Assessing the brain response to the Rotating Snake illusion by TD-fNIRS

Alessandro Lia[1], **Augusto Bonilauri**[2], **Giuseppe Baselli**[2], **Lorenzo Spinelli**[3], **Fabrizio Martelli**[4], **Paolo Antonino Grasso**[4], **Massimo Gurioli**[4], **Alessandro Torricelli**[1,3], **Davide Contini**[1]
[1]*Dipartimento di Fisica, Politecnico di Milano, Milan, Italy*
[2]*Dipartimento di Elettronica Informazione e Bioingegneria, Politecnico di Milano, Milan, Italy*
[3]*Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche, Milan, Italy*
[4]*Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Sesto Fiorentino, Italy*
Alessandro.lia@polimi.it

Abstract: We assessed the cortical hemodynamic activity induced by static illusory-motion image, detected using a multichannel TD-fNIRS device. Differences in the hemodynamic response function seem located around the motion sensitive area of the visual cortex V5.

1. Introduction

There are a variety of static images that evoke illusory motion perception to the observer. One example is the Rotating Snakes proposed by Kitaoka [1], which circles appear to rotate in the peripheral vision due to a particular arrangement of colors. To our knowledge, there are just two studies of this kind of illusion using neuroimaging techniques: one using functional magnetic resonance imaging fMRI [2] and one using continuous wave (CW) function near-infrared spectroscopy (fNIRS) [3]. We have studied the cortical hemodynamic response to this type of stimulus by Time Domain (TD) fNIRS, aiming at adding valuable information in understanding and localizing which area of the brain are involved in the processing of this illusion. Starting from the results obtained with fMRI, we evaluated changes in cortical activity in the motion sensitive areas of the visual cortex V5/hMT and in the frontal cortex. We compared the hemodynamic response function (HRF) signal for a static illusory-motion image (Rotating Snakes) with respect to two control stimuli: a color changed version of the original one, inducing no motion and a movie in which the 'Rotating Snakes' effectively rotate.

2. Methods

Three adult participants from the Physics Department of Politecnico di Milano provided informed consent and volunteered for this study. All participants had normal or corrected-to-normal vision and reported to perceive the illusion stimuli rotate while this effect was strongly reduced for the control no illusion case.

2.1. Stimuli

For the experiment we adopted a classical block design paradigm consisting of baseline, stimulus and post-stimulus resting periods as reported in Fig. 1. The protocol consisted in 40 s baseline with the subject fixing a grey screen followed by a block of 10 s rest, 20 s stimuli and 10 s recovery repeated 5 times for each of the three visual stimuli for a total of ten minutes. Each block was separated by an inter-stimulus interval between 0-10 sec and the order of conditions was randomized throughout the experiment for each participant.

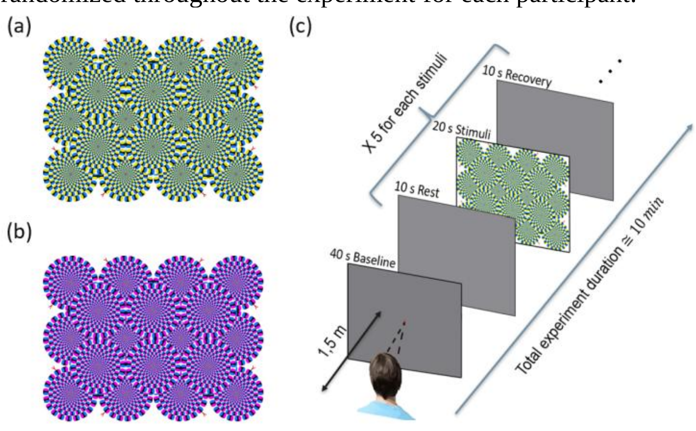

Fig. 1. a) Rotating Snakes: illusion stimulus. b) Control: no illusion case. c) Schematic of the experimental protocol.

2.2. Optodes placement

For the optodes placement we exploited the correspondence between regions of the international 10-20 system and respective cortical anatomical areas. From the fMRI results, relevant differences between the illusion stimulus and the control case for the BOLD signal have been observed around V5/hMT, which is an area of the visual cortex related to the elaboration of motion, while no difference has been observed around the primary visual cortex V1. Starting from these results we selected the following fiber geometry for our measurements reported in Fig.2, with most of our probes covering the occipitotemporal region, where according to the 10-20 system should be located V5 and a source-detector couple on the forehead monitoring also the frontal cortex and a possible cognitive load. One source was placed around PO6/PO4 coupled with detectors P2, P4, PO4/PO2, P6, O2, P8 and PO8 and the other in Fp2 coupled with detector AF8.

Fig. 2. Picture of the probes geometry where in red are labelled the sources and in blue the detectors.

2.3. fNIRS acquisition

For the data acquisition we used a multichannel (16 sources, 8 detectors) TD-fNIRS device operating at two wavelengths (687 and 826 nm), based on space wavelength multiplexing [4]. For the injection module we adopt a couple of picosecond pulse diode lasers (LDH-P PicoQuant GmbH), with 80 MHz repetition rate, and a multi-channel (2x18) fiber optic switch (Leoni GmbH) to control the injection of light through the 18 possible input sources. The detection unit consists of 8 identical and independent detection lines each made of a fiber bundle, a hybrid photomultiplier tube (H-PMT) with high dynamic range and free from after-pulse phenomenon and a board (SPC-130 EM, Becker&Hickl GmbH) for time-correlated single photon counting (TCSPC) to provide a sensitivity down to a single photon detection. Time-resolved reflectance measurements were simultaneously performed in the frontal and occipital temporal areas at the two wavelengths with an overall acquisition time of 1 s for each detector (i.e. 0.5 s for each wavelength/frame).

