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Chapter 28

Functional Near-Infrared Spectroscopy: Proof of Concept for Its Application in Social Neuroscience

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The mission of social psychology is to understand "how the thoughts, feelings, and behaviour of individuals are influenced by the actual, imagined, or implied presence of others."[1] The mission of social neuroscience is to understand the neural and broader biological underpinnings of social psychological phenomena.[2] Like every scientific discipline, the success of social neuroscience rests on the effectiveness of its methods. Recent years have witnessed a proliferation of methods that hold promise for advancing social neuroscience. One such method is continuous-wave functional near-infrared spectroscopy (fNIRS), a functional neuroimaging technique that can be used to measure brain activity noninvasively.[a] In this chapter we demonstrate the utility of fNIRS for social neuroscience in identifying well-established patterns of prefrontal activity when people make self- and other-referential judgments.[3]

A BRIEF INTRODUCTION TO FNIRS AND ITS POTENTIAL FOR SOCIAL NEUROSCIENCE

Detailed reviews of continuous-wave fNIRS methodology and instrumentation are available elsewhere,[4,5] so here we provide only a brief outline of fNIRS principles. Measurements of brain activity obtained by fNIRS are based on the hemodynamic response, or more specifically on the fact that neuronal activity is fueled by glucose metabolism in the presence of oxygen. The hemodynamic response is a homeostatic process that replenishes the nutrients used by biological tissues by adjusting blood flow to areas of focal activity. Increases in neuronal activity set off a series of vascular events that result in the flooding of neuronal tissues with oxygenated hemoglobin (oxy-Hb), the protein molecules that carry oxygen within the blood. During bouts of activity the rate of oxy-Hb delivery typically exceeds the rate of oxygen utilization, resulting in a temporary increase in the concentration of oxy-Hb and a decrease in the concentration of deoxygenated hemoglobin (deoxy-Hb).

Whereas most biological tissues are transparent to near-infrared (NIR) light, oxy-Hb and deoxy-Hb are known to absorb and scatter NIR light of slightly different wavelengths in the range of 700–1000 nm. Continuous-wave fNIRS capitalizes on this property of oxy-Hb and deoxy-Hb. Light emitters placed on the surface of the scalp radiate NIR light into the head. Given the differential absorption and backscattering of oxy-Hb and deoxy-Hb, a portion of this NIR light returns to the surface of the scalp, where it is measured with photodetectors. Spectroscopic methods may thus be used to detect changes in the concentrations of oxy-Hb and deoxy-Hb. Typical fNIRS sensor pads geometrically position emitters and photoreceptors so that activity at the outer surface of the cortex may be measured with a spatial resolution in the order of square centimeters.

There are three main reasons why fNIRS is a promising neuroimaging technique for social neuroscience. First, compared to traditional neuroimaging systems such as functional magnetic resonance imaging (fMRI), which carry initial costs of up to several million dollars, continuous-wave fNIRS systems are relatively inexpensive—some available for less than $100,000 USD. A second key advantage of fNIRS is the low monetary cost of running participants.[4] Whereas the cost of running participants in fMRI studies can reach several hundred dollars per head, the cost of running participants with fNIRS

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a. We restrict our focus on continuous-wave fNIRS. "Time resolved" and "frequency domain" fNIRS systems are outside the purview of the current chapter.

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is no different than the cost of administering a standard paper-and-pencil questionnaire. This allows social neuroscientists to enhance the statistical power of their research by recruiting larger samples. Indeed, an oft-cited challenge in social neuroscience is the curtailed levels of statistical power of individual studies, and fNIRS is well suited to help meet this challenge. Finally, fNIRS systems are relatively insensitive to participant motion and have a portable, compact, and increasingly miniaturized design. This means that fNIRS can be flexibly deployed in naturalistic settings for enhanced ecological validity.[7]

THE CURRENT STUDY

To illustrate the utility of fNIRS for social neuroscience, we attempted to identify and replicate well-established patterns of prefrontal activity when people make self- and other-referential judgments. One of the most robust findings of social neuroscience studies using fMRI is that regions within the medial prefrontal cortex (MFPC), particularly the frontal midline regions within Brodmann's area 10, play an important role in representing knowledge about the self, relative to knowledge about other people.[3,8] For example, Kelly et al.[9] asked people to reflect upon their own personality characteristics and those of the former United States president George W. Bush, and found that the MPFC was preferentially engaged when participants reflected upon their own characteristics. In the present research, we constructed a personality judgment task to test the role of the MPFC across self- and other-referential processing using fNIRS.

