DIFFUSE OPTICS AND SPECKLE BASED SENSING: FROM CARDIOVASCULAR TO NEUROVASCULAR MONITORING

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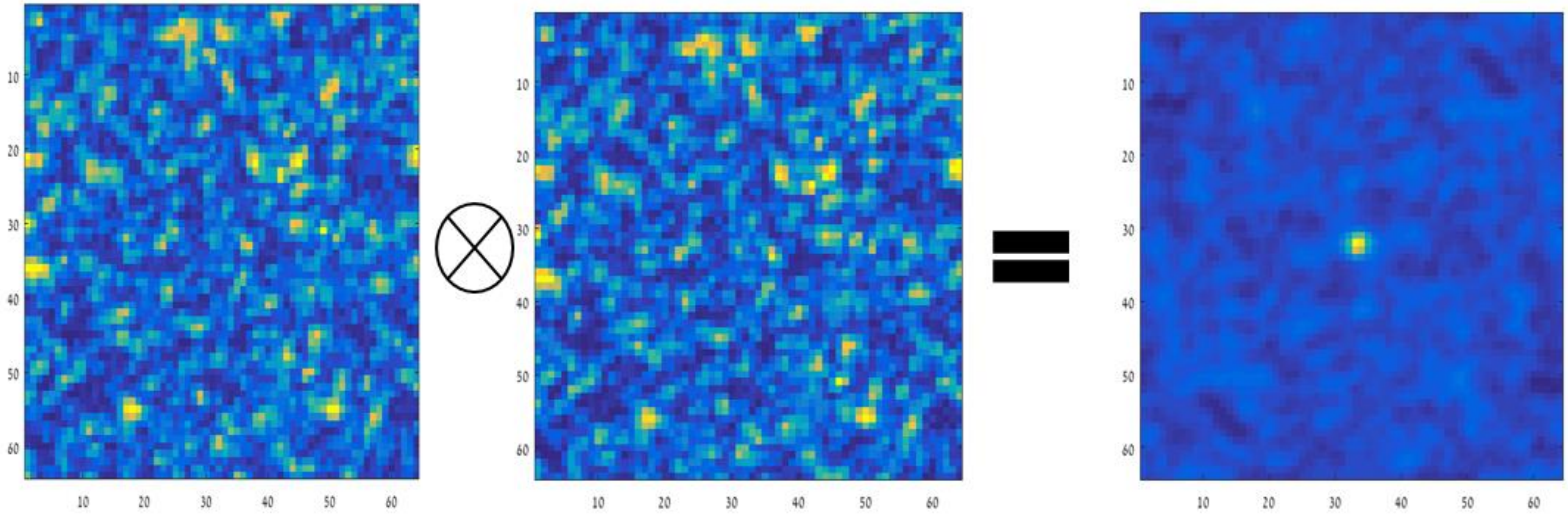
HARVARD MEDICAL SCHOOL AND MGH (VISITING SCHOLAR)

A BIT ABOUT ME..

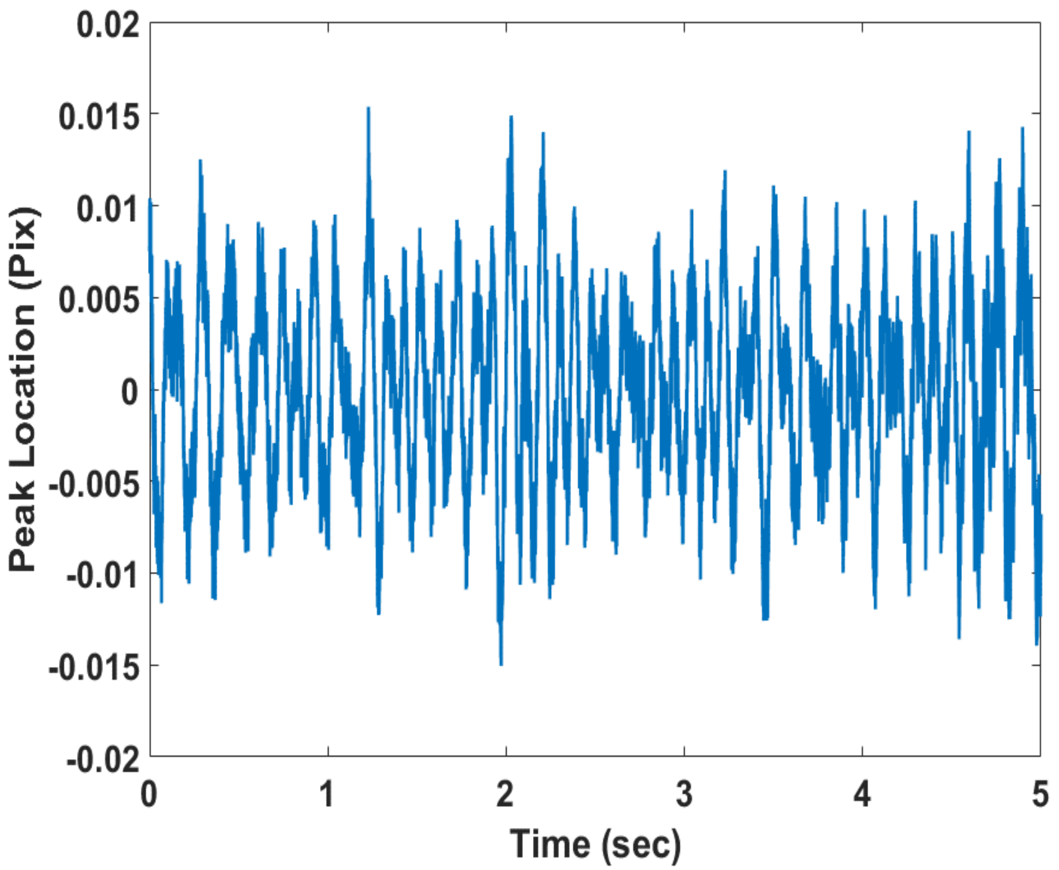
Speckle Based Remote Sensing: From Cardiovascular to Neurovascular Sensing

SPECKLE TRACKING

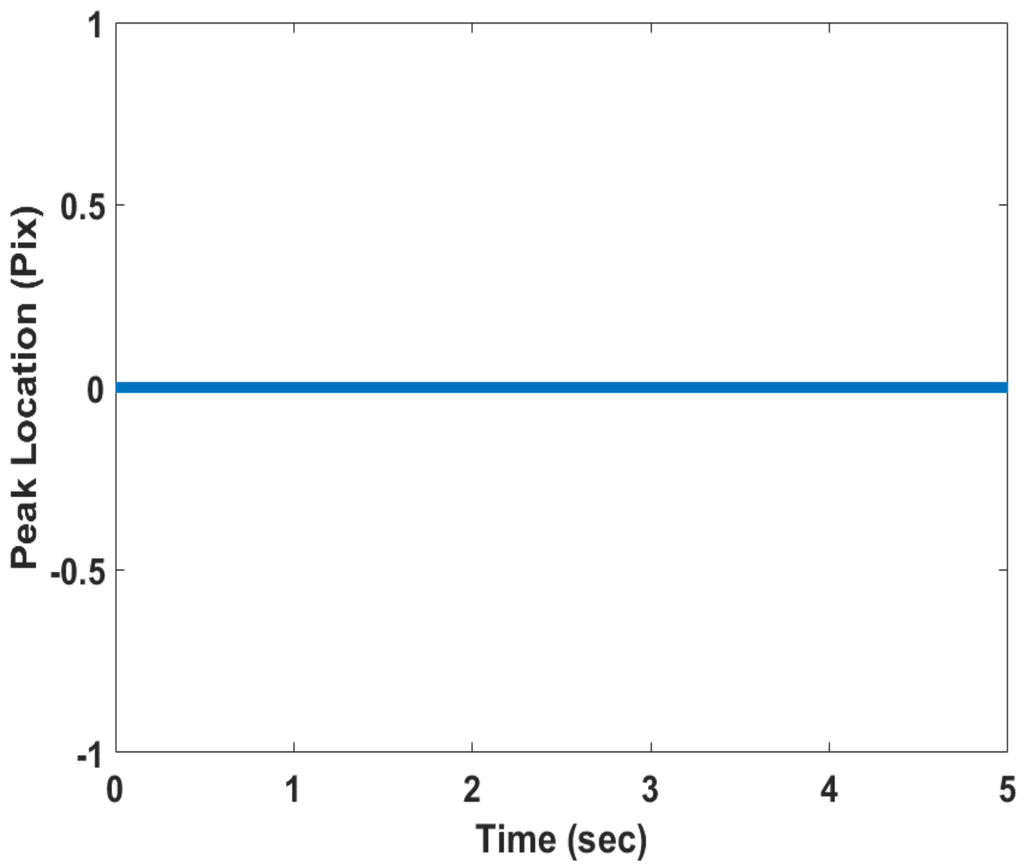


SUB PIXEL APPROXIMATION

Sub Pixel Vibrations

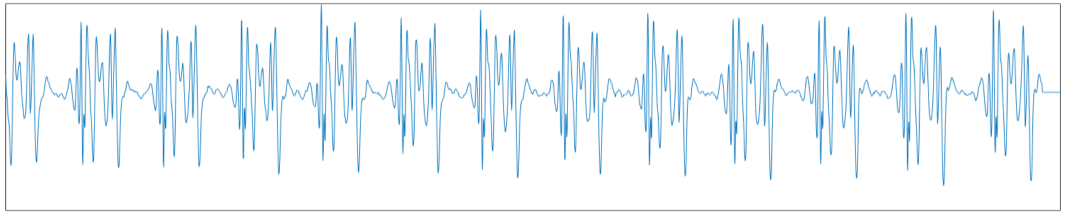


Pixels Vibrations



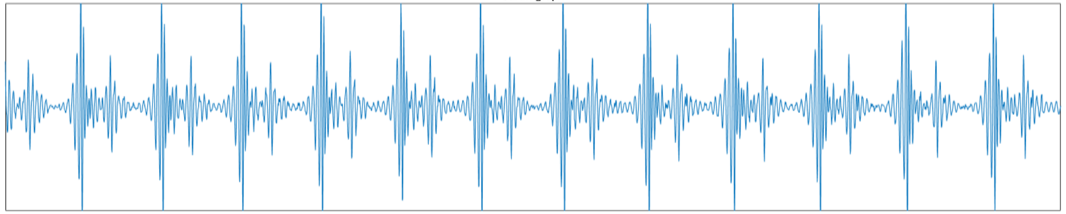
REMOTE SENSING– CARDIOGRAPH

Raw Signal:



