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Explore the Brain Activity During Translation and Interpreting Using Functional Near-Infrared Spectroscopy

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ABSTRACT

Since the mid-1970, functional near-infrared spectroscopy (fNIRS) has been developing a non-invasive technique to investigate brain activities under different stimuli by measuring the changes of hemodynamic responses based on the near-infrared light between 650 nm and 950 nm. fNIRS has been used to localize or monitor the cerebral activity under different cognitive tasks including visual, auditory, memory, attention, perception, somatosensory, motor, language and even translation.

Interestingly the text-to-text translation and simultaneous interpreting are both complex activities involved in many sub-skills including perception, listening and speaking, reading and writing, reasoning and decision making, problem solving, memory, and attention and so on. The neuroimaging techniques are essential to investigate the basic neurological mechanism underlying the translation and interpreting. Recently a bunch of work has been conducted for translation and interpreting based on electroencephalogram (EEG), functional magnetic resonance (fMRI), direct electrostimulation and positron emission tomography (PET), however, few have adopted the fNIRS measures. In this book chapter, we will talk about the fundamental of fNIRS and its basic applications in the study of translation and interpreting.

INTRODUCTION

Since the mid-1970, functional near infrared spectroscopy (fNIRS) has been developing a non-invasive technique to investigate brain cerebral hemodynamic levels associated with brain activity under different stimuli by measuring the change of absorption coefficient of the near-infrared light between 650 nm and 950 nm [1-8]. Compared to the available functional neuroimaging modalities, such as functional magnetic resonance (fMRI) and positron emission tomography (PET), fNIRS has the advantages of portable, convenience and low cost, and more importantly, it offers unsurpassed high temporal resolution and quantitative information for both oxy-hemoglobin (HbO_2) and deoxy-hemoglobin (HbR), which is essential for identifying rapid changes of dynamic patterns of brain activities including changes of blood oxygen, blood volume and blood flow.

As a neuroimaging method, fNIRS enables continuous and noninvasively monitoring of changes in blood oxygenation and blood volume related to human brain function. fNIRS can be implemented in the form of a wearable and noninvasive or minimally intrusive device, and it has the capacity to monitor brain activity under real life conditions and in everyday environments. During neural stimulus processing, there will be local increase in blood flow, blood volume and also an increase in blood oxygenation in a stereotyped hemodynamic response. Recently, advances in the understanding of light propagation in diffusive media (also known as photon migration) and technical developments in optoelectronics components have made it possible to extract valuable optical/hemodynamic information from human brain. Different fNIRS instruments including commercial systems or laboratory prototypes have been developed and used effectively in preclinical and clinical studies. Obtaining measurements of the hemodynamic response of localized regions of the brain allows for inferences to be made regarding local neural activity.

In addition, the text-to-text translation and simultaneous interpreting are both complex activities, which consist of many sub-skills including perception, listening and speaking, reading and writing, reasoning and decision making, problem solving, memory, and attention and so on. Successful execution of simultaneous interpreting to a large extent depends on verbal working memory, simultaneous speech perception and articulation, and switching between languages. And the capability for translating and interpreting is an accompaniment of bilingualism. So far a lot of work has been conducted to study the basic neural mechanism of the translation and simultaneous interpreting using different neuroimaging methods including electroencephalography (EEG), fMRI, direct cortical electrostimulation, PET and fNIRS [9-17]. Findings from previous work have indicated that 1) the types namely, single words, sentences and the direction of translation are the key factors involved in neural substrates; 2) there is a hemispheric lateralization process involved in the translation; 3) Broca's area seems to be the most important in response to translation tasks; and 4) no particular brain regions have been demonstrated to be shown exclusive to translation

processes. In this book chapter, we will first talk about the methods and instrumentations of fNIRS. Then the applications of fNIRS in translation and simultaneous interpreting will be discussed.

