Chapter 35
Gender and Age Analyses of NIRS/STAI Pearson Correlation Coefficients at Resting State

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Abstract According to the valence asymmetry hypothesis, the left/right asymmetry of PFC activity is correlated with specific emotional responses to mental stress and personality traits. In a previous study we measured spontaneous oscillation of oxy-Hb concentrations in the bilateral PFC *at rest* in normal adults employing two-channel portable NIRS and computed the *laterality index at rest* (LIR). We investigated the Pearson correlation coefficient between the LIR and anxiety levels evaluated by the State-Trait Anxiety Inventory (STAI) test. We found that subjects with right-dominant activity at rest showed higher STAI scores, while those with left dominant oxy-Hb changes at rest showed lower STAI scores such that the Pearson correlation coefficient between LIR and STAI was positive. This study performed Bootstrap analysis on the data and showed the following statistics of the target correlation coefficient: mean = 0.4925 and lower confidence limit = 0.177 with confidence level 0.05. Using the KS-test, we demonstrated that the correlation did not depend on age, whereas it did depend on gender.

Keywords NIRS • STAI • Pearson correlation coefficient • Bootstrap analysis • Kolmogorov-Smirnov test

1 Introduction

The valence asymmetry hypothesis [1–3], asserts that the left/right asymmetry of prefrontal cortex (PFC) activity is correlated with specific emotional responses to mental stress and personality traits. Electroencephalography (EEG) has demonstrated that subjects with greater relative left PFC activity shows more positive and

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less negative dispositional mood than their right-dominant counterparts. In contrast, right frontally activated subjects respond more to negative affective challenges and less to positive affective challenges than their left dominant counterparts [4, 5].

Near-infrared spectroscopy (NIRS) is a noninvasive method for monitoring neuronal activity by measuring changes of oxyhemoglobin (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) concentrations in cerebral vessels [6–8]. In [9], we proposed a new information criterion LIR (*Laterality Index at Rest*) defined in terms of oxy-Hb concentration changes from the right and left PFC at resting condition:

$$LIR = \frac{\sum_{t \in analysis\ \ interval} ((\Delta oxyR_t - oxyR_{min}) - \ (\Delta oxyL_t - oxyL_{min}))}{\sum_{t \in analysis\ \ interval} ((\Delta oxyR_t - oxyR_{min}) + (\Delta oxyL_t - oxyL_{min}))} \quad (35.1)$$

where $\Delta oxyR_t$ and $\Delta oxyL_t$ stand for oxy-Hb concentration changes of the right and left PFC, whereas $\Delta oxyR_{min}$ and $\Delta oxyL_{min}$ are respective minimum values. Thus, LIR computes the degree of the right/left asymmetry of oxy-Hb concentration changes normalized between [−1,+1]. It is to be noted that LIR always converges, because the denominator is always non-negative. We demonstrated that there is a positive Pearson Correlation Coefficient between LIR and STAI-1 (State Anxiety of State-Trait Anxiety Inventory). A subject at rest is referred to as a subject is not performing any explicit task so that no task experimental design is necessary.

There were at least two issues for improvements over [9]:

1. The number of data as was small.
2. Parametric form of the probability distribution of Pearson Correlation Coefficient was difficult to obtain.

The purpose of this study is threefold:

(a) We will use bootstrap method [10] which is non-parametric in that no assumption is assumed about parametric form of the probability distribution of Pearson Correlation Coefficient and additional bootstrapped samples can be drawn. This could "robustify" the positive Pearson Correlation Coefficient.
(b) We will show that distribution of Pearson Correlation Coefficient does not depend on age by using Kolmogorov-Smirnov test.
(c) We will also show that distribution of Pearson Correlation Coefficient for male subjects appear different from that of female subjects, again by Kolmogorov-Smirnov test.

2 Material and Methods

2.1 Material

There were two groups consisting of young and aged subjects. The details are given in Table 35.1.

2.2 Experimental Protocol

The experimental protocol consists of the following:

1. STAI 1 questionnaire
2. Calibration
3. 1 min. preparation
4. 3 min. resting (analysis period)

The equipment used in this study was Pocket NIRS, Hamamatsu Photonics K.K., Japan for measurements of the concentration changes of oxy-Hb in the PFC. This system is wireless (Bluetooth®); such that the subject could move relatively freely. It is equipped with two channels where each uses light emitting diodes with wavelengths 735, 810, and 850 nm as light sources and one photo- detector. Two AAA batteries are used which can operate up to 8 h of continuous measurement for the two-probe operation. The sampling rate was 61.3 Hz. The concentration changes of hemoglobin were expressed in arbitrary units (a.u.). The NIRS probes were set symmetrically on the forehead with a flexible fixation pad, so that the midpoint between the emission and detection probes was 3 cm above the centers of the upper edges of the bilateral orbital sockets. The distance between the emitter and detector was set at 3 cm. This positioning is similar to positions Fp1 (left) and Fp2 (right) of the international electroencephalographic 10–20 system. Magnetic resonance imaging (MRI) confirmed that the emitter-detector was located over the dorsolateral and front polar areas of the PFC.

Table 35.1 Details of the subjects participated in the experiment

Gender/age	Male	Female	Total
Young (20–24)	6	13	19
Aged (60–69)	4	16	20
Total	10	29	39

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2.3 Bootstrap Algorithm

One of the methods of "robustifying" the results under such circumstances is the bootstrap algorithm [6]. The bootstrap algorithm is non-parametric in that it does not assume any parametric form of a target probability distribution. It is one of the resampling methods *with replacements* such that many samples become available. Since it assumes no parametric form for target distributions, it is flexible for problems with unknown or difficult target distributions. It has been widely used in practical problems.

In order to explain the concept, consider Fig. 35.1 where the number of available data is n and each data is two dimensional consisting of LIR and STAI 1 from each subject. Bootstrap algorithm [10] draws B samples with replacement as demonstrated on the right hand side of the figure. The number of samples B in the experiment to be reported later, for instance, was 10,000. From those samples, we compute Pearson Correlation Coefficient between LIR and STAI 1 for each sample i, $i = 1, \ldots, B$, and draw histogram of the Pearson Correlation Coefficients. Given the histogram, one can compute confidence interval http://en.wikipedia.org/wiki/Statistical_hypothesis_testing.

2.4 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test quantifies the distance between the empirical distribution functions of two datasets xi, i = 1,. . .,n, yj , j = 1,. . .,m. The empirical density and empirical distribution functions of the target random variables X and Y are defined as:

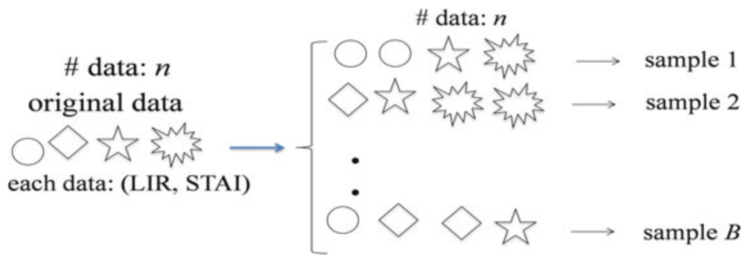

Fig. 35.1 A schematic of Bootstrap Algorithm

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$$X_i(x) = \begin{cases} 1 & (x_i \leq x) \\ 0 & (x_i > x) \end{cases}, \ F(x) := \frac{1}{n}\sum_{i=1}^{n} X_i(x)$$
$$Y_j(x) = \begin{cases} 1 & \left(y_j \leq x\right) \\ 0 & \left(y_j > x\right) \end{cases}, \ G(x) := \frac{1}{m}\sum_{i=1}^{m} Y_j(x)$$

The test statistic is

$$D := \sup_{-\infty < x < \infty} |F(x) - G(x)| \tag{35.2}$$

The null hypothesis here is that the two data come from the same distribution. It is to be rejected at level α if

$$\sqrt{\frac{-(n+m)log(\alpha/2)}{2nm}} < D \tag{35.3}$$

otherwise, there is no reason to reject the null hypothesis.

3 Results

3.1 Bootstrap Histogram of the Pearson Correlation Coefficient

With the number of bootstrap samples 10,000, confidence level $\alpha = 0.05$, we obtained the following:

Mean = 0.4925
Upper confidence limit = 0.738
Lower confidence limit = 0.177

This indicates that the Pearson Correlation Coefficient between LIR and STAI-1 would be positive at least for the current dataset.

3.2 Kolmogorov-Smirnov Test for Pearson Correlation Coefficient Between LIR and STAI-1 Among Young and Aged Subjects

Recall D defined in (35.2). With confidence level $\alpha = 0.05$,

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$$\sqrt{\frac{-(n+m)log(\alpha/2)}{2nm}} = 0.278 > D = 0.255$$

so that Pearson Correlation Coefficient *does not depend on age* at least among the present datasets.

3.3 Kolmogorov-Smirnov Test for Pearson Correlation Coefficient Between LIR and STAI-1 Between Male and Female Subjects

With confidence level $\alpha = 0.05$,

$$\sqrt{\frac{-(n+m)log(\alpha/2)}{2nm}} = 0.0136 < D = 0.0327$$

Therefore, Pearson Correlation Coefficient for male and female come from *different distributions* at least among the present datasets. One cannot, however, draw conclusions of how the two distributions are different at this stage.

4 Conclusions

We have attempted to "robustify" our previous result on the positivity of the LIR/STAI-1 Pearson Correlation Coefficient by using Bootstrap Algorithm. Since the algorithm is non-parametric and since the number of bootstrapped samples was reasonably large, the result was statistically robust. We have also used the Kolmogorov-Smirnov test together with the Bootstrap Algorithm to show that the probability distribution of the LIR/STAI-1 Pearson Correlation Coefficient does not appear to depend on age. Finally, we have demonstrated that the Kolmogorov-Smirnov test reveals that the Pearson Correlation Coefficient for male and female come from different distributions at least among the present datasets. One cannot, however, draw conclusions about how the two distributions are different at the moment.

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