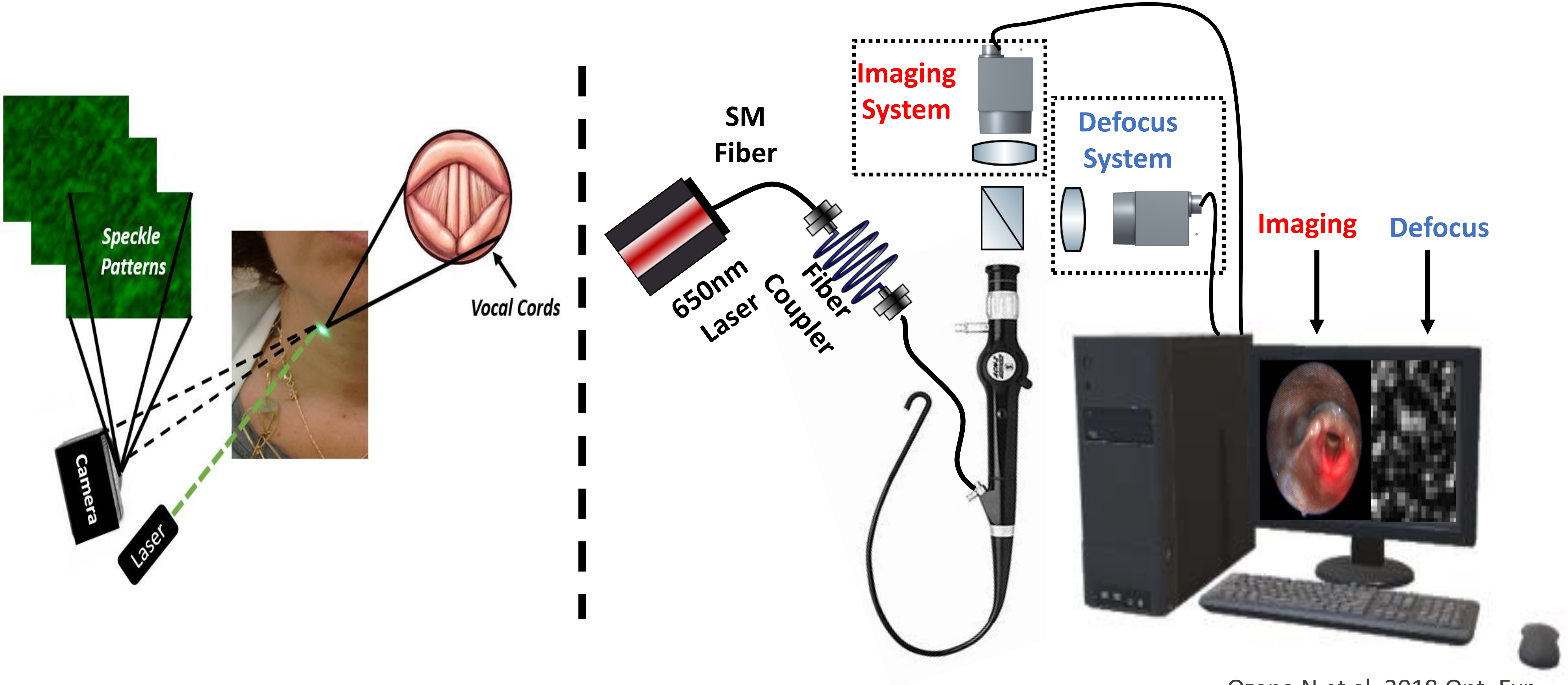
Extracting the **Cardiograph** from the **Raw Signal**

Cardiograph:



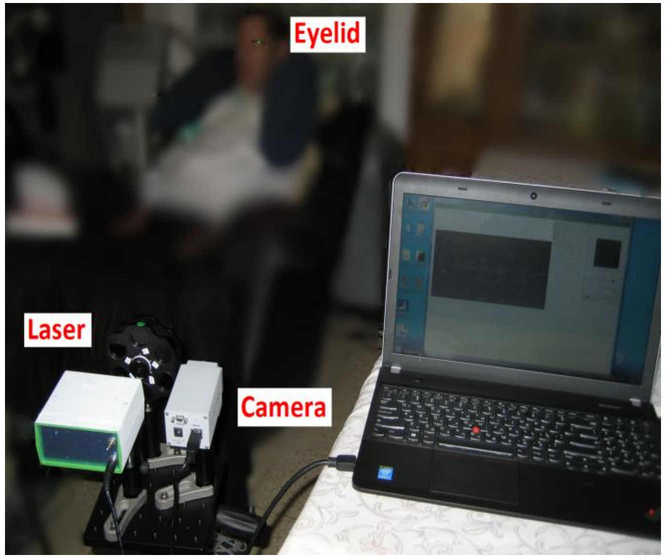
Prof. Zeev Zalevsky

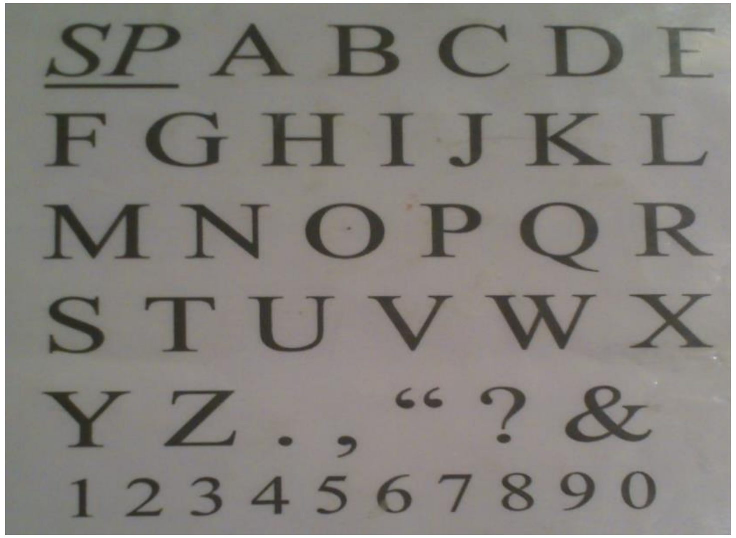
REMOTE SENSING – ENDOSCOPY



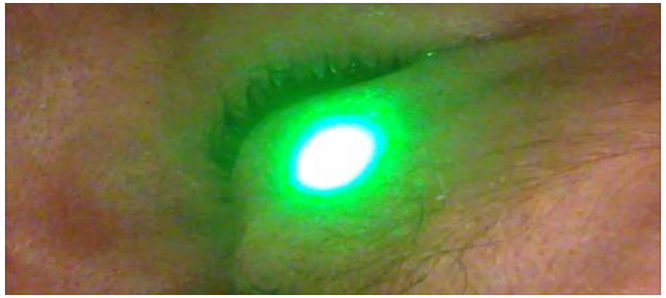
Ozana N et al. 2018 Opt. Exp.

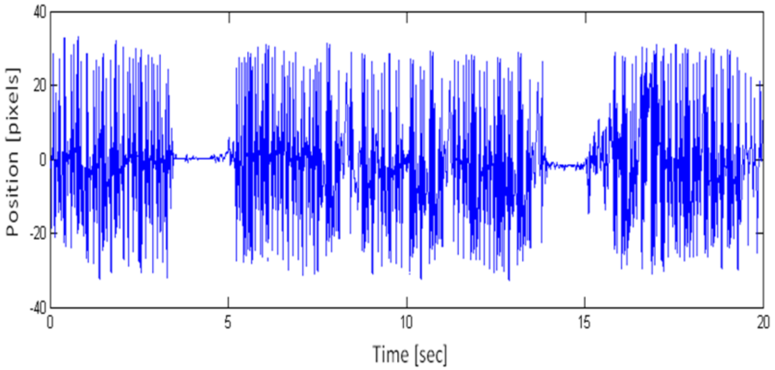
AUGMENTATIVE ALTERNATIVE COMMUNICATION (ALS)



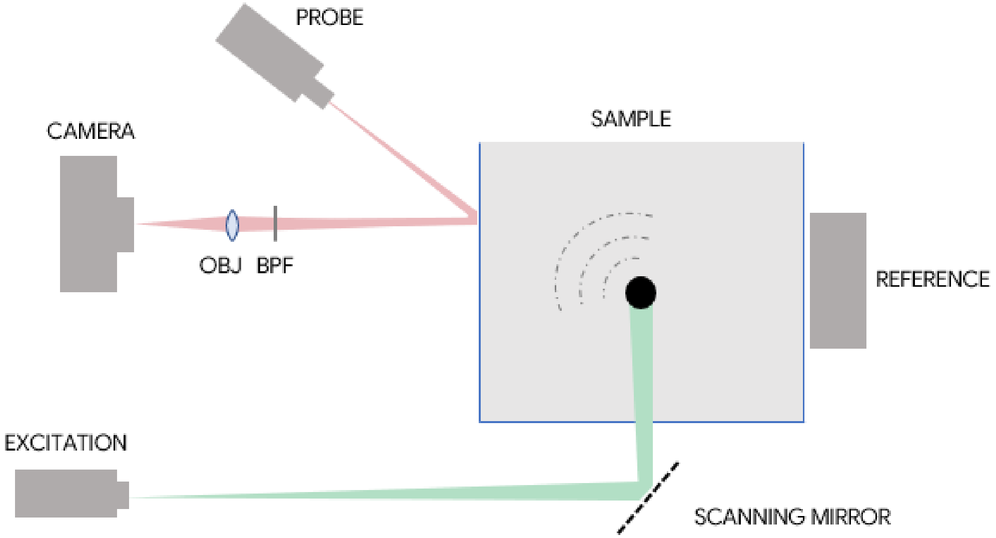


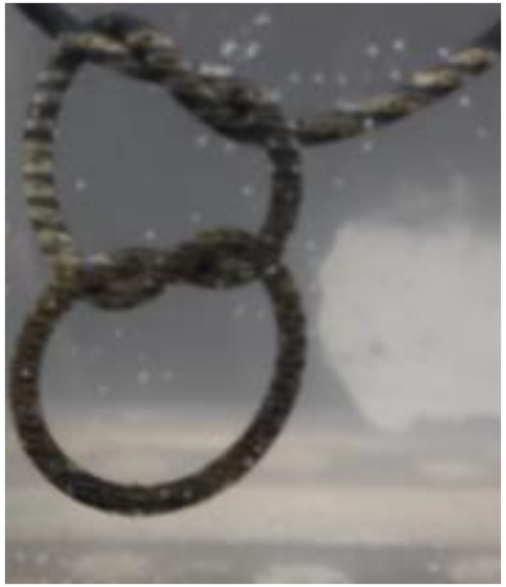
PRIZE4LIFE
No limits. Finding a cure for ALS

