近紅外光訊號雜訊與假影
fNIRS Noise & Motion Artifacts

盧家鋒 助理教授
alvin4016@ym.edu.tw

本週課程內容

- Noise & Motion Artifacts
- Motion correction techniques

- [NeuroImage 2014] Motion artifacts in functional near-infrared spectroscopy: A comparison of motion correction techniques applied to real cognitive data
- [Frontiers in Neuroscience 2012] A systematic comparison of motion artifact correction techniques for functional near-infrared spectroscopy

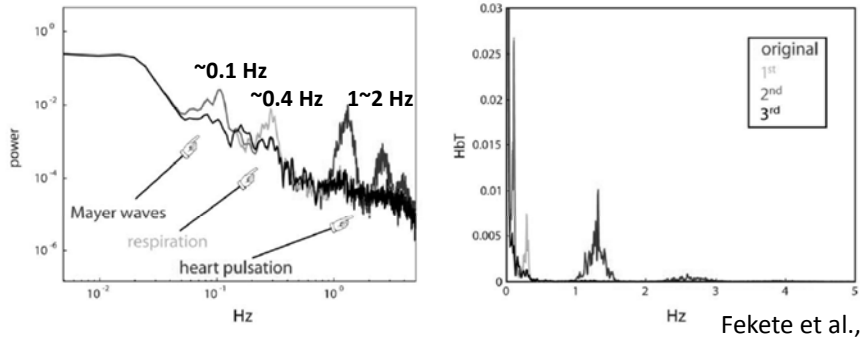
雜訊與運動假影
Noise & Motion Artifacts

Common noise in fNIRS

- Physiological components
  - Heartbeat, respiration, and blood pressure
- High frequency noise
  - Hair interference
  - The contact of optodes to the head
- Motion artifacts

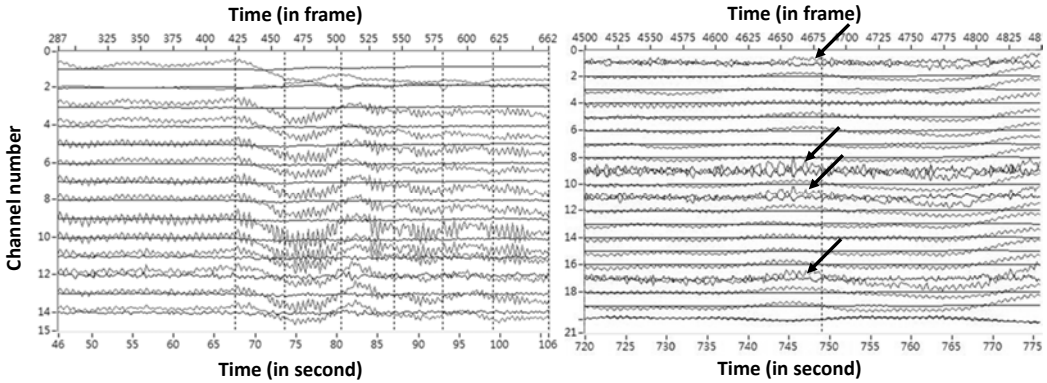
Physiological components

- Heartbeat, respiration, and blood pressure (Mayer waves)



Fekete et al., 2011.

High frequency noise



Motion Artifacts

- Movement of head, eyebrows, or the jaw
  - A decoupling between the source/detector optodes and the scalp
- Signal artifacts
  - A high-frequency spike
  - A shift from the baseline intensity
  - Low-frequency variations

