

Brain tissue temperature dynamics during functional activity & possibilities for Imaging

by

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Dedication

Mama.

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April 1, 2012

Date

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Chapter 1

Introduction

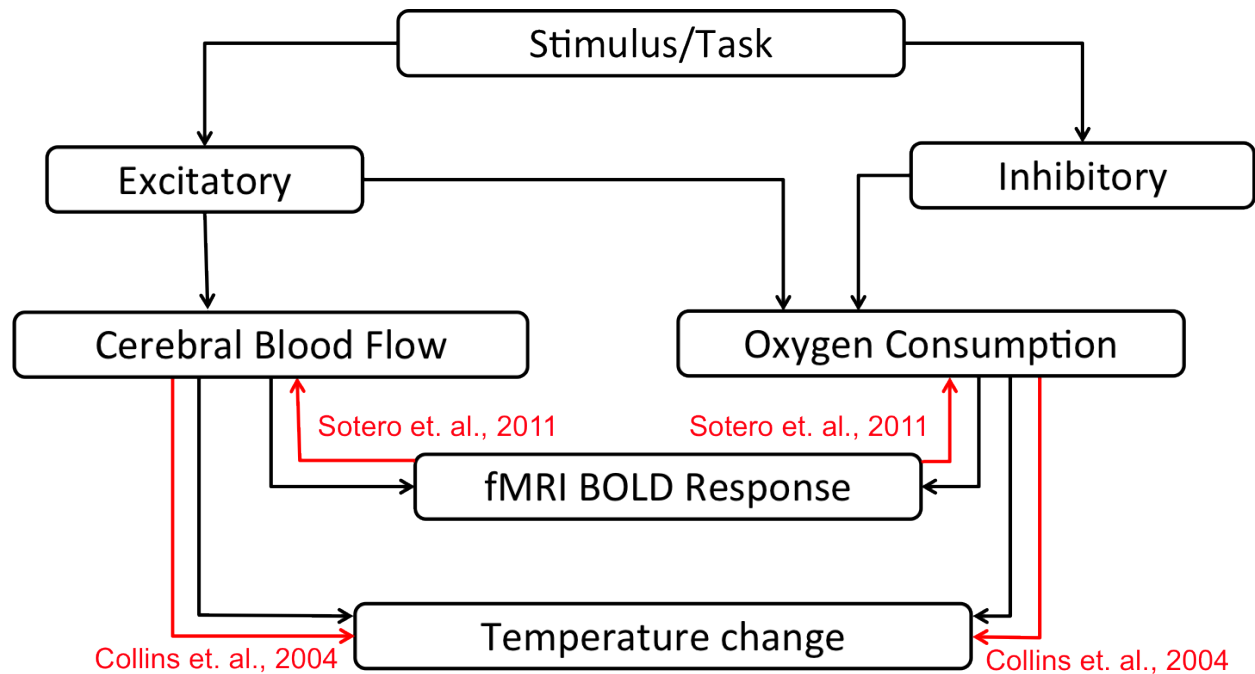


Figure 2.1: bla bla bla

Chapter 2

Calculating Temperature Changes using the fMRI BOLD Response

2.1 Background

2.1.1 Generation of the Blood Oxygen Level Dependent (BOLD) Response

2.1.2 Previously Proposed Temperature Models

Single-Voxel Approach

Multi-Voxel Approach

Chapter 3

Detector Applications to measuring the active brain

3.1 Functional Near-Infrared fNIR Imaging

$$I = I_0 e^{-\alpha x} \tag{3.1}$$

3.2 Temperature Measurements

From the Beer-Lambert law eq. (3.1), the penetration depth, δ_p can be expressed as

$$\delta = \frac{1}{\alpha} \tag{3.2}$$

where α is the absorption coefficient. At body temperature (37°) the peak wavelength in the blackbody spectrum is approximately BLA. For water at this wavelength, α is approximately HUGE, so δ is VERY SMALL.