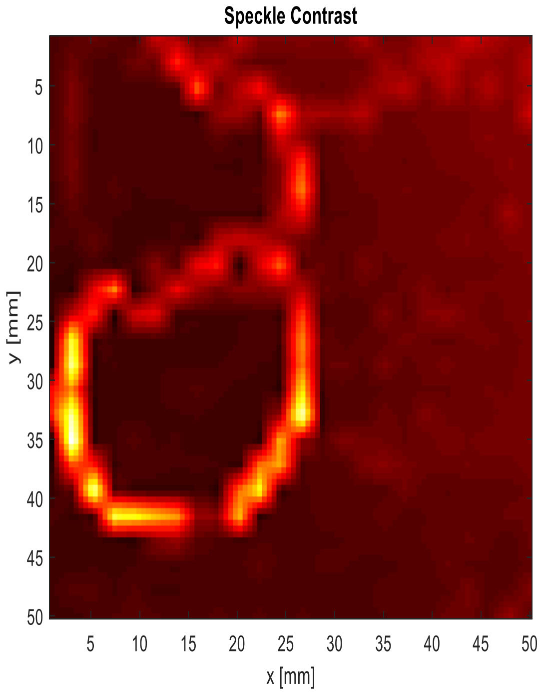




REMOTE PHOTOACOUSTIC SENSING



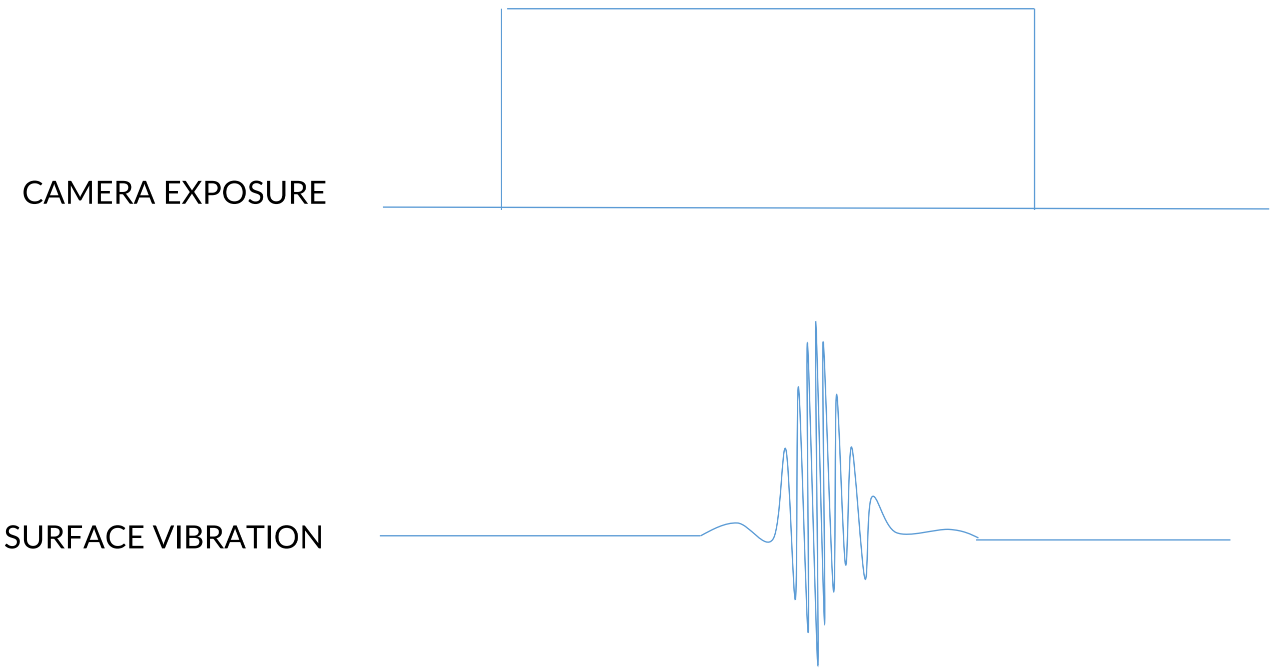


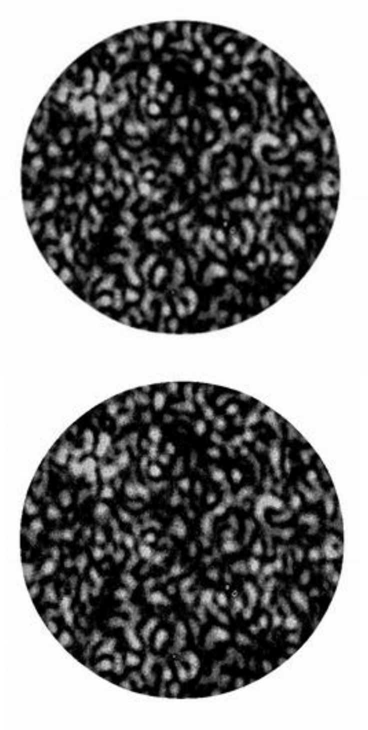


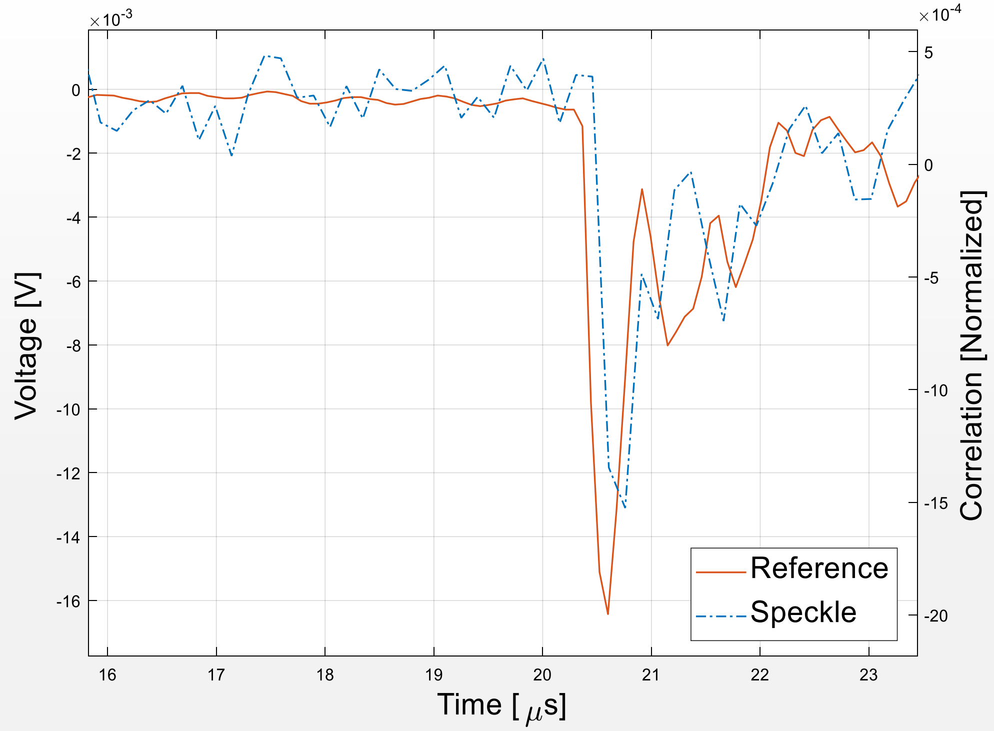
M. Benyamin, R. Califa, H. Genish, and Z. Zalevsky and N. Ozana, Opt. Letters, 2019