BASIC PRINCIPLES OF FNIRS

Frans Jöbsis, the founder of in vivo fNIRS, reported the first real-time non-invasive detection of hemoglobin oxygenation using transillumination spectroscopy in 1977 [4]. Jöbsis and Chances also used fNIRS to study cerebral oxygenation in human subjects after concerning the applications of this technique in laboratory animals [18-20]. Later Ferrari investigated the effects of carotid artery compression on regional cerebral blood oxygenation and blood volume of cerebrovascular patients together with the data on newborn brain measurements by utilizing prototype fNIRS instruments [21,22]. Importantly, Delpy performed the first quantitative measurement of various oxygenation and hemodynamic parameters in newborn infants including changes in oxygenated HbO_2, deoxygenated HbR and total hemoglobin (HbT) concentrations, cerebral blood volume, and cerebral blood flow [23,24].

fNIRS is based on the physical and physiological mechanisms that human tissues are relatively transparent to light in the near infrared (NIR) spectral window and the relatively high attenuation of NIR light in tissue is due to the main chromophore hemoglobin (the oxygen transport red blood cell protein) located in small vessels of the microcirculation, such as capillary, arteriolar and venular beds. fNIRS is weakly sensitive to blood vessels >1 mm because they completely absorb the light. Given the fact that arterial blood volume fraction is approximately 30% in humans brain [25,26], the fNIRS technique offers the possibility to obtain information mainly concerning oxygenation and blood volume changes occurring within the venous compartments.

fNIRS is a non-invasive and safe neuroimaging technique that utilizes laser diode and/or light emitting diode light sources spanning the optical window and flexible fiber optics to carry the NIR light from (source) and to (detector) tissues. Fiber optics are very suitable for any head position and posture. fNIRS measurements can be performed in natural environments without the need for restraint or sedation. Adequate depth of NIR light penetration (almost one half of the source-detector distance) can be achieved using a source-detector distance around 3 cm. The selection of the optimal source-detector distance depends on NIR light intensity and wavelength, as well as the age of the subjects and the head regions measured. As a consequence of the complex light scattering effect by different tissue layers, the length of the NIR light path through tissue is longer than the physical distance between the source and detector pair.

According to Beer's law [6], the wavelength-dependent tissue optical density changes can be written in terms of the changes of the chromophores including HbO_2 and HbR at time t with wavelength ,

$$\begin{bmatrix} \Delta OD(r,t)\big|_{\lambda_1} \\ \Delta OD(r,t)\big|_{\lambda_2} \end{bmatrix} = DPF(r)l(r)\begin{bmatrix} \varepsilon_1(\lambda_1) & \varepsilon_2(\lambda_1) \\ \varepsilon_1(\lambda_2) & \varepsilon_2(\lambda_2) \end{bmatrix}\begin{bmatrix} \Delta HbO_2(r,t) \\ \Delta HbR(r,t) \end{bmatrix} \quad (1)$$

in which OD is the optical density as determined from the negative log ratio of the detected intensity of light with respect to the incident intensity of light using continuous-wave (CW) measurements, ΔOD is the optical density change (unitless quantity) at the position r, DPF(r) is the unitless differential path length factor, l(r) (mm) is the distance between the source and the detector, $\varepsilon_i(\lambda)$ is the extinction coefficient of the ith chromophore at wavelength λ of laser source, ΔHbO_2 and ΔHbR (μM) is the chromophore concentration change for oxy- and deoxy-hemoglobin, respectively. After multiply the inverse matrix of the extinction coefficients for both sides of Eq. (1), the time series matrix for the changes of HbO_2 and HbR is written as

$$\begin{bmatrix} \Delta HbO_2(r,t) \\ \Delta HbR(r,t) \end{bmatrix} = \begin{bmatrix} Q_{HbO_2}(r,t) \\ Q_{HbR}(r,t) \end{bmatrix} / (DPF(r)l(r)) \tag{2}$$

in which Q (r,t) vectors are the product of the inversion matrix of the extinction coefficients and the optical density change vectors. Similar operational procedures could be extended to nth wavelength case based on regularization methods:

$$\begin{bmatrix} \Delta HbO_2 \\ \Delta HbR \end{bmatrix} = (\mathbf{E}^T\mathbf{R}^{-1}\mathbf{E})^{-1}\mathbf{E}^T\mathbf{R}^{-1} \begin{bmatrix} \Delta OD\big|_{\lambda_1} \\ \Delta OD\big|_{\lambda_2} \\ \cdots \\ \Delta OD\big|_{\lambda_n} \end{bmatrix} / (DPF \times l)\ ; \quad \mathbf{E} = \begin{bmatrix} \varepsilon_1(\lambda_1) & \varepsilon_2(\lambda_1) \\ \cdots & \cdots \\ \varepsilon_1(\lambda_n) & \varepsilon_2(\lambda_n) \end{bmatrix} \tag{3}$$

where the matrix E is the extinction coefficient matrix and R is defined as the a priori estimate of the covariance of the measurement error. The change of total hemoglobin concentration ΔHbT (μM) is defined as the sum of ΔHbO_2 and ΔHbR.

THE fNIRS INSTRUMENTATIONS

Different fNIRS instruments with related key features, advantages and disadvantages, and parameters measurable by using different fNIRS techniques have been developed and listed in Table 1 [27,28]. Briefly, three typical signal measurement techniques using fNIRS light are currently being used for optical tissue imaging: CW, time-domain (TD) and frequency-domain (FD) methods. CW fNIRS systems directly measure the intensity of light transmitted or reflected through the tissue. The light source used in CW systems generally has a constant intensity or is modulated at a low frequency (a few kHz). TD systems use short laser pulses, with temporal spread below a nanosecond, and detect the increased spread of the pulse after passing through tissue. FD systems use an amplitude-modulated source at a high frequency (a few hundred MHz) and measure the attenuation of amplitude and phase shift of the transmitted signal. Typically in this approach, a radio-frequency oscillator drives a laser diode and provides a reference signal for phase measurement. Among the three methods, the CW approach is relatively cheap and easy to implement. So far CW setups are also the most used optical neuroimaging/spectroscopy systems.

Table 1: Three typical fNIRS measurements systems.

Main characteristics	fNIRS techniques-based instrumentation		
	Continuous wave	Frequency-domain	Time-domain
Sampling rate (Hz)	≤100	≤50	≤10
Spatial resolution (cm)	≤1	≤1	≤1
Penetration depth with a 4 cm source-detector distance	Low	Deep	Deep
Discrimination between cerebral and extra-cerebral tissue (scalp, skull, CSF)	n.a.	Feasible	Feasible
Possibility to measure deep brain structures	Feasible on newborns	Feasible on newborns	Feasible on newborns
Instrument size	Some bulky, some small	Bulky	Bulky
Instrument stabilization	n.r.	n.r.	Required
Transportability	Some easy, some feasible	Feasible	Feasible
Instrument cost	Some low, some high	Very high	Very high
Telemetry	Available	Difficult	Not easy
Measurable parameters			
[HbO_2], [HbR], [HbT]	Yes, changes	Yes, absolute value	Yes, absolute value
Scattering and absorption coefficient and pathlength measurement	No	Yes	Yes
Tissue HbO_2 saturation measurement (%)	No	Yes	Yes

CSF = cerebrospinal fluid, HbR = deoxy-hemoglobin, n.a. = not available, n.r. = not required, HbO_2 = oxy-hemoglobin, HbT = HbO_2+HbR.

The development of fNIRS instrumentation started in 1992 with a single channel system with low temporal resolution and poor sensitivity, as shown in Figure 1. In 1995, the multi-channel systems (the first 10-channel system) were reported. The present high temporal resolution multi-channel systems, using the three different fNIRS techniques and complex data analysis systems, provide simultaneous multiple measurements and display the results in the form of a map or image over a specific cortical area or the whole brain, as displayed in Figure 2. The potential that exists for fNIRS more than for any other neuroimaging modality is represented by the realization of multi-channel wearable and/or wireless systems that allow fNIRS measurements even in normal daily activities.