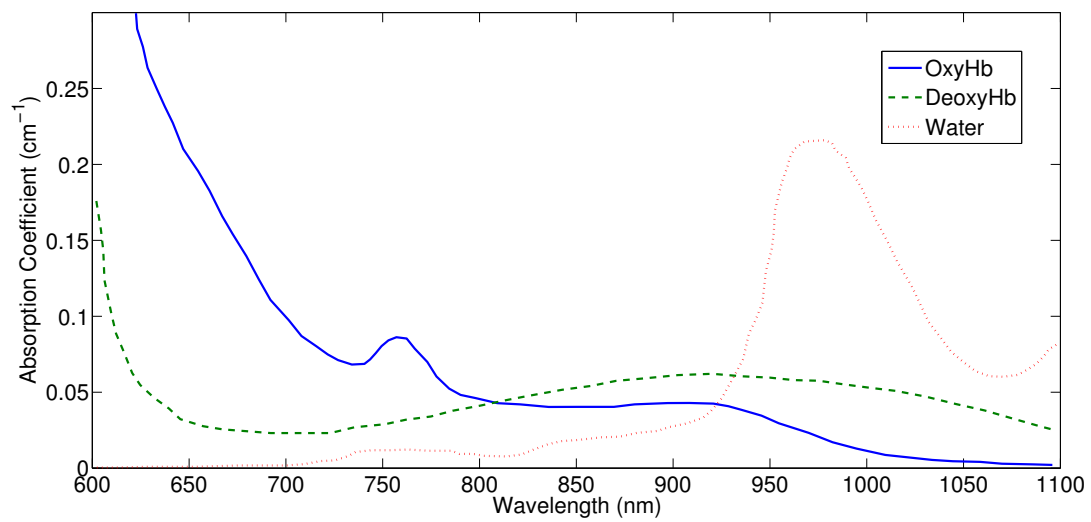


Figure 3.1: Absorption spectra of water, Hb and Dhb. From Cope [1] and HB stuff from Horecker [2]

Chapter 4

Conclusion

Bibliography

- [1] M Cope. The development of a near infrared spectroscopy system and its application for non invasive monitoring of cerebral blood and tissue oxygenation in the newborn infants. *London University*, 1991.
- [2] B L Horecker. The absorption spectra of hemoglobin and its derivatives in the visible and near infra-red regions. *The Journal of Biological Chemistry*, 1942.

Calculating the Temperature Change

```
1 function temperatureOut = tempCalcChangingMetabolismFlow(tissue,bloodT,
    airT,nt,tmax,pastCalc,start,stop,amplitudeMet,amplitudeFlow,region,
    savesteps)
2 % tempCalcChaning Metabolism How does changin metabolism affect things?
3 % tissue: holds all of the strucual information
4 % bloodT: Temperature of the blood
5 % airT: Temperature of the surrounding ait
6 % nt: Number of time steps
7 % tmax: Total amount of time the simulation should run over
8 %
9 % region: logical matrix same size as head
10 % start: units of steps
11 % stop: units of steps
12 %
13 % Writen by Gregory Rothmeier (greggroth@gmail.com)
14 % Georgia State University Dept. Physics and Astronomy
15 % May, 2011
16 %#codegen
17
18 %% Default Values
19 if nargin<2, bloodT = 37; end
20 if nargin<3, airT = 24; end
21 if nargin<4, nt = 3; end
22 if nargin<5, tmax = 1; end
23 if nargin<6, pastCalc = 0; end % Voxel size (m)
24 if nargin<7, start = 10; end % in steps
25 if nargin<8, stop = 20; end % in steps
26 if nargin<9, amplitudeMet = 1.2; end % normalized
27 if nargin<10, amplitudeFlow = 1.2; end % normalized
28 if nargin<11, savesteps = 1; end
29
```

```

30
31 dx = 2*10^-3;
32 if nt < (2*tmax),
33     warning('Time step size is not large enough. Results will be
        unreliable. Consider increasing the number of steps or reducing
        tmax.')
34 end
35
36
37 % Constants used that aren't already stored in tissue
38 [xmax ymax zmax t] = size(tissue);
39 clear t;
40 dt = tmax/(nt-1);
41 % rhoBlood = 1057;
42 % wBlood = 1000;
43 % cBlood = 3600;
44
45 statusbar = waitbar(0, 'Initializing');
46
47 %% Maps
48 % Creates a map that identifies where there is tissue
49 % the condition squeeze(tissue(:,:,:)~=airIndex picks out the elements
    that are
50 % tissue
51
52 temperatureOut = ones(ceil((nt-1)/savesteps),xmax,ymax,zmax,'single');
53 temperature = ones(2,xmax,ymax,zmax,'single')*airT;
54 if pastCalc == 0
55     temperature(1,squeeze(tissue(:,:,:,1))~=1) = bloodT;
56 else
57     temperature(1,:,:,:) = pastCalc(end,:,:,:);
58     % temperature(1,:,:,:) = pastCalc;