2.4. Data analysis

For the data analysis we modelled the head as a bilayer structure and we applied the time gating approach to remove the extra-cerebral superficial contribution from the cortical one related to the activation due to stimuli [5]. Then the signal for each channel was fitted with a model of the HRF made of the two gamma functions [6] convolved with a boxcar function following the stimuli onset. Amplitude and the delay of the response were used as fitting parameter.

3. Results

In Fig. 3 first column, the results for a single subject after applying the time gating approach for the illusion case are reported. Since all the occipitotemporal channels report a similar behavior we reported the signal of just one channel, as an example in the first line, where the bold lines are the fit with the HRF. We can see an evident cortical activation (increase in oxygenated O_2Hb, decrease in deoxygenated HHb hemoglobin) which confirms the involvement of V5 in the elaboration of the illusion. If we compare this signal with the one of the no illusion cases in the second column, some differences can be observed in the shape of the response: amplitude and delay which allow us to distinguish between the two. Finally, we have the signal for the real motion which closely resembles the illusion case with the intensity of the response in all the channel a bit higher as expected since in this case the stimulus is really moving. For all the three condition no relevant activations are observed in the frontal area (see Fig.3 panels d-f).

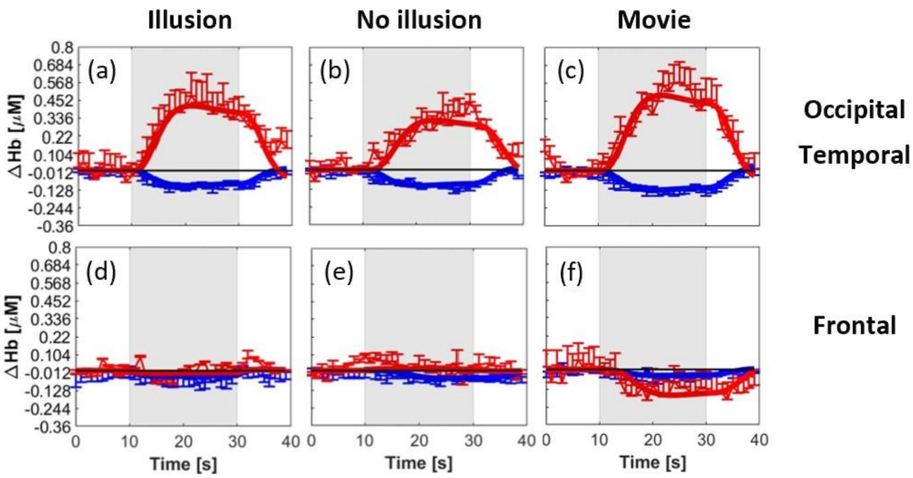

Fig. 3. Average time course of hemodynamic parameters ΔO_2Hb (red) and ΔHHb (blue) for the occipitotemporal area first line (couple PO6/PO4-P6), and frontal (Fp2-AF8) second line, divided by stimuli (columns). The "task" region is indicated in light grey and error bars represents the variation over the 5 repetitions.

4. Conclusion

We have seen with this study the feasibility to detect and map brain activations related to motion illusion induced by Rotating Snakes stimuli using a multichannel TD-NIRS device. We have seen that the frontal cortex seems not involved in the elaboration of the image with no relevant activations, on the contrary of all the regions on the occipital temporal area covered with the selected fiber geometry. Such HRF signal seems to be different between the illusion and the control case and closely resemble what observed in literature with fMRI, the gold standard [2]. For what concern future improvements, first of all we will improve our sensitivity to V5/hMT with the use of software that simulate the propagation of photons (e.g. Nirstorm package) trying to maximize ad localize the response. Then, increasing the number of subjects we will try to extract the shape of the responses figuring out some quantitative parameters to distinguish the illusion from the control case. In this perspective, we are considering to implement some eye movement control to quantify the effect of the illusion introduced, being the effect strongly related to the latter as observed and confirmed in literature [2].

5. References

[1] Kitaoka, A. and Ashida, H. "Phenomenal characteristics of the peripheral drift illusion". Vision, 15, 261–262. (2003).

[2] Kuriki I, Ashida H, Murakami I and Kitaoka A. "Functional brain imaging of the Rotating Snakes illusion by fMRI". Journal of vision (2008).

[3] Hashimoto. T., Yasuyo Minagawa-Kawai. Y. and Kojima. S. "Motion illusion activates the visual motion area of the brain: A near-infrared spectroscopy (NIRS) study". Brain Research (2006).

[4] R. Re et al. "Multi-channel medical device for time domain functional near infrared spectroscopy based on wavelength space multiplexing". Biomed Opt Express, (2013).

[5] L. Zucchelli et al. "Method for the discrimination of superficial and deep absorption variations by time domain fNIRS". Biomed Opt Express, (2013).

[6] M.Uga et al. "Optimizing the general linear model for functional near-infrared spectroscopy: an adaptive hemodynamic response function approach". Neurophotonics vol. 1,1, (2014).