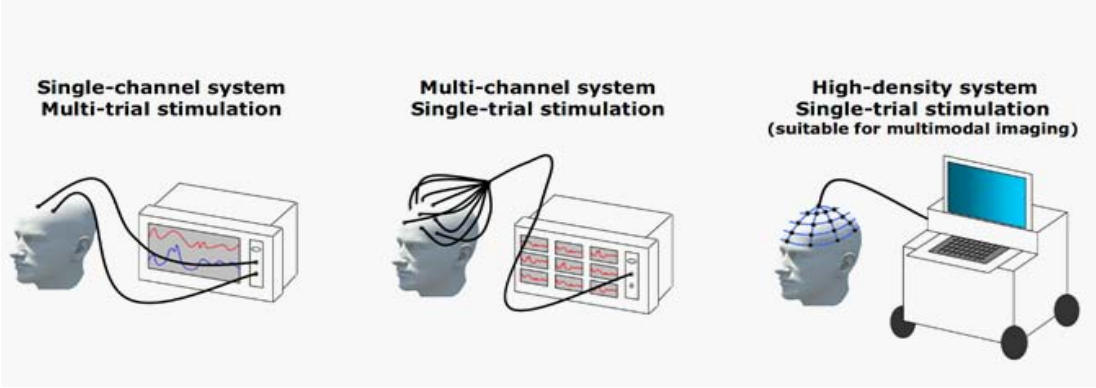

Figure 1: Sketch of the development of fNIRS instrumentation from single channel with a low temporal resolution and poor sensitivity up to the multi-channel systems.

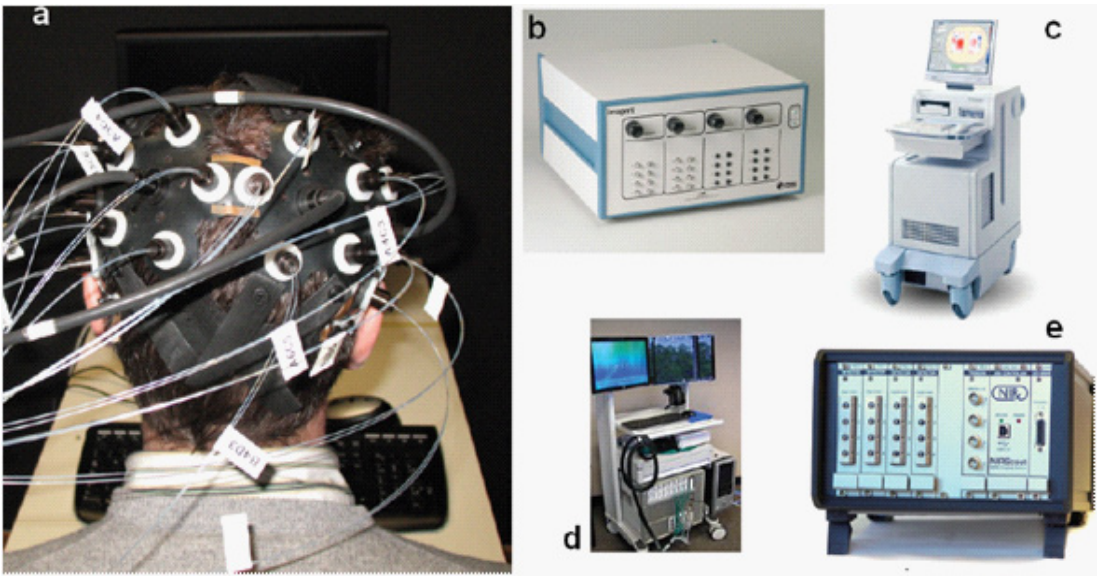

Figure 2: (a) A typical example of an fNIRS probe holder placed on the head of a participant (bilateral parietal lobe). In this setup, thin optical fibers (diameter 0.4 mm) convey near infrared light to the participant's head (note that each location comprises two optical fibers, one for each wavelength), whereas optical fiber bundles (diameter 3 mm) capture the light that is scattered through the brain tissue.