```

```

59 end
60 temperatureOut(1,:,:,:) = temperature(1,:,:,:);
61 metabMultiplier = ones([xmax ymax zmax],'single');
62 flowMultiplier = ones([xmax ymax zmax],'single');
63
64 %% Do Work.
65 % This is a vectorized version of the next section. For the love of
    god
66 % don't make any changes to this without first looking below to make
    sure
67 % you know what you're changing. This is [nearly] impossible to
68 % understand, so take your time and don't break it.
69 % data is stored in 'tissue' as such :
70 % [tissuetype 0 Qm c rho k w]; <-- second element is blank for all.
71 % [ 1 2 3 4 5 6 7
72
73 % This makes an array that has smoothed out variations in k by averaging
74 % all of the k's around each voxel (including itself). This is a
75 % hap-hazard solution to the problem that if you only take the value of
    k
76 % for the voxel without considering what surrounds it, it doesn't matter
77 % whether the head is surrounded by air, water or anything else. Since
78 % water is a better thermal conductor than air, we need a way of
79 % accounting for this. This is one way:
80 averagedk = (circshift(tissue(:,:,:,:),[1 0 0])+circshift(tissue(:,:,:,:),6)
    ,[-1 0 0])+circshift(tissue(:,:,:,:),[0 1 0])+circshift(tissue(:,:,:,:),6)
    ,[0 -1 0])+circshift(tissue(:,:,:,:),[0 0 1])+circshift(tissue(:,:,:,:),6)
    ,[0 0 -1])+tissue(:,:,:,:),6))/7;
81 rhoblood = 1057;
82 cblood = 3600;
83
84 %% Only saves every 4 steps

```

```

85 tic
86 for t2 = 1:nt-1
87     waitbar(t2/(nt-1),statusbar,sprintf('%d%',round(t2/(nt-1)*100)));
88     if (start<t2) && (t2<stop) % for __ steps
89         metabMultiplier(region) = amplitudeMet; % region is hardcoded
90         here
91         flowMultiplier(region) = amplitudeFlow;
92     elseif t2==stop % once the period is over, reset it back to ones
93         metabMultiplier(region) = 1;
94         flowMultiplier(region) = 1;
95     end
96
97 temperature(2,:,:,:) = squeeze(temperature(1,:,:,:)) + ...
98 dt/(tissue(:,:,:5).*tissue(:,:,:4)).* ...
99 ((averagedk/dx^2).*...
100 (circshift(squeeze(temperature(1,:,:,:)),[1 0 0])-2*squeeze(
101     temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
102     ,[-1 0 0])+... % shift along x
103     circshift(squeeze(temperature(1,:,:,:)),[0 1 0])-2*squeeze(
104     temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
105     ,[0 -1 0])+... % shift along y
106     circshift(squeeze(temperature(1,:,:,:)),[0 0 1])-2*squeeze(
107     temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
108     ,[0 0 -1]))... % shift along z
109     -(1/6000)*rhoblood*flowMultiplier.*tissue(:,:,:7)*cblood.*(
110     squeeze(temperature(1,:,:,:))-bloodT)+metabMultiplier.*
111     tissue(:,:,:3));
112
113 % resets the air temperature back since it's also modified above,
114 but
115 % it needs to be kept constant throughout the calculations
116 temperature(2,squeeze(tissue(:,:,:1))==1) = airT;
117 temperatureOut(ceil(t2/savesteps),,:,:,:) = temperature(2,:,:,:);