Motion Artifacts

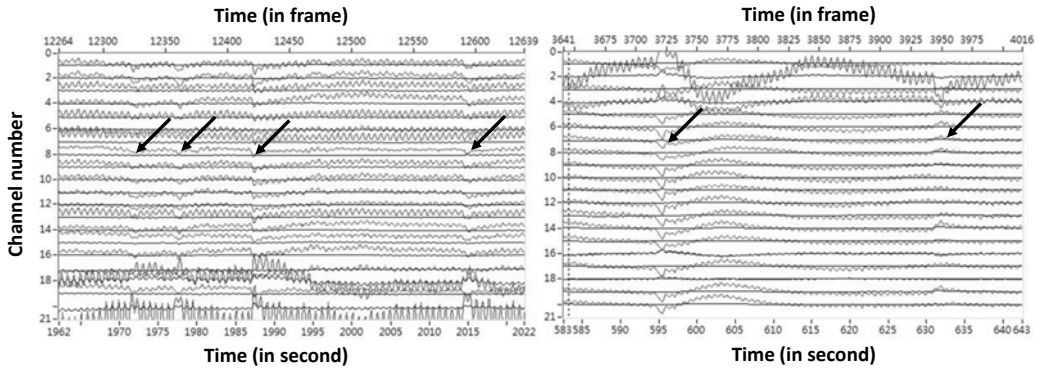
- Different shapes, frequency content, and timing
- High amplitude, high frequency spikes
  - Easily detectable
- Lower frequency content
  - Be harder to distinguish from normal hemodynamic signals
- Data-dependent motion correction technique is demanded

Motion Artifacts

- Variations between machines, subjects and channels
- Machines with miniature design
  - Little inertia in inducing optode-scalp discoupling
- Participants with less hair
  - Fiber holder placed more tightly to the head
  - Less artifacts motion
- Channel variation

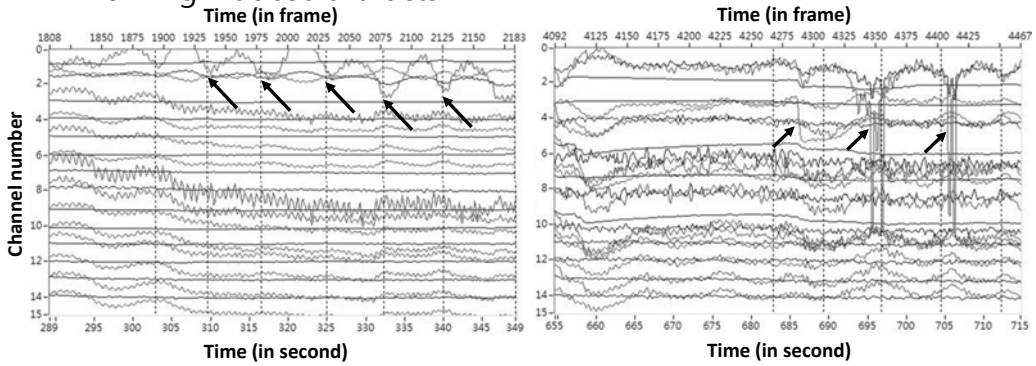
Cross channel artifacts

- Induced by head movement



Noise/artifacts

- Turning induced artifacts



運動假影校正技術
Motion correction techniques

Generate motion artifacts

- Real data with motion artifacts
- Simulate motion artifacts
  - Scholkmann et al., 2010
- Move head purposely
  - Izzetoglu et al., 2010; Robertson et al., 2010
- Add a simulated HRF to resting-state data
  - Cooper et al., 2012

Motion Correction Techniques

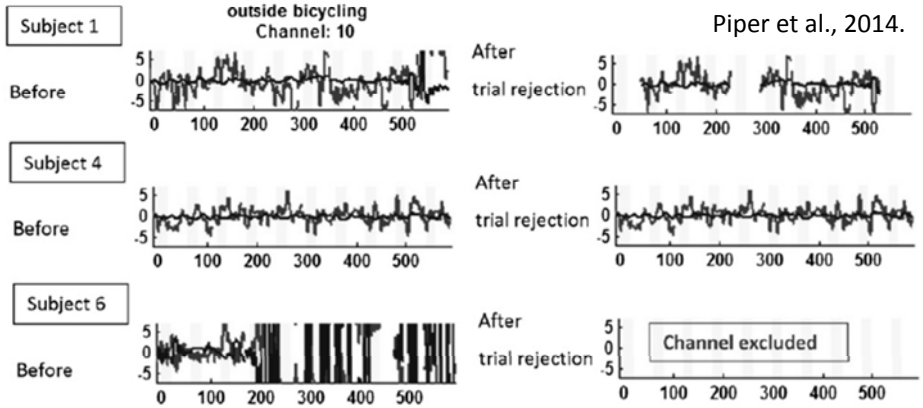
- Channel/Trial rejection
  - The number of survived trials
  - May not be suited for the challenging populations (e.g. infants, clinical patients, and children)
- Correction with complementary measures
  - A short-separation channel
  - An accelerometer
- Post-processing techniques
  - Inherent changes in the amplitude and frequency

Channel/Trial Rejection

- Coefficient of variation (CV)
  - $CV = \frac{\sigma}{\mu} \times 100\%$ μ is the mean value of the signal; σ is he standard deviation of the signal
- Channel CV (CV_{chan})
  - Reject channels with CV_{chan} >15 %
- Trial CV (CV_{trial})
  - Reject trials with CV_{trial} >5 %

Piper et al., 2014.

Channel/Trial Rejection



Piper et al., 2014.

Post-processing Techniques

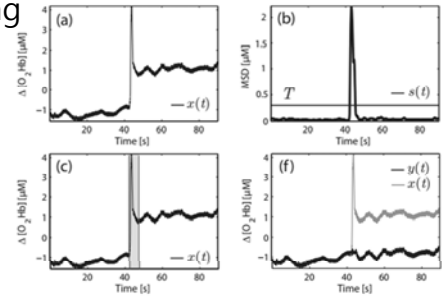
- Spline interpolation
  - Scholkmann et al., 2010
- Principal component analysis (PCA)
  - Zhang et al., 2005
- Wavelet filtering
  - Molavi and Dumont, 2012
- Correlation-based signal improvement (CBSI)
  - Cui et al., 2010
- Kalman filtering
  - Izzetoglu et al., 2010

Spline Interpolation

Baseline shift correction

- A channel-by-channel approach
- Detect artifact segment by the moving standard deviation.
- The period of motion artifact is then modeled via a cubic spline interpolation.
- Substract the interpolation from the original signal.
- Adjust mean value.

Scholkmann et al., 2010



Principal Component Analysis

Based on signal variance

- Orthogonal transformation
  - N-measurement original data set ➔ N uncorrelated components
- The order of components is related to the variance of the data.
  - First component ➔ largest proportion of the variance of data

Principal Component Analysis

Based on signal variance

- Motion artifacts creates larger changes in amplitude than normal physiological signals
  - constitute a large proportion of the variance of the data
- It is supposed that the first M components will represent the variance caused by the motion artifacts.
  - Removing the first M components from the signal should correct for the motion artifacts.

Zhang et al., 2005; Wilcox et al., 2005.

Wavelet filtering

Wavelet coefficient distribution

- A channel-by-channel approach
- Assumptions of wavelet filtering
  - The measured signal is a linear combination of the physiological signal of interest and the artifacts.
  - The wavelet coefficients have a Gaussian probability distribution.
  - The hemodynamic response is smoother and slower than motion artifacts.

Molavi and Dumont, 2012.

Wavelet filtering

Wavelet coefficient distribution

- The coefficients accounting for the evoked response will be centered around zero and with low variance, while the outliers of the Gaussian distribution are the coefficients accounting for the motion artifacts.
- reconstructing the signal with the inverse discrete wavelet transform without outlying coefficients.

Molavi and Dumont, 2012.

Correlation-based signal improvement

Negative correlation between HbO and HbR

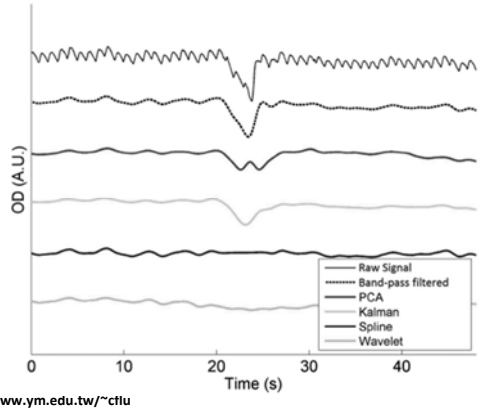
- A channel-by-channel approach
- Assumptions
  - The HbO and HbR signals should be negatively correlated during functional activation.
  - They become more positively correlated when a motion artifact occurs.

$$\begin{cases} x = x_0 + \alpha * F + Noise \\ y = y_0 + F + Noise \end{cases} \quad \begin{cases} x_0 = (x - \alpha * y)/2 \\ y_0 = -(1/\alpha) * x_0 \end{cases} \quad \alpha = std(x)/std(y)$$

Cui et al., 2010.

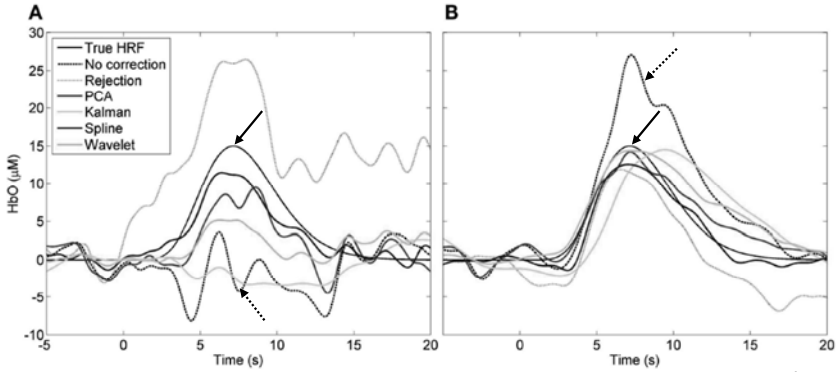
Comparisons

- Simulated dataset
- Bandpass filtered of 0.01 ~ 0.5 Hz



Cooper et al., 2012.

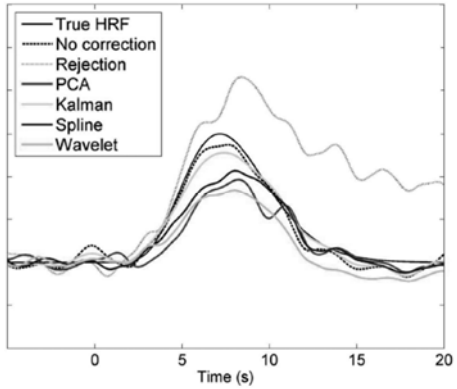
Comparisons



Cooper et al., 2012.

Distortion by correction

- For the data without motion artifacts, correction techniques may insert an extra signal distortion, though it may be little.

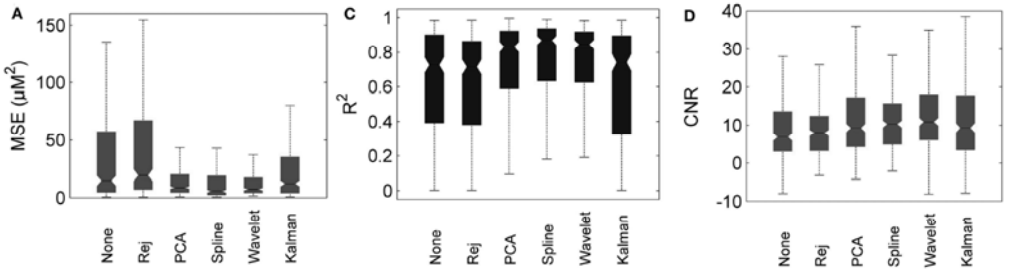


Cooper et al., 2012.

Comparisons Results

- True vs. corrected HRF
  - Mean-squared error, MSE
  - Pearson's correlation coefficient (R^2)

Cooper et al., 2012.



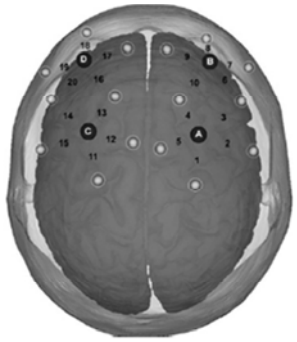
Test dataset

- Real data acquired during a cognitive linguistic paradigm
  - A task related, low frequency artifact with amplitude comparable with that of the HRF.
  - Motion artifact is caused by the jaw movement during the vocal response.

Color naming task

Good Data Quality Poor

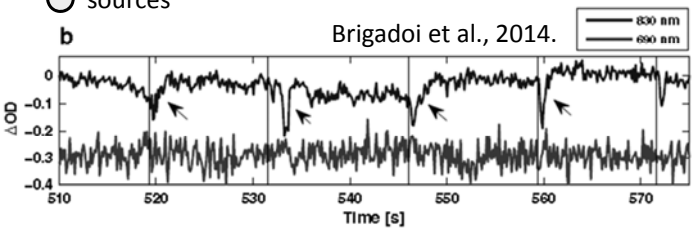
Jaw Motion Artifacts



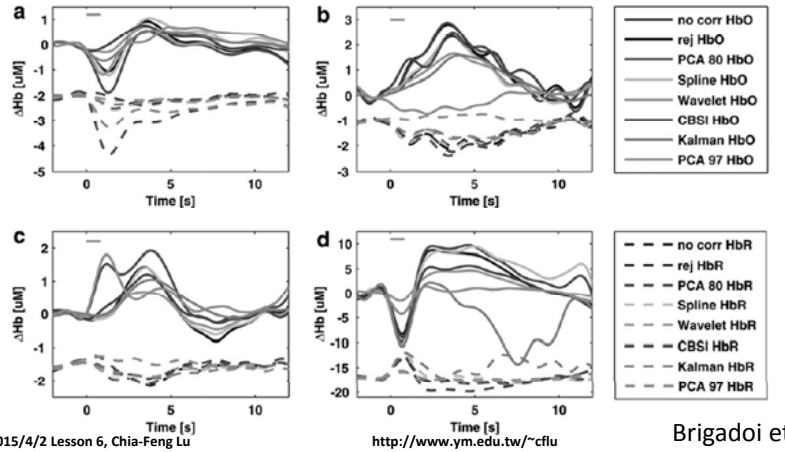
- The motion artifact is correlated to the task.

detectors
sources

Brigadoi et al., 2014.



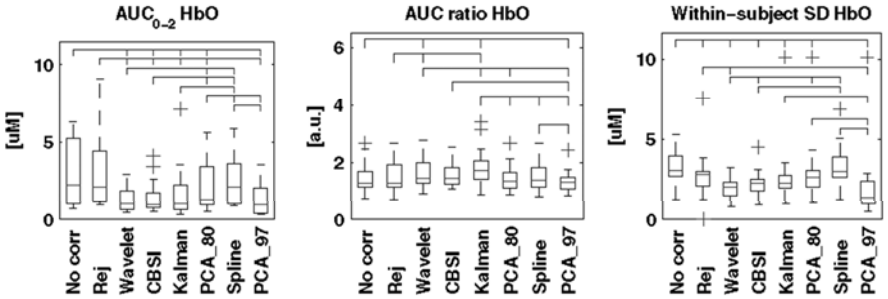
Comparison Results 4 subjects



Brigadoi et al., 2014.

Comparison Results

- AUC: area under curve
- AUC ratio = $AUC_{2\text{-}4}/AUC_{0\text{-}2}$



Brigadoi et al., 2014.

Suggestions

- It is always better to correct for motion artifacts than reject trials.
- **Spline interpolation** is useful for the spike and baseline shift corrections.
- **Wavelet filtering** and **PCA** are two effective approaches to correct most kinds of artifacts.

THE END

alvin4016@ym.edu.tw