(b) The ISS Imagent: http://www.iss.com/biomedical/instruments/imagent.html; (c) the Hitachi ETG 4000: http://www.hitachi-medical-systems.eu/products-and-services/optical-topography/etg-4000.html; (d) the Nirsoptix Brain Monitor: http://www.nirsoptix.com/CW6.php and (e) the NIRScout: http://www.nirx.net/imagers/nirscout-xtended.

THE APPLICATIONS OF FNIRS IN TRANSLATION AND INTERPRETING

Since the mid-1990, most of the research work done in neurosciences using fNIRS has been focused on quantitative analysis and imaging of human and small animal brain functions. They have utilized these two techniques to localize or monitor the cerebral responses under different stimulus including visual [29-31], auditory [32], somatosensory [33], motor [34-36], language [37], and even translation [38].

Interestingly it was found from previous work that the findings using the native language (L1) or the non-native language (L2) in different settings during monolingual communication is not the same as that from translating [39-41]. It follows that translation-specific processes cannot be directly inferred from research on, or models of the bilingual brain. It was also reported from several behavioral studies that translation training has been shown to be able to modulate accuracy and response times (RTs) in a variety of linguistic and non-linguistic tasks. For example, Bajo et al. [42] reported that professional interpreters are able to perform better than interpretation students and bilinguals without translation experience in a semantic categorization task when nontypical exemplars are involved. It was also found that professional interpreters respond faster and more precisely than bilingual university students in both language and working memory tasks [43], and that they can even outperform foreign language teachers in terms of accuracy RTs. In particular, a comparison of stress-induced physiological responses between interpretation students and professional interpreters was performed, which revealed that the latter tend to maintain a lower and more constant pulse rate during simultaneous interpreting sessions [44]. The features on linguistic processing differences between interpreters and non-interpreters seem to be developed during the early stages of formal translation training [45].

Recent fNIRS work [38] has been reported to utilize a 12-channel CW system to explore the hemodynamics changes of the brain regions related to the translation tasks [38]. In this study, 8 right-handed male subjects aged between 19 to 24 years old participated in the tests, in which the subjects were native students and early bilinguals-Dutch (L1) and English (L2). In the experiment, the subjects were asked to implement four tasks including: 1) Translated from native language (L1) into non-native language (L2); 2) Translated from non-native language (L2) into native language (L1); 3) Translated 7 short sentences in each direction, for example, 'I want to go shopping.' and 'She writes with a pencil.' 4) A control task composed of reading simple sentences out loud. The four tasks were randomly presented and each were performed 4 times. The NIR instrument utilized in this study was two pulsed synchronised instruments (OXYMON, Artinis Medical Systems, Arnhem, and The Netherlands) [39]. Two wavelengths (775 and 850 nm) with a laser power of about 1 mW were used and the light was transmitted and collected using a 2-meter-long optic fiber bundles with 4 mm diameter (four sources and five detectors). All the sources and the detectors were placed on a probe holder to keep the source–detector

distance at 3.5 cm. The geometry of the probe allowed the concomitant measurement of 12 sites over a head area of about 7 cm × 7 cm. The sampling frequency of the system was 0.1 Hz. Figure 3 shows how the probe holder was positioned on the left lateral frontal lobe and centered around the Broca's area.

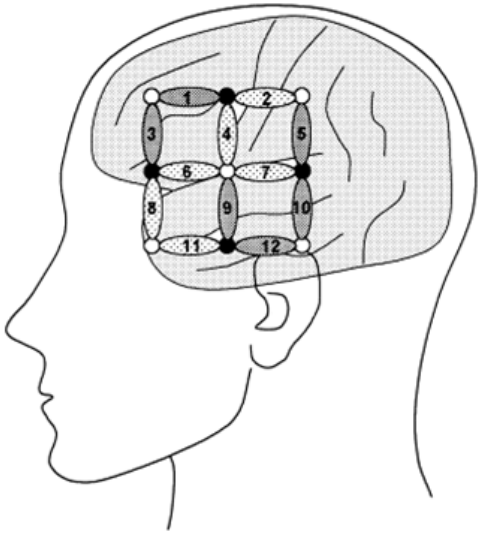

Figure 3: Schematic representation of the optical probe (the white circles stand for source; the black circles represent detector;12 channels). The optical probe was located on the left lateral frontal lobe and centred around the Broca's area according to the 10–20 system. (From reference 38 with permission).

A topographic presentation of the time courses of hemodynamic changes in the left hemisphere during translation from Dutch into English of seven short visually presented sentences was provided in Figure 4. It was observed from Figure 4 that left inferior frontal cortex including the Broca's area showed a consistent and incremental rise in HbO_2 accompanied by a smaller decrease in HbR, which indicated that Broca's area was related to the neural activity during the translation process. The hemodynamic change pattern such as decreased HbR and increased HbO_2 is a representative feature of a localized increase in cerebral blood flow. A delay in the response of the HbR compared that from HbO_2 may be identified.

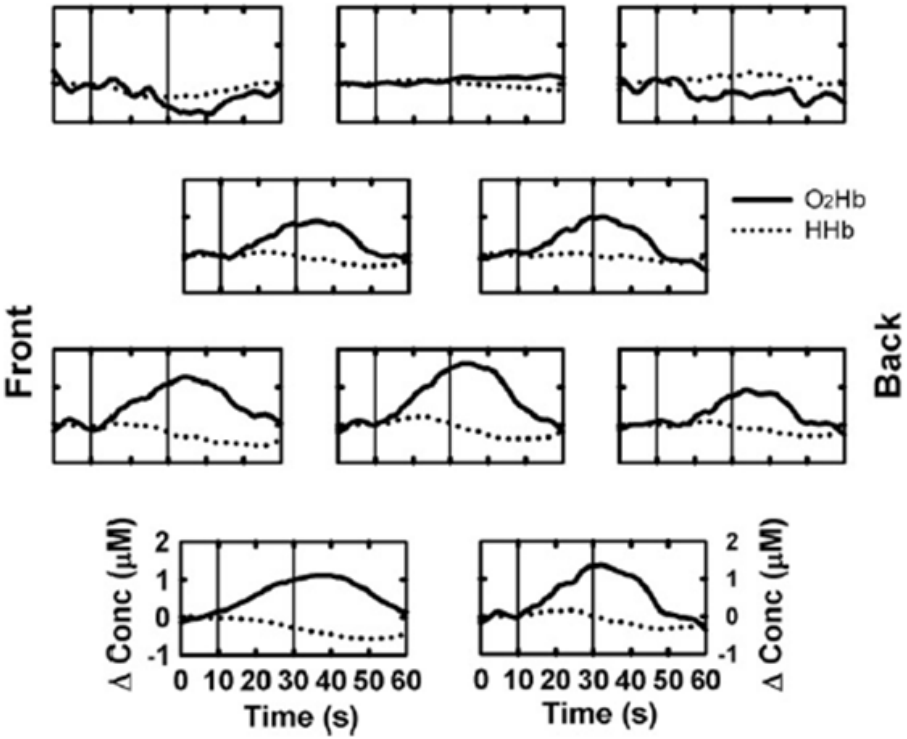

Figure 4: Typical topographic presentation of the time courses of hemodynamic changes (average of responses over four 21-s blocks) during a translation task (consisting of a translation from Dutch into English of seven short visually presented sentences). The vertical lines indicate the translation period. During the rest period the subjects watched a row of crosses presented every 3 s on the screen. Here O_2Hb represents HbO_2 while HHb represents HbR (from reference 38 with permission).

In addition, it was observed from Figure 4 that the activation areas were more pronounced in the inferior frontal cortex, including Broca's area. However, the sites adjacent to Broca's area were not uniformly activated.

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