```

```

107     temperature(1,:,:,:) = temperature(2,:,:,:); % moves 2 back to 1
108 end
109 close(statusbar);
110 toc
111 %% Keeps all of the data
112 % Note: Make sure that temperature() has enough preallocated space
113 %{
114 tic
115 for t2 = 1:nt-1
116     %tic
117     waitbar(t2/(nt-1),statusbar,sprintf('%d%%',round(t2/(nt-1)*100)));
118     if (start<t2) && (t2<stop) % for 10 steps
119         metabMultiplier(region) = amplitudeMet; % region is hardcoded
120         here
121         flowMultiplier(region) = amplitudeFlow;
122     elseif t2==stop % once the period is over, reset it back to ones
123         metabMultiplier(region) = 1;
124         flowMultiplier(region) = 1;
125     end
126     temperature(t2+1,:,:,:) = squeeze(temperature(t2,:,:,:)) + ...
127         dt/(tissue(:,:,:5).*tissue(:,:,:4)).* ...
128         ((averagedk/dx^2).*...
129         (circshift(squeeze(temperature(t2,:,:,:)),[1 0 0])-2*squeeze(
130             temperature(t2,:,:,:))+circshift(squeeze(temperature(t2,:,:,:))
131             ,[-1 0 0])+... % shift along x
132             circshift(squeeze(temperature(t2,:,:,:)),[0 1 0])-2*squeeze(
133                 temperature(t2,:,:,:))+circshift(squeeze(temperature(t2,:,:,:))
134                 ,[0 -1 0])+... % shift along y
135                 circshift(squeeze(temperature(t2,:,:,:)),[0 0 1])-2*squeeze(
136                     temperature(t2,:,:,:))+circshift(squeeze(temperature(t2,:,:,:))
137                     ,[0 0 -1])))... % shift along z

```

```

131         -(1/6000)*rhoblood*flowMultiplier.*tissue(:,:,:,7)*cblood.*(
            squeeze(temperature(t2,:,:,:))-bloodT)+metabMultiplier.*
            tissue(:,:,:,3));
132     %   resets the air temperature back since it's also modified above,
        but
133     %   it needs to be kept constant throughout the calculations
134     temperature(t2+1,squeeze(tissue(:,:,:,1))==1) = airT;
135     %dispTimeLeft(1,1,nt-1,t2)
136 end
137 close(statusbar);
138 toc
139 %}
140
141 %% Old Code
142 %   This is what used to be used.   It's much slower (~60 times slower),
        but
143 %   it's much easier to understand compared to the above code.   If any
144 %   changes need to be made above, first look through this code to ensure
145 %   you understand what's happening before making changes.   It's really
        easy
146 %   to mess up the code above and nearly impossible to figure out where.
147
148 %   good luck.
149
150
151 %{
152 for t2 = 1:nt-1
153     for x2 = 2:xmax-1
154         for y2 = 2:ymax-1
155             for z2 = 2:zmax-1
156                 if tissue(x2,y2,z2,1) ~= 1,

```

```

157         temperature(t2+1,x2,y2,z2) = temperature(t2,x2,y2,z2)
           + (dt/(tissue(x2,y2,z2,5)*tissue(x2,y2,z2,4)))*((
           tissue(x2,y2,z2,6)/dx^2)*...
158         (temperature(t2,x2+1,y2,z2)-2*temperature(t2,x2,y2,
           z2)+temperature(t2,x2-1,y2,z2)+...
159         temperature(t2,x2,y2+1,z2)-2*temperature(t2,x2,y2,
           z2)+temperature(t2,x2,y2-1,z2)+...
160         temperature(t2,x2,y2,z2+1)-2*temperature(t2,x2,y2,
           z2)+temperature(t2,x2,y2,z2-1))...
161         -(1/6000)*rhoBlood*wBlood*cBlood*(temperature(t2,x2
           ,y2,z2)-bloodT)+tissue(x2,y2,z2,3));
162     end
163 end
164 end
165 end
166 end
167 %}
168
169
170 end

```

Calculating The Equilibrium Temperature