HMS(Hemodynamic Modality Separation Method)

"Separation of fNIRS Signals into Functional and Systemic Components Based on Differences in Hemodynamic Modalities", T.Yamada, et al. 2012 PLOS ONE

Method：

ΔHbO: *measured oxy* ΔHbR: *measured deoxy*

ΔHbO_F ΔHbR_F ***functional component of oxy,deoxy***

ΔHbO_S ΔHbR_S ***systemic component of oxy,deoxy***

Source of oxy,deoxy are separated to functional and systemic components.

$$\begin{pmatrix} \Delta\mathrm{HbO} \\ \Delta\mathrm{HbR} \end{pmatrix} = \begin{pmatrix} \Delta\mathrm{HbO_F} \\ \Delta\mathrm{HbR_F} \end{pmatrix} + \begin{pmatrix} \Delta\mathrm{HbO_S} \\ \Delta\mathrm{HbR_S} \end{pmatrix} \quad (1)$$

ASSUMPTION(1)：
functional components of oxy and deoxy are negatively correlated
systemic components of oxy and deoxy are positively correlated

$$\Delta\mathrm{HbR_F} = k_F \Delta\mathrm{HbO_F} \text{ where } -1 < k_F < 0.$$
$$\Delta\mathrm{HbR_S} = k_S \Delta\mathrm{HbO_S} \text{ where } k_S > 0. \quad (2)$$

ΔHbO_F ΔHbR_F are expressed by ΔHbO ΔHbR

ΔHbO_S ΔHbR_S are expressed by ΔHbO ΔHbR

$$\begin{pmatrix} \Delta\mathrm{HbO_F} \\ \Delta\mathrm{HbR_F} \end{pmatrix} = \frac{1}{k_F - k_S} \begin{pmatrix} -k_S & 1 \\ -k_F \cdot k_S & k_F \end{pmatrix} \begin{pmatrix} \Delta\mathrm{HbO} \\ \Delta\mathrm{HbR} \end{pmatrix}$$
$$\begin{pmatrix} \Delta\mathrm{HbO_S} \\ \Delta\mathrm{HbR_S} \end{pmatrix} = \frac{1}{k_F - k_S} \begin{pmatrix} k_F & -1 \\ k_F \cdot k_S & -k_S \end{pmatrix} \begin{pmatrix} \Delta\mathrm{HbO} \\ \Delta\mathrm{HbR} \end{pmatrix} \quad (3)$$

ASSUMPTION(2):
k_F value is determined by existing fNIRS studies, according to Stimulation.
k_F = 0.6

ASSUMPTION(3):
k_S value is derived to minimize "the mutual information(4)" between k_F and k_S.
Substituting k_F and k_S into equation (3), the result will be got.

$$I(k_F, k_S) = \sum_{\Delta\mathrm{HbO_F}} \sum_{\Delta\mathrm{HbO_S}} p(\Delta\mathrm{HbO_F}, \Delta\mathrm{HbO_S}) \cdot \log \frac{p(\Delta\mathrm{HbO_F}, \Delta\mathrm{HbO_S})}{p(\Delta\mathrm{HbO_F}) p(\Delta\mathrm{HbO_S})} \quad (4)$$

CBSI Method (1/2)

"Functional Near Infrared Spectroscopy (NIRS) signal improvement based on negative correlation Between oxygenated and deoxygenated hemoglobin dynamics", Xu Cui, et al. Neuroimage 2010

Methods：

x : measured oxy-Hb y : measured deoxy-Hb x_o : true oxy-Hb y_o: true deoxy-Hb
α: the ratio of the noise amplitude in oxy-Hb and deoxy-Hb
β: the ratio of the noise amplitude of true oxy-Hb and deoxy-Hb
F: external noise, independent from the true signal x_o and y_o

relation of x , y, x_o , y_o

$$x = x_0 + \alpha F + Noise$$
$$y = y_0 + F + Noise$$

"Noise" is high frequency white noise introduced by NIRS device. This term fluctuate independently in oxy- and deoxy-Hb signal. removed by standard filtering techniques so we exclude this term.

ASSUMPTION (1)
x_o and y_o should be maximally negatively correlated (close to -1)

$$x_0 = -\beta y_0$$

***F and x_o* are expressed**

$$F = \frac{1}{\alpha+\beta}(x+\beta y)$$
$$x_0 = \frac{\beta}{\alpha+\beta}(x-\alpha y)$$

ASSUMPTION (2)
x_o and F should be minimally correlated (close to 0)
Correlation of coefficient of x_o and F is equal to 0

$$\sum_t x^2 + (\beta-\alpha)\sum_t xy - \alpha\beta\sum_t y^2 = 0$$

ASSUMPTION (3)
$\alpha = \beta$ ∵ α, β are proportionally low, this assumption is based on empirical data rather than theory.
α is derived

$$\alpha = \sqrt{\frac{\sum x^2}{\sum y^2}} = \frac{std(x)}{std(y)}$$

std: standard deviation

Finally, a very simple result is got.

$$x_0 = \frac{1}{2}(x-\alpha y)$$
$$y_0 = -\frac{1}{\alpha}x_0$$

CBSI Method (2/2)

"Functional Near Infrared Spectroscopy (NIRS) signal improvement based on negative correlation Between oxygenated and deoxygenated hemoglobin dynamics", Xu Cui, et al. Neuroimage 2010

This report describes the limitation of this method precisely, as follows (page 9, Discussion) :

Our method is based on the assumption that oxy-Hb and deoxy-Hb are negatively correlated. This has been justified by numerous independent studies and by our own data. However, while our method assumes that oxy-Hb and deoxy-Hb are *perfectly* negatively correlated, this is not true in practice. As Figure 1 shows, the correlation is less negative during the plateau period. It is also likely that the correlation is more complicated during the "overshooting" and controversial "initial dip" phases of the hemodynamic response. As a consequence, the corrected signal estimated by the CBSI method might be different from the true signal. While this is true, we propose that our approach is a reasonable approximation. First, as we have seen in Figure 2, the correlation of oxy-Hb and deoxy-Hb is typically close to −1. Second, the time period during which the oxy-Hb and deoxy-Hb correlation deviates from −1 is usually when they don't change (at baseline or plateau), and we are more interested in signal change during activation. Third, a method based on the assumption of a dynamic correlation is technically difficult to develop, and would likely require introducing free parameters or information about the experimental paradigm (e.g. event onset timing). However, it is likely that such a method could improve the signal quality even further.