METHOD

Participants

The research involved 109 individuals (78 females, 31 males), who participated for course credit or monetary compensation ($45 CAD). They ranged in age from 18 to 27 ($M=20.30$, $SD=2.02$).

Personality Judgment Task

As part of a larger study examining neural correlates of social support and the representation of self-knowledge,[6] participants were instructed to nominate a friend with the understanding that they would then describe themselves and their nominated friend using a list of trait adjectives. They were asked to rate themselves and their nominated friend on 120 adjectival markers of the "big five" trait dimensions.[10] We focused on markers for two of the big five traits, conscientiousness and extraversion, because these traits have clear behavioral expressions and are the most accurately perceived of the big traits.[11] Sample adjectives for conscientiousness were *dependable*, *efficient*, and *orderly*. Sample adjectives for extraversion were *assertive*, *energetic*, and *playful*. The personality-reflection task was presented using a block design consisting of 24 blocks: 12 for each of the self and friend conditions. Each block featured 10 consecutive adjectives for either conscientiousness or extraversion.

Fig. 28.1 shows the flow of one trial in the self–other reflection task. Participants responded to these adjectives by sliding and clicking a computer mouse cursor with their right hand over the appropriate scale response. They were instructed to respond as quickly as possible to each trial. After each click the cursor disappeared and the selected response flashed on the screen. Participants were instructed to slide the mouse to its original position on the mouse pad after each response. At the start of each trial, the location of the mouse cursor was reset to its original position in the middle of the screen.

fNIRS Procedures and Signal Processing

Activity of the prefrontal cortex was monitored using the fNIR Imager 1000, a 16-channel continuous-wave fNIRS system (FNIR, Potomac, MD; www.fnirdevices.com). The system is composed of a sensor pad with a source–detector separation of 2.50 cm and a data acquisition control box running Cognitive Optical Brain Imaging Studio software. The sensor pad had a temporal resolution of 500 ms per scan, a penetration depth of 1.25 cm into the prefrontal cortex, and light sources with peak wavelengths at 730 and 850 nm. The sensor pad was secured in alignment with electrode positions F_7, F_{P1}, F_{P2}, and F_8 based on the international 10/20 system. This positioning corresponds to Brodmann areas 9, 10, 45, and 46. Fig. 28.2A displays the location of each channel on a standard MRI template.[12]

After acquisition, recorded light intensities were visually inspected by a trained experimenter. Saturated channels were excluded from analyses. Subsequently, signal and physiological artifacts were excluded with a low-pass filter consisting of a finite impulse response and a linear-phase filter with an order of 20 and a cut-off frequency of 0.1 Hz. A sliding-window rejection algorithm was applied to the filtered data to exclude motion artifacts. Activation segments were extracted using time-synchronization markers via a serial connection from the computer used to display the personality-reflection task. Relative changes in concentrations of oxy-Hb (Δoxy-Hb) for each activation segment were calculated using fNIRSoft Professional Edition.

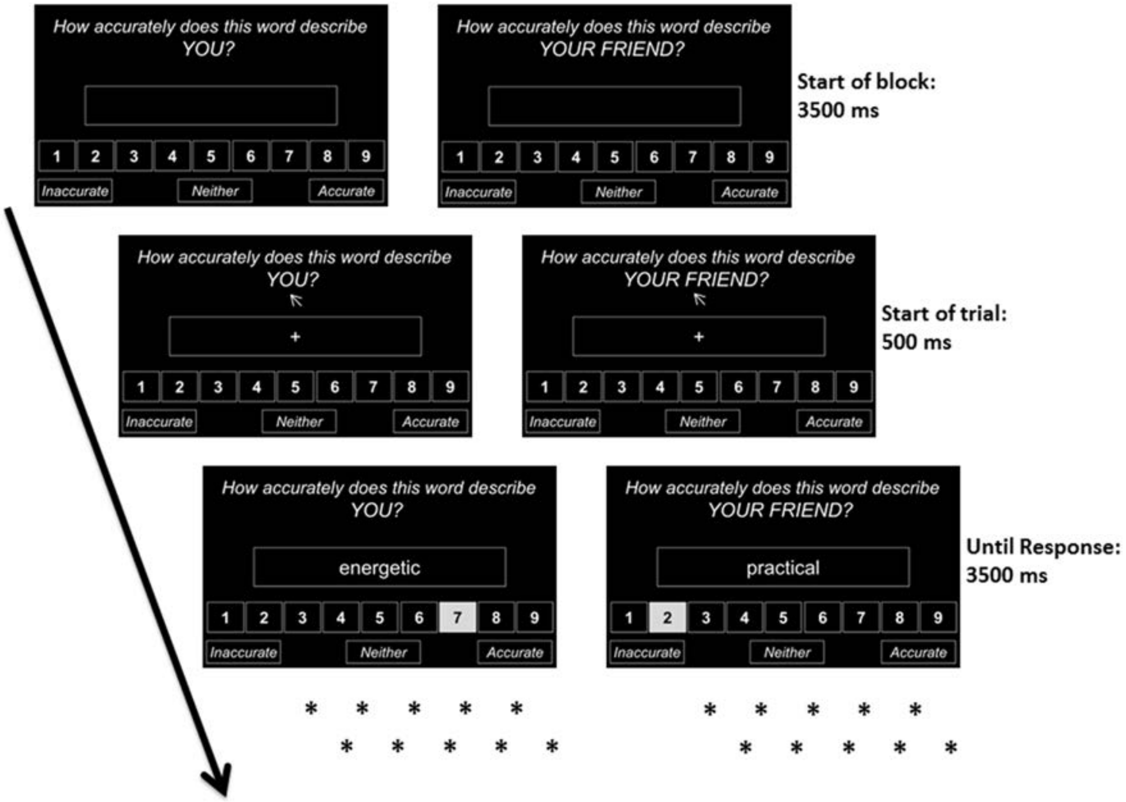

FIGURE 28.1 Exemplary flow of one trial in the personality judgment task.

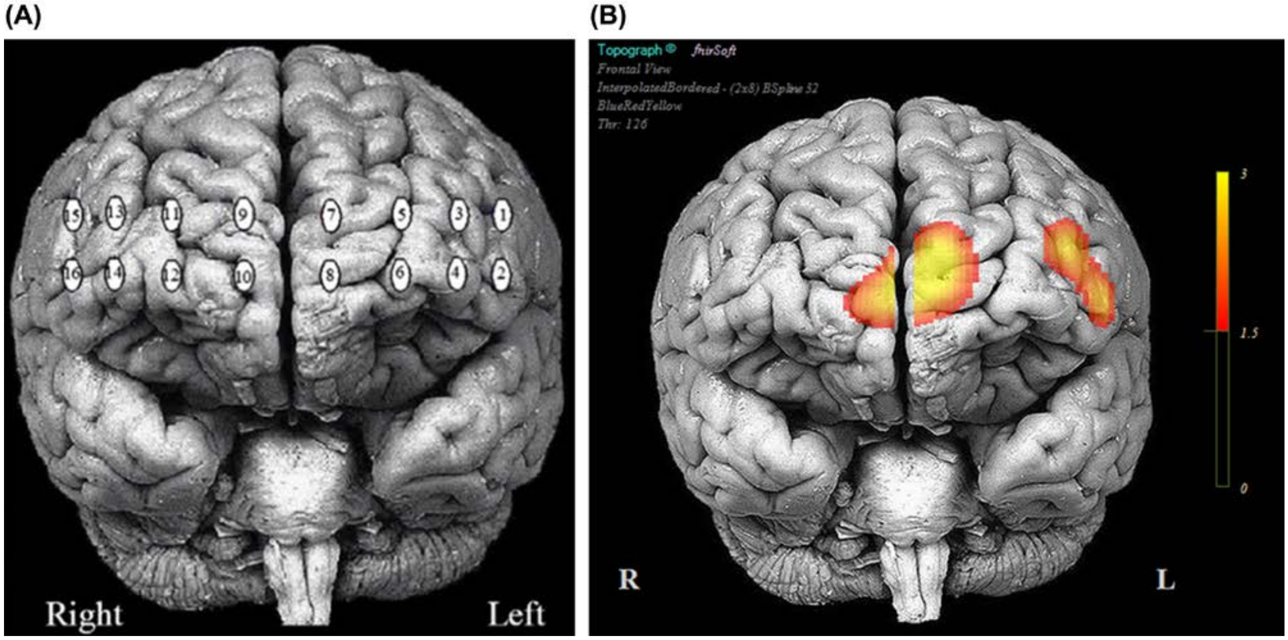

FIGURE 28.2 (A) The 16 measurement locations (channels) of the fNIRS sