.

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