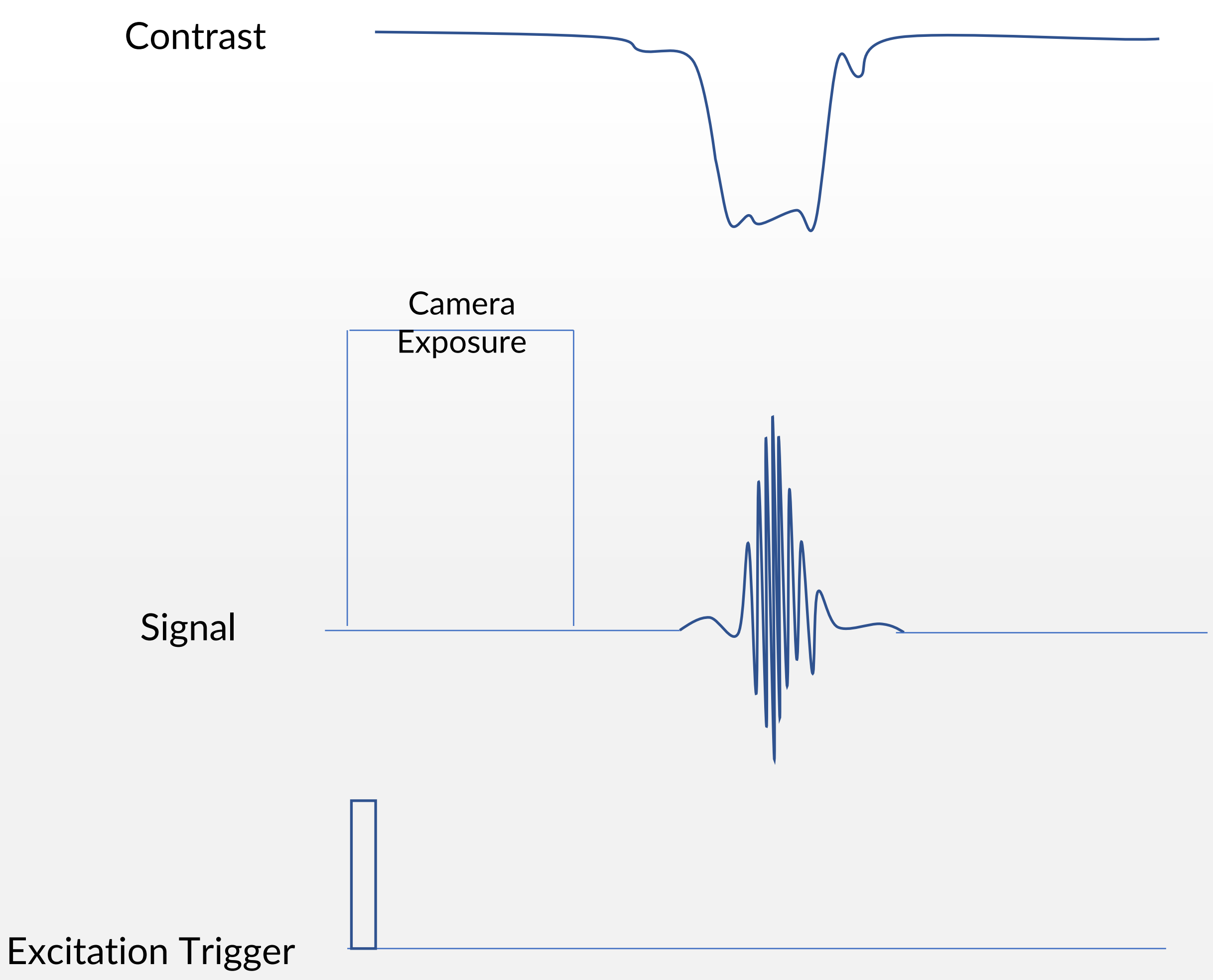
CONTRAST ANALYSIS

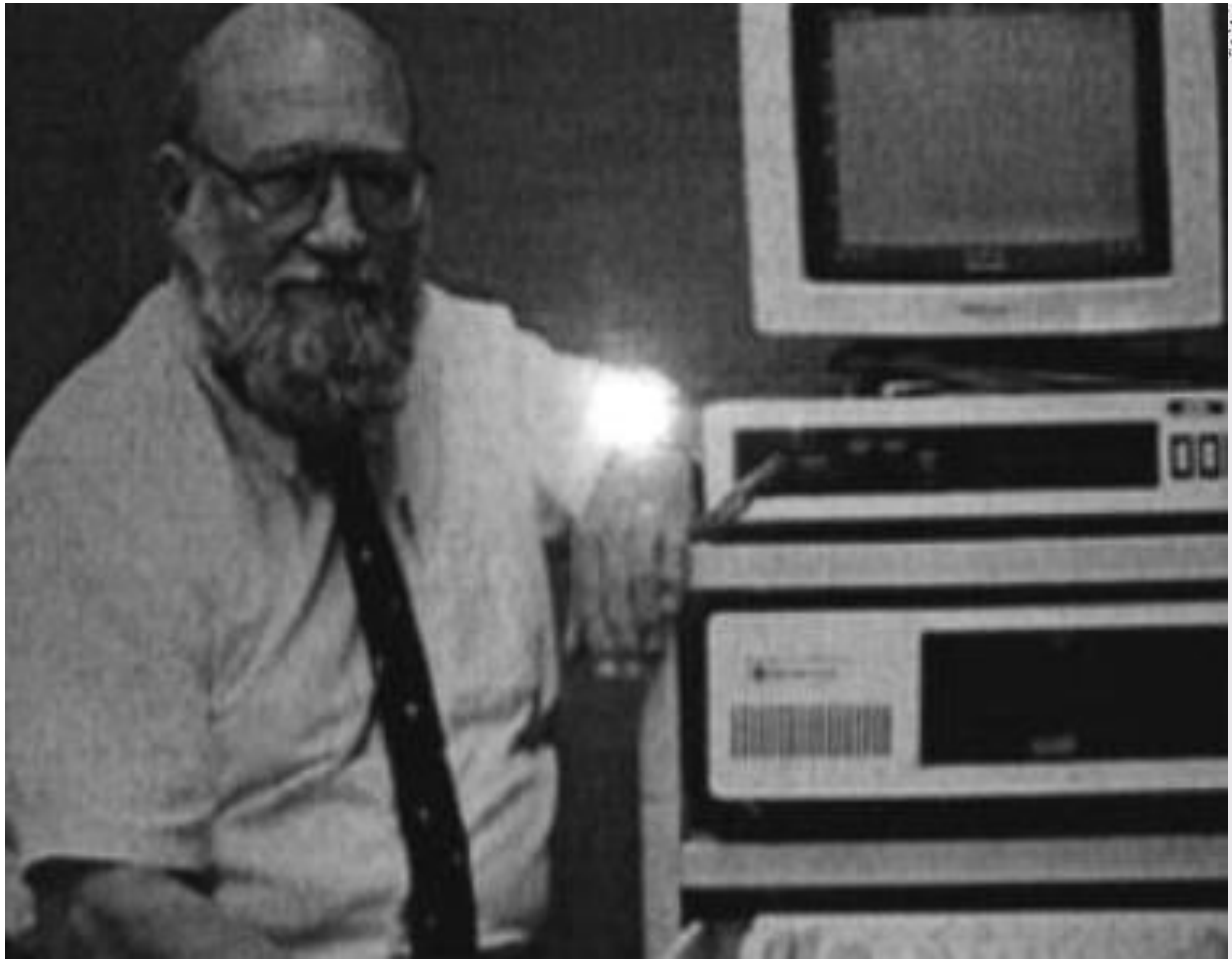
$$K = \frac{\sigma}{< I >}$$






×10-3
×10-4
Voltage [V]
Correlation [Normalized]
Time [μs]
Reference
Speckle
0
-2
-4
-6
-8
-10
-12
-14
-16
5
0
-5
-10
-15
-20
16
17
18
19
20
21
22
23


Contrast
Camera
Exposure
Signal
Excitation Trigger



eprinted from
December 1977, Volume 198, pp. 1264-1267

SCIENCE

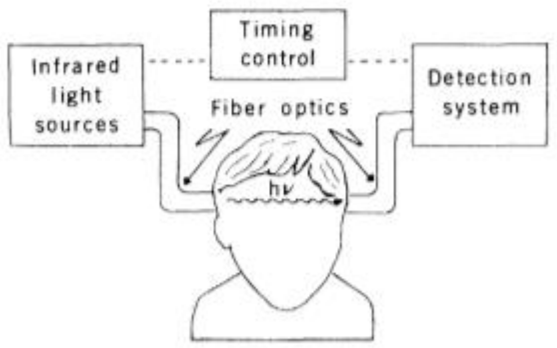


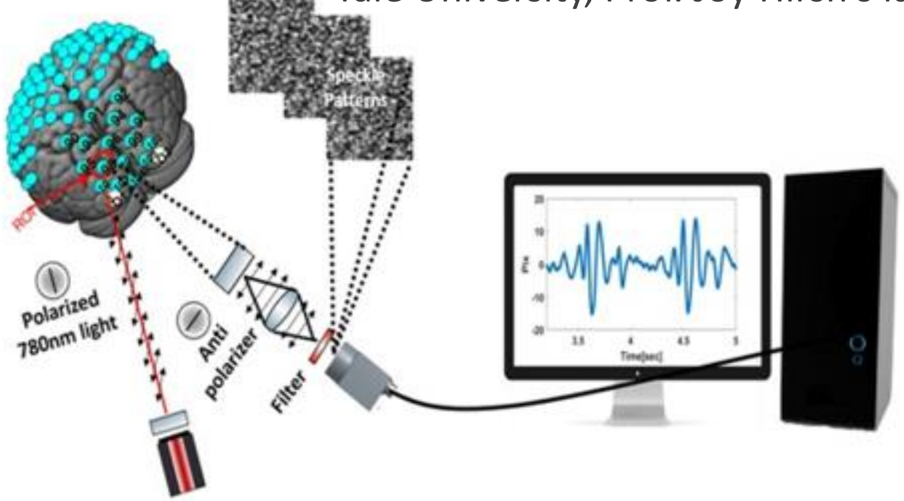
Fig. 4. Infrared monitoring of cerebral circulation and oxygen sufficiency.

Jobsis F. (1977) Science 198, 1264–1267

fMRI Neuroimaging

functional MRI

Yale University, Prof. Joy Hirsh's lab



Ozana N et al. 2019 J. Biophotonics

We know little about the neural system involved in natural interactions

Optical and Acoustical Neuroimaging

Involve interactions with a natural environment

University College London (JOVE video)

Performance like driving, running, walking…

U. of Oldenburg & German Aerospace Research Center -Central Nippon Expressway, Tokyo

Cognitive development

Require social interaction among groups

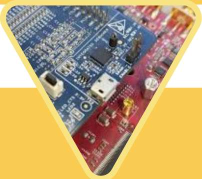
NIRSport, NIRx

Functional Neuroimaging System

Develop a functional neuroimaging system (fDCS)

* Large area coverage
* 1064 nm operation
* Improved spatial resolution
* Higher brain sensitivity

Optical System



Designing and building Custom made Lasers, Detectors, Head probes

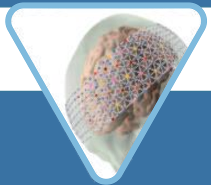
Hardware System

FPGA Design, Data acquisition, Data analysis,

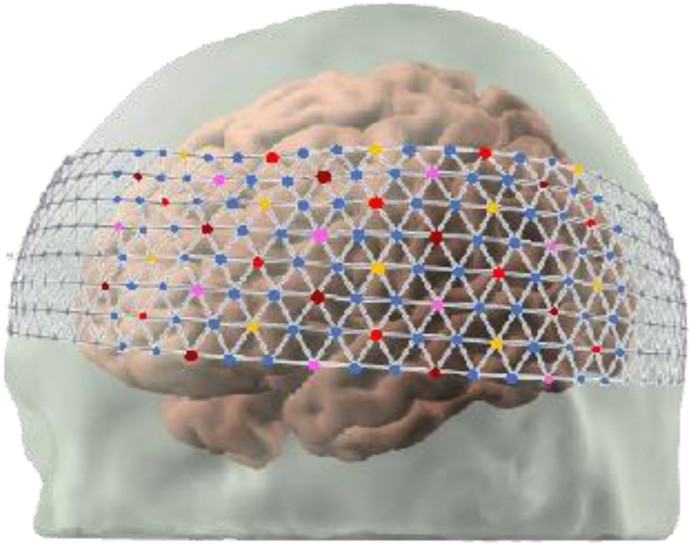
Algorithms

Monte Carlo Simulations, Machine Learning and Neural Network

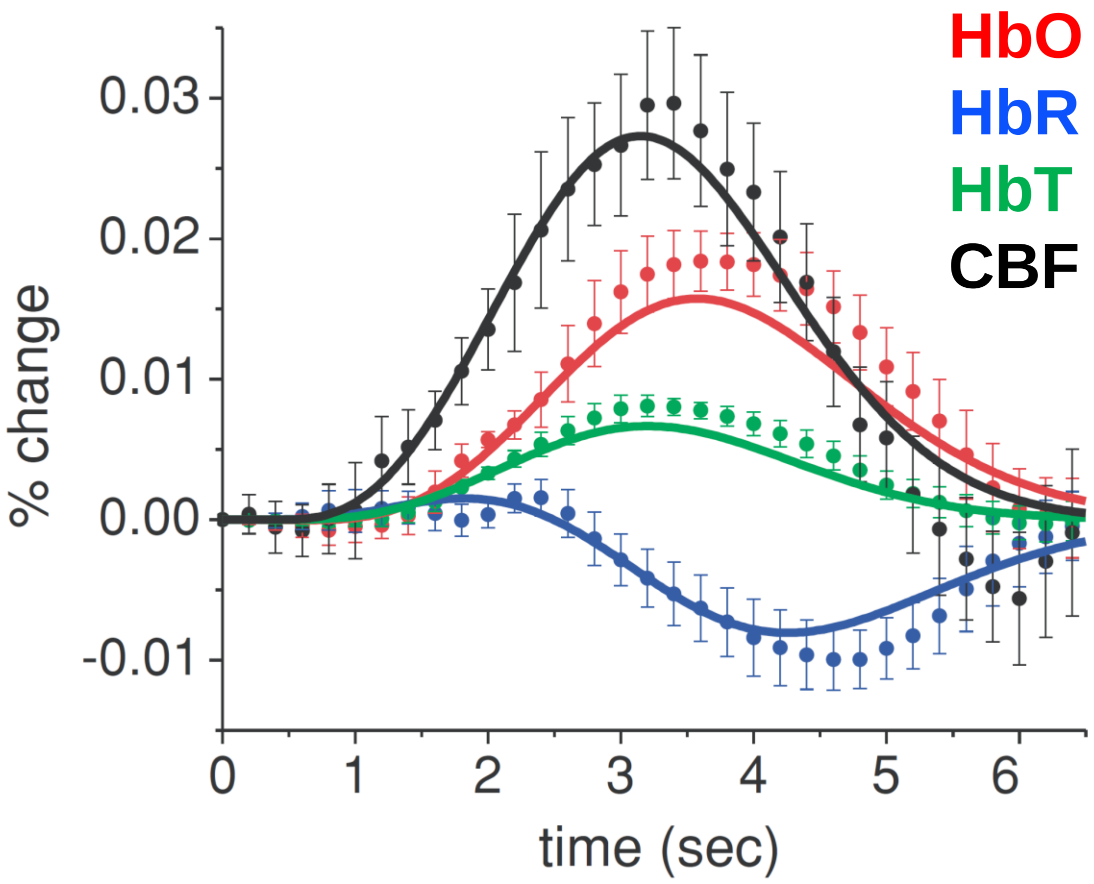
Human



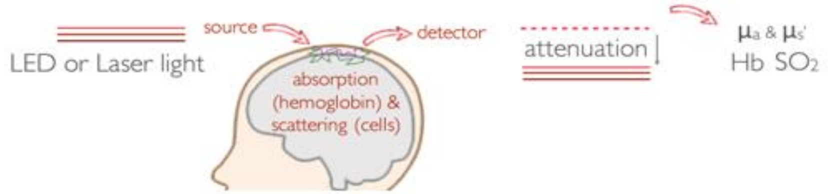
Physiology, Functional, and Data Analysis



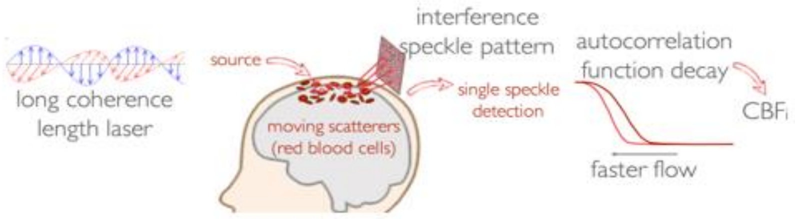
Functional Imaging and Cerebral Blood flow



R C Mesquita *et al* 2008 *Phys. Med. Biol.* **54** 175



Near-Infrared Spectroscopy



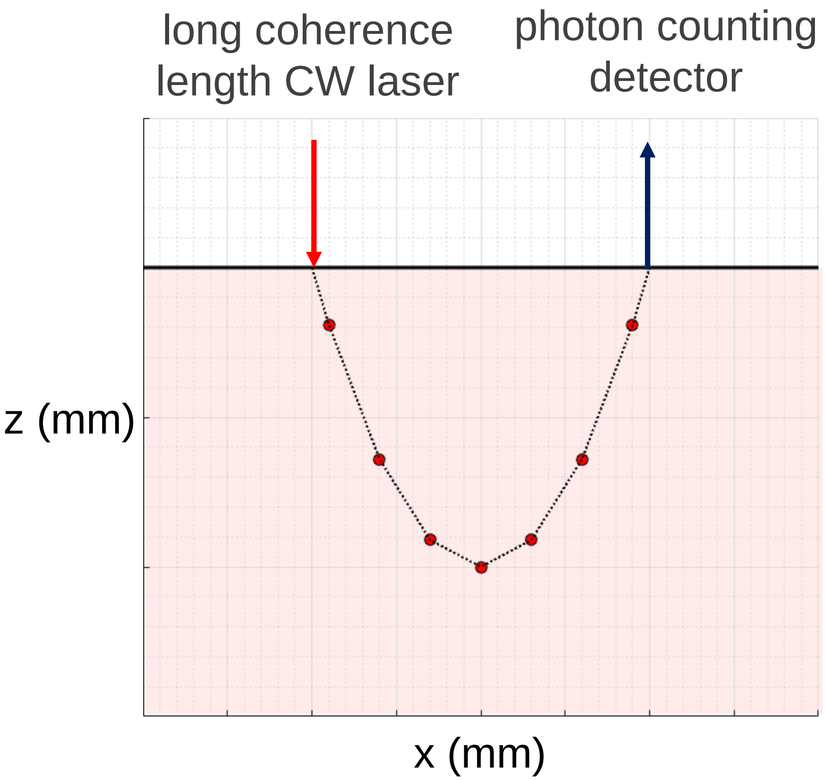
Diffuse Correlation Spectroscopy

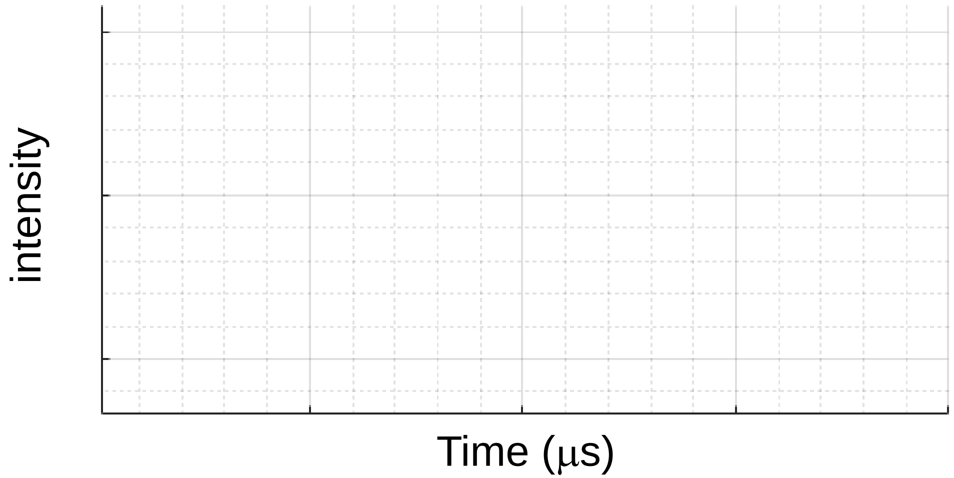
Neural activity drives perfusion
Hb changes are secondary effects

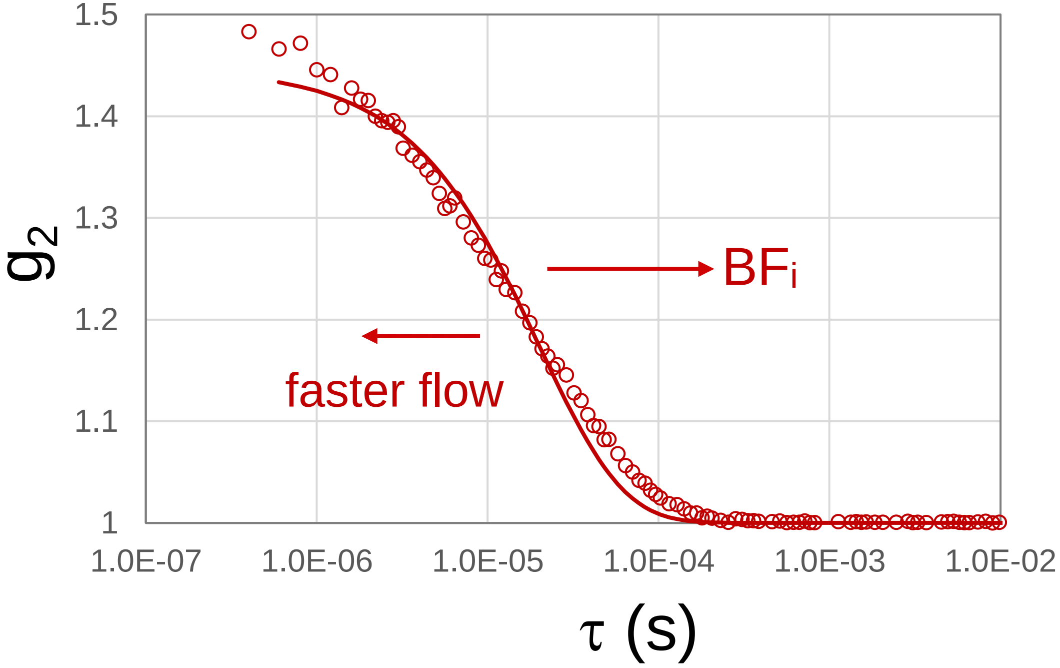
Flow change bigger and faster
Better suited for neurofeedback and BCI

Knowledge of perfusion levels probes underlying physiology as well

Diffuse Correlation Spectroscopy



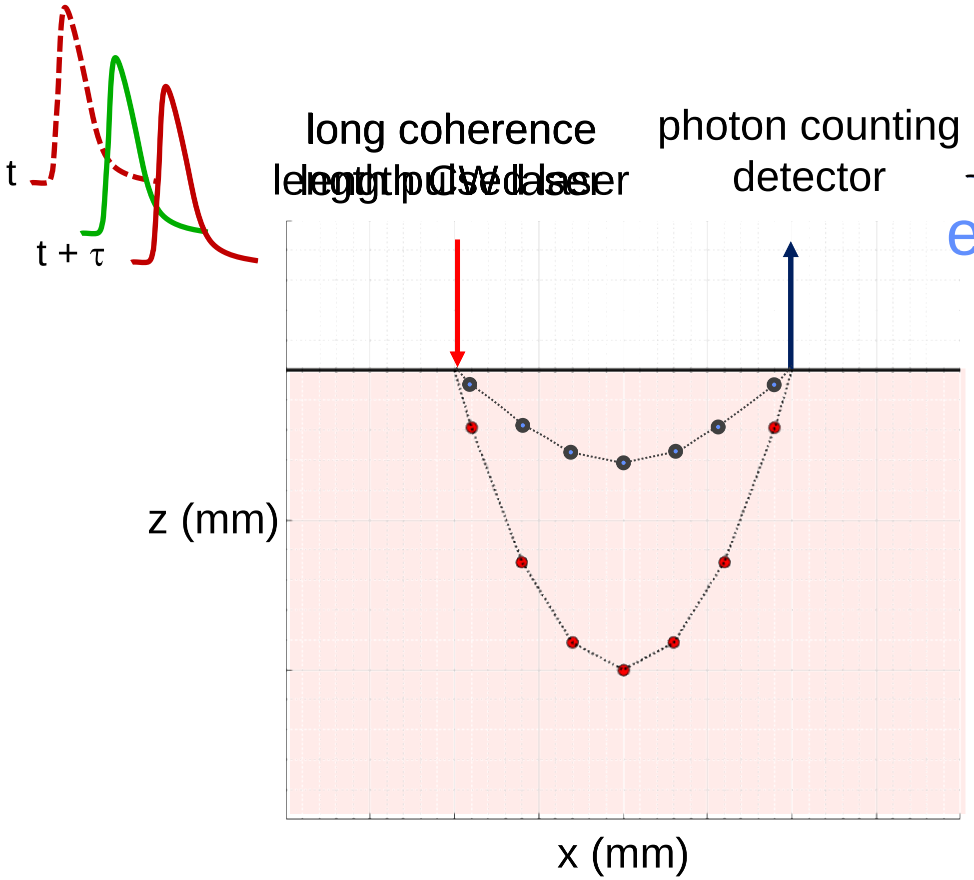


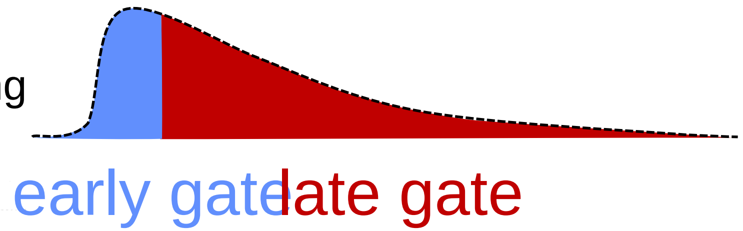


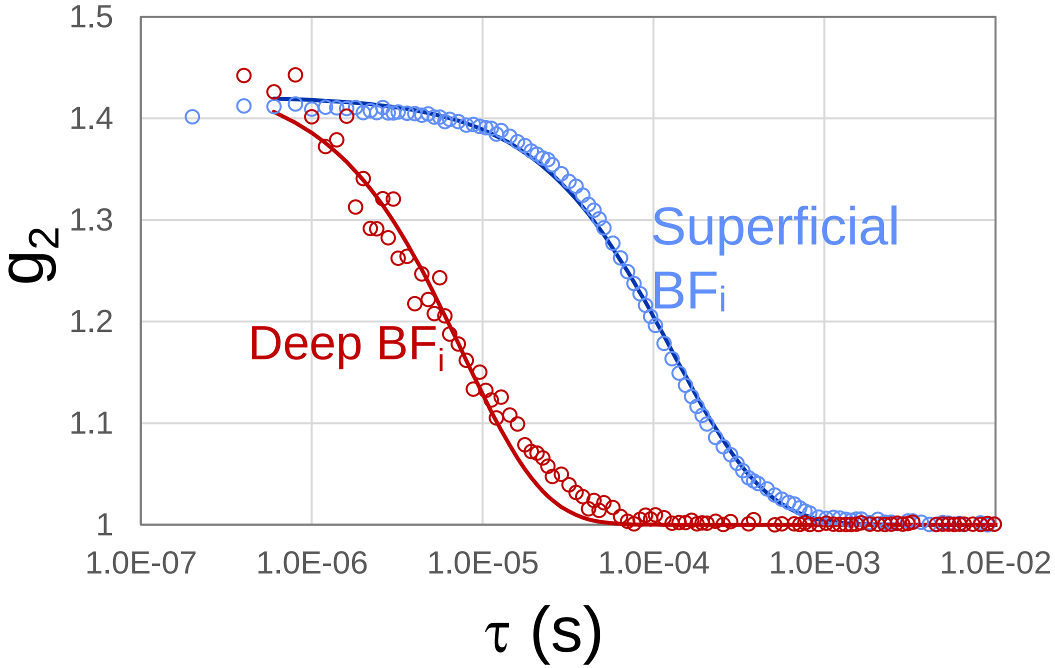
Temporal Intensity Autocorrelation Function

$$g_2(\tau) = \frac{< I(\tau)I(0) >}{< I(0) >^2}$$

Time-resolved Diffuse Correlation Spectroscopy

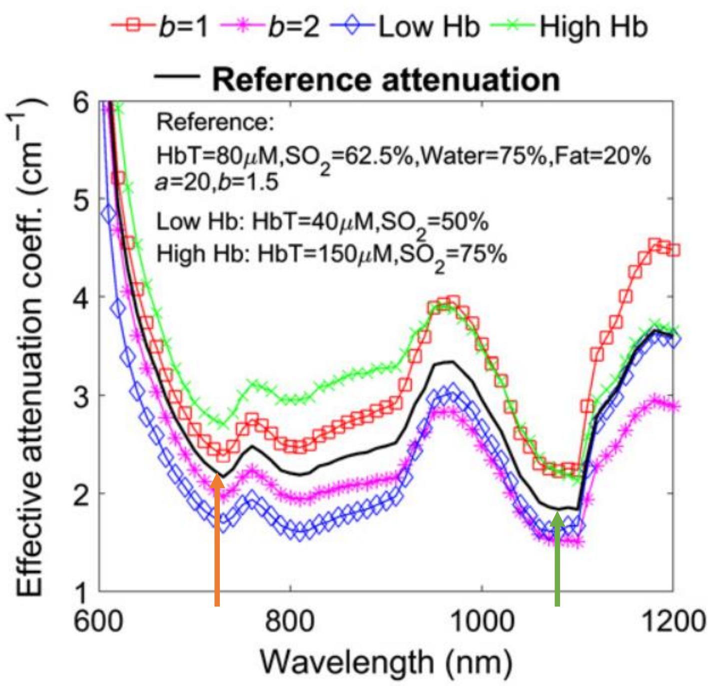




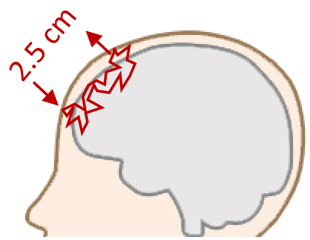


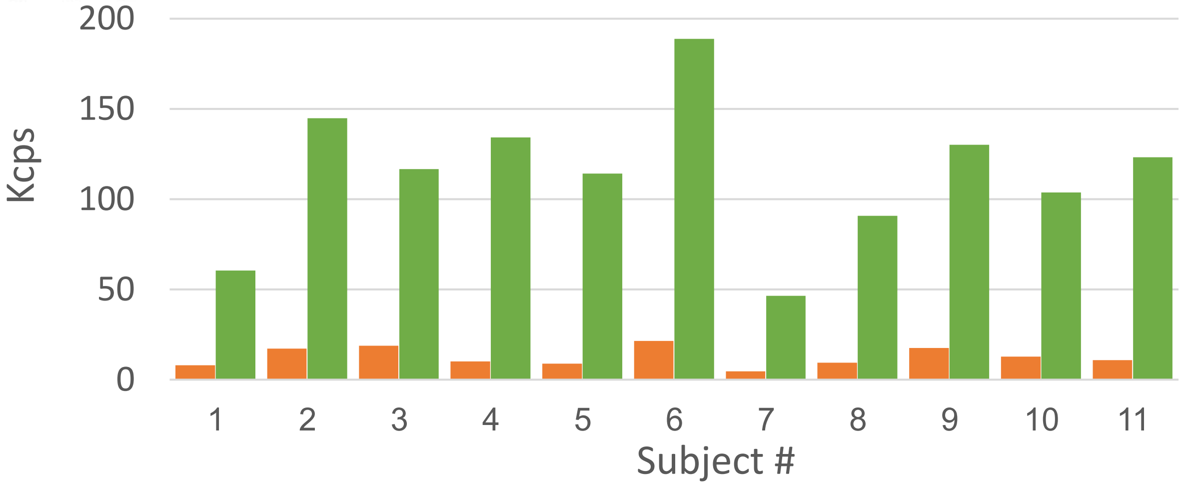
With time-resolved methods we can select photons that have travelled longer path and discard early photons that have only travelled to the surface

Operation at 1064 nm: higher photons availability



	Maximum laser power (>1mm diameter spot)		photons carry less energy at longer λ $E_{\lambda_1} = E_{\lambda_0} \cdot \frac{\lambda_0}{\lambda_1}$		Lower attenuation (μ_{eff}) at longer λ $I_1 = I_0 \cdot e^{(\mu_{eff_0} - \mu_{eff_1})r}$		
765 nm	25 mW ➪ **1**	x	765/765➪ **1**	x	2.2 cm^{-1}➪ **1**	=	1
1064 nm	100 mW ➪ **4**	x	1064/765➪**1.4**	x	1.7 cm^{-1}➪ **1.9**	=	10
	4x energy delivered		40% more photons		15-20% lower attenuation		**x more # of photons**





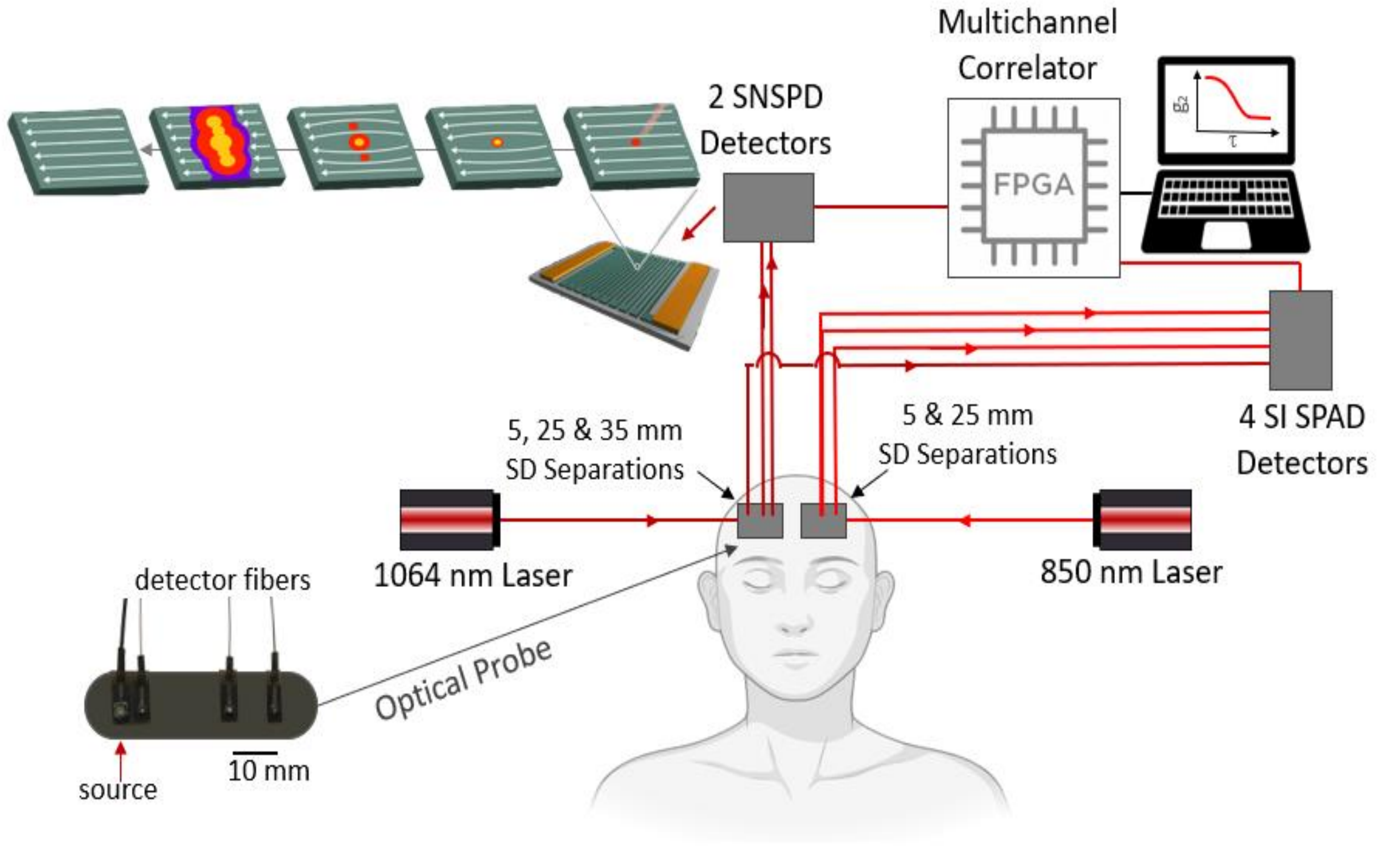
1064 nm
114±40 Kcps

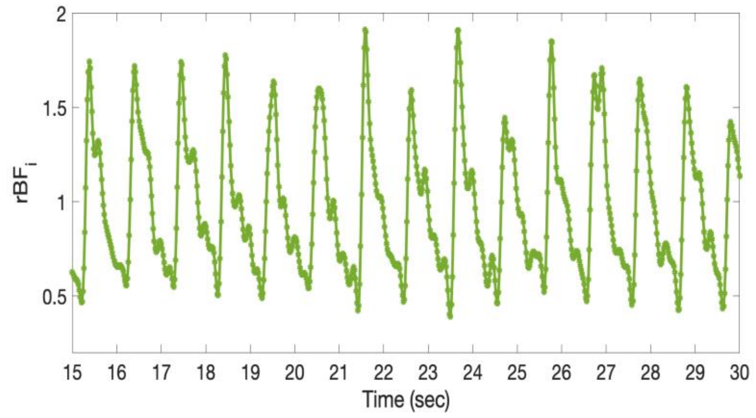
765 nm
12±5 Kcps

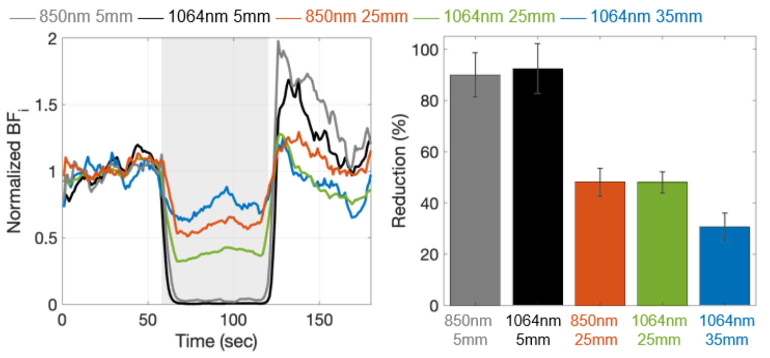
@ 1064 we detect 10 times more photons than @ 765 nm

Ozana N et al. 2021 Neurophotonics

Superconductive Nanowire Single Photon Sensing





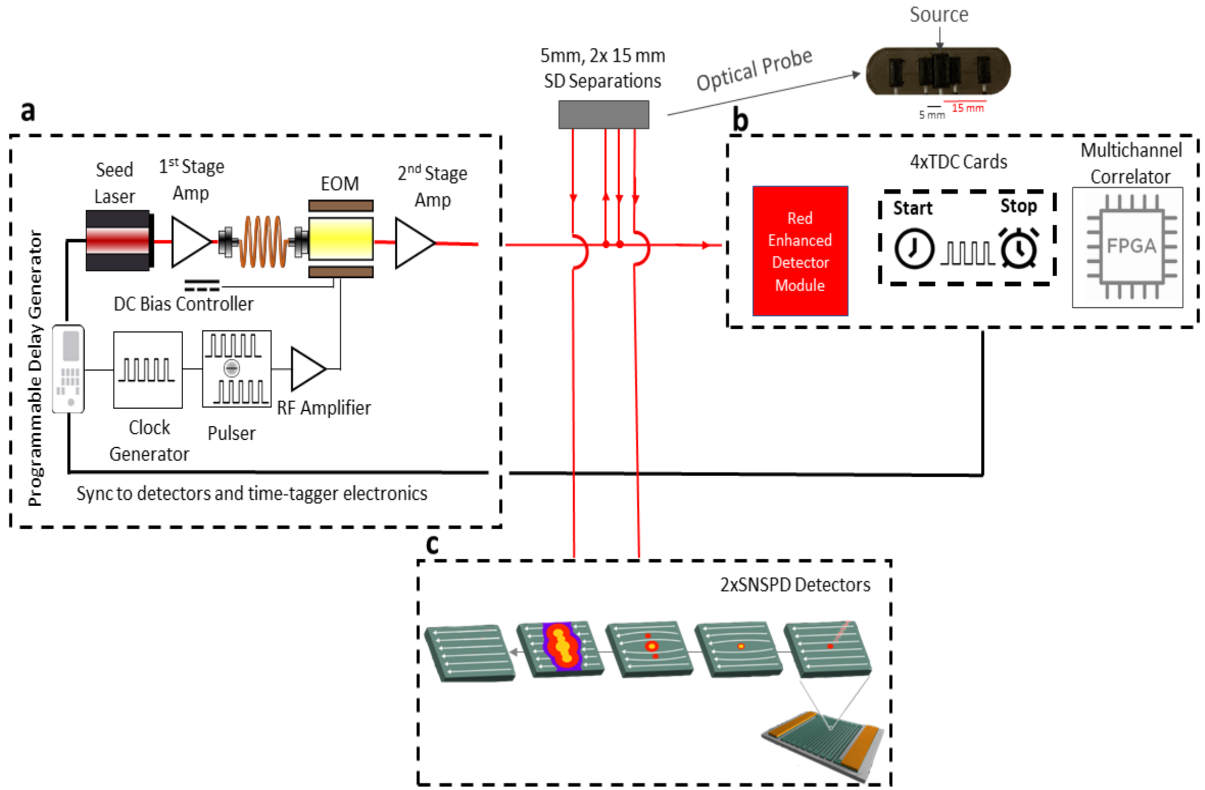


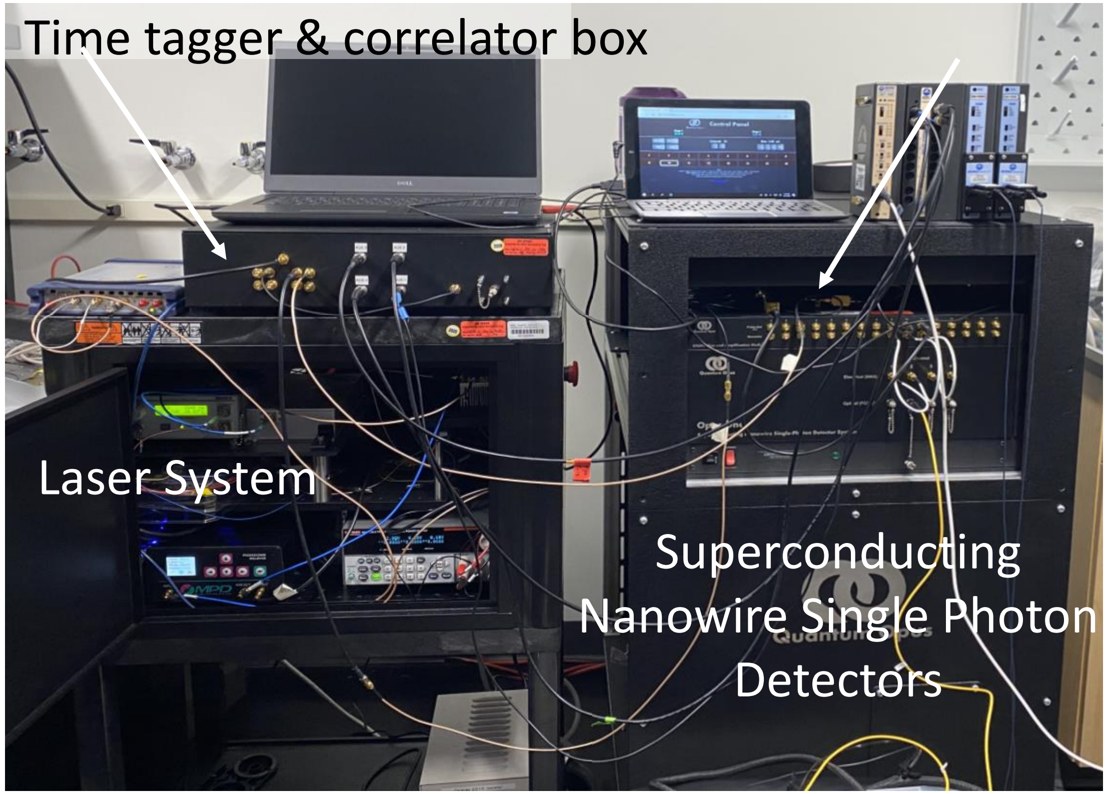
Superconducting nanowire detectors accurately estimate blood flow in the brain – Physics World, Ozana et al.

@ 1064 and SNSPD we can sense long separations with 17% higher sensitivity

Ozana N et al. 2021 Neurophotonics

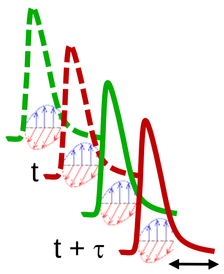
Time Domain Diffuse Correlation Spectroscopy System



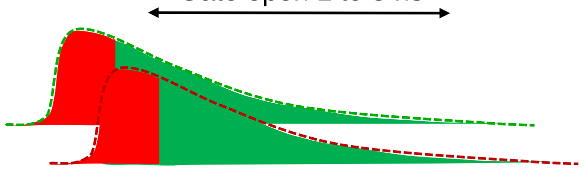


Laser Source: 1W+ 1064 nm, 300 ps pulsed laser
Detectors: Quantum Opus One 4 ch. SNSPD, 90% efficiency at 1064 nm
TCSPC: MPD TDC cards, 10 ps resolution, 160 ns full scale range time-tagger: lab-built, 150 MHz

Train of long-coherence length laser pulses



TPSF

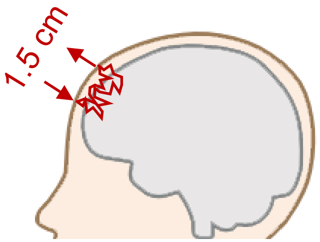


Time-gated photon counting detection

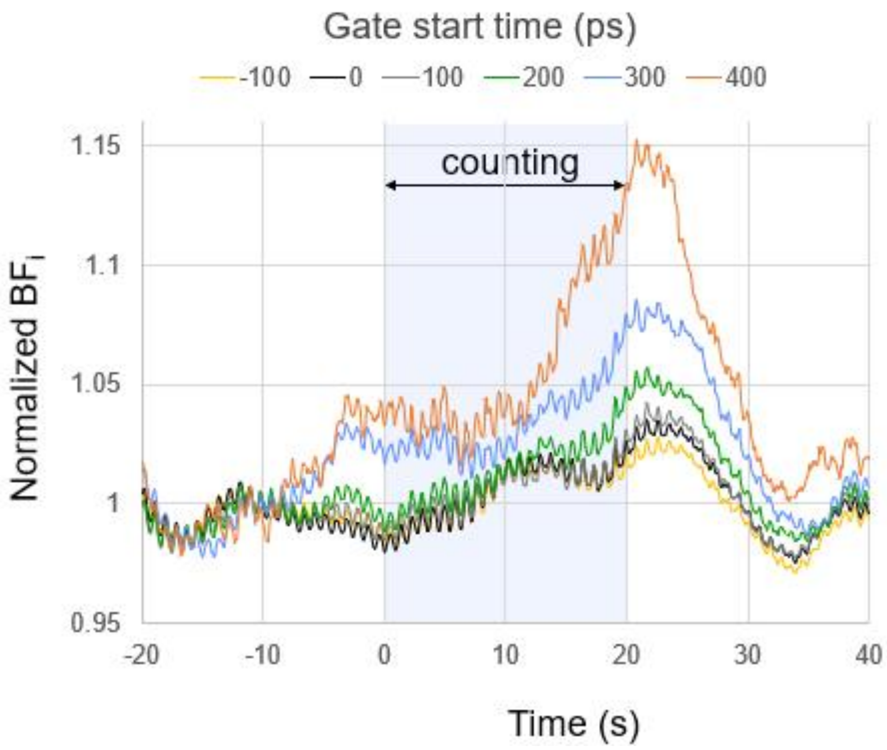
Ozana N et al. 2022, Fron. Neuro.

Functional Blood Flow Changes

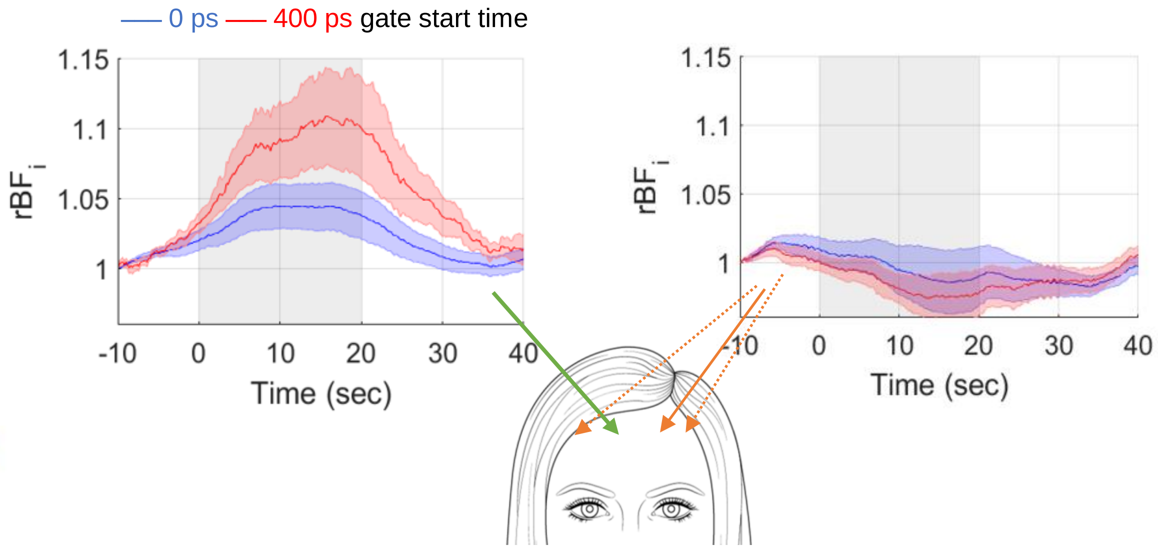
5 repetitions of backwards counting,
3 digits - 1 digit, 20 s task and 30 s rest



Laser FWHM 300 ps
Gate width 1000 ps
S-D sep. 1.5 cm



TD-DCS FUNCTIONAL TASK (subtraction)



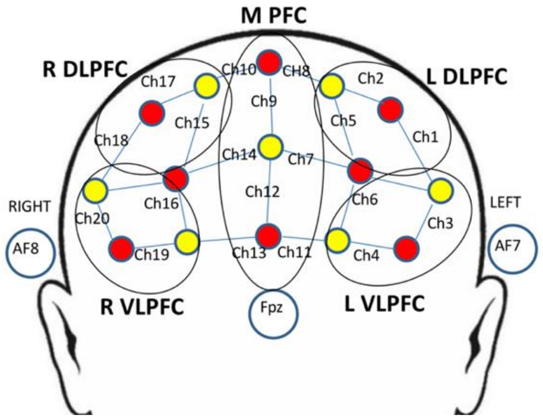
Functional response at active location (right prefrontal) and one non-active location (left prefrontal). Each task was repeated six times in each subject (6 subjects).

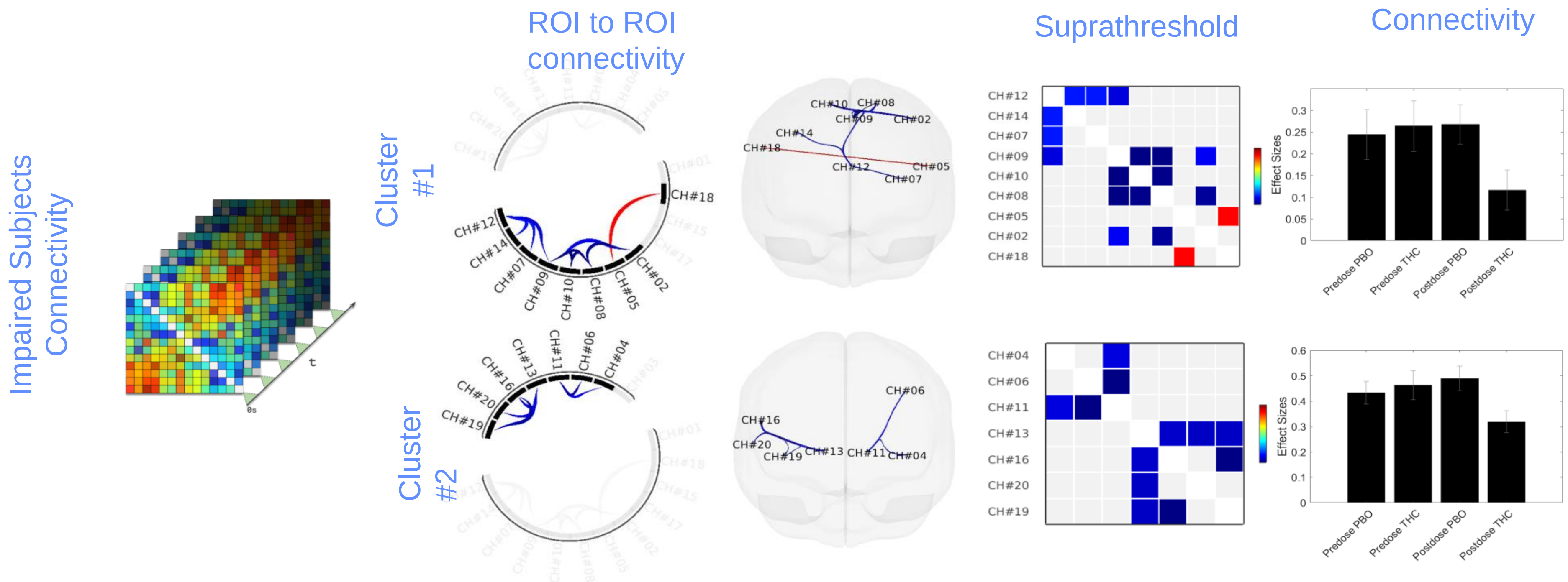
Prof. Maria Angela
Franceschini

Optics @ Martinos

Ozana N et al. 2022, Front. Neuro.

Optical noninvasive resting-state identification of Δ9-tetrahydrocannabinol (THC) Impairment





Jodi Gilman, PhD

Michael Pascale

A. Eden Evins, MD

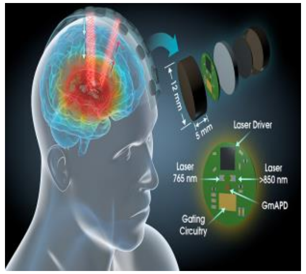
MASSACHUSETTS GENERAL HOSPITAL
A Teaching Hospital of Harvard Medical School

Center for Addiction Medicine

Ongoing Projects – Speckle and DCS Neuromonitoring

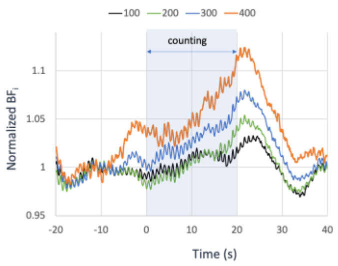
Time domain and heterodyne via multi speckle

TD iDCS Multi Speckle



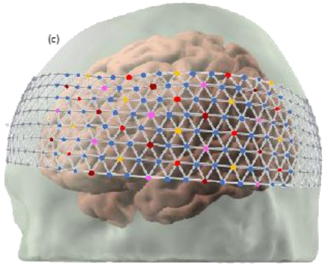
Functional Tests for Brain Computer Interface

Human Tests



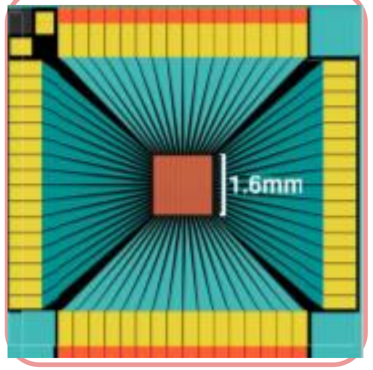
Multichannel System via EEG and Speckle.

Multichannel EEG & Speckle Based



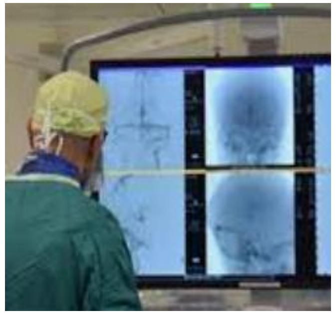
Multichannel SNSPD Sensing

Multichannel SNSPD



Clinical Tests in the hospitals using law cost speckle-based systems

Clinical Neuromonitoring



Acknowledgments

Bar Ilan University, Israel

Harvard Medical School and MGH

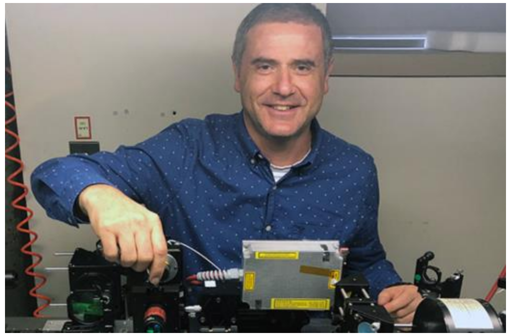
Martinos Center

MGH/HST Athinoula A. Martinos Center for Biomedical Imaging

Yale University

University of Valencia

Meiji University, Japan



Questions? Feel free to send them to ozanan@biu.ac.il