Neurovascular Factors in Resting-State fMRI

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Resting-State fMRI

Fox and Raichle 2005; Iannetti and Wise 2007; http://www.youtube.com/watch?v=VaQ66lDZ-08&feature=plcp
Decrease in HDR amplitudes leads to a decrease in correlation between BOLD measures of 0.54 to 0.41.

Liu, NIMG 2013
Broadening of both hemodynamic response functions leads to a decrease in correlation between the BOLD measures of 0.54 to 0.34.
Broadening of the lower hemodynamic response function (red to green) leads to a decrease in correlation between the BOLD measures of 0.54 to 0.17.

Liu, NIMG 2013
Approaches and Issues

• Arguments based on BOLD signal model and prior observations.
• Comparing effects across networks.
• Calibrated fMRI
• Global Signal Effects
• Multimodal Experiments
BOLD Signal Model

Neural Activity \rightarrow Cerebral Blood Flow (CBF) \rightarrow \Delta BOLD / BOLD_0 \approx M \left(1 - f^{\alpha-\beta} m^\beta \right)

f = \frac{CBF}{CBF_0} ; \quad m = \frac{CMRO_2}{CMRO_{2,0}}
\[ \frac{\Delta BOLD}{BOLD_0} \approx M \left( 1 - f^{\alpha-\beta} m^\beta \right) \]

Maximal BOLD signal
\[ M = TE \cdot A \cdot CBV_0 \cdot [dHb_0]^\beta \]

CBF/CMRO\textsubscript{2} Coupling Factor
\[ n = \frac{\%\Delta CBF}{\%\Delta CMRO_2} = \frac{f - 1}{m - 1} \]
Different ways to accomplish the same change in BOLD

\[ n=2.50; \ M=6.3 \]
\[ n=2.5; \ M=8.0 \]
\[ n=2.15; \ M=8.0 \]
Case Study: Effects of Hypercapnia on Functional Connectivity

Biswal et al, JCBFM 1997

Xu et al, JCBFM 2011
Chen and Pike, JCBFM, 2010

Xu et al, JCBFM 2011

Liau et al NIMG 2009
Case Study: Effects of Caffeine on Functional Connectivity

Functional connectivity maps for representative subject

Wong et al; NIMG 2012; Rack-Gomer et al, NIMG, 2009
CBF₀ ↓ → dHB₀ ↑ → M ↑ → BOLD ↑
CMRO₂₀ ↑ → ?

n ↓ → BOLD ↓

Chen and Parrish 2009; Rack-Gomer et al, NIMG, 2009; Griffeth et al 2011; Xu et al ISMRM2014, p. 4168
Case Study: Effects of Propofol

Connectivity reduced in frontoparietal network, but not in auditory and visual networks.
Also, prior studies indicate propofol does not alter either CBF response or flow-metabolism coupling.

Boveroux et al 2010
Neural Activity \rightarrow \text{Cerebral Blood Flow} \rightarrow \text{Metabolism (CMRO}_2) \rightarrow \text{ASL Signal} \rightarrow \text{Cerebral Blood Volume} \rightarrow \text{deoxyHb} \rightarrow \text{BOLD Signal}
Calibrated fMRI of Resting-state Connectivity

Wu et al, NIMG 2009
Calibrated fMRI of Resting-state Measures

Task
\[ \beta = \frac{\Delta \text{BOLD}}{\text{BOLD}_0} \]

\[ n = 2.6 \]

Rest
\[ n = 1.7 \]

As BOLD signals get smaller

\[ \left( \frac{\text{CMRO}_2}{\text{CMRO}_{20}} \right)^{\beta - \alpha} \rightarrow \left( \frac{\text{CBF}}{\text{CBF}_0} \right)^{1 - \frac{\alpha}{\beta}} \]

CMRO\(_2\) estimates are driven primarily by the CBF measures

Restom et al 2008; Rack-Gomer 2011
How global signal regression can alter interpretation of an experiment

Wong et al, NIMG 2012
Case Study: Effects of Caffeine Revisited

![Image showing a case study diagram with pre and post test results for men and women taking caffeine or placebo.](image-url)
Source Space

Sensor Space

Inverse Model

Forward Model

Brookes et al. 2011
Relative EEG

Higher vigilance $\rightarrow$ lower GS $\rightarrow$ more anticorrelation
Summary

• Most rs-fMRI studies use the BOLD signal.
• Changes in BOLD functional connectivity can be difficult to interpret on their own.
• The use of prior observations and BOLD signal models can help to distinguish between vascular and neural effects.
• However, in some cases multimodal measures are needed to determine the primary causes.
• Some preprocessing approaches, such as global signal regression, should be used with caution as they can mask the effect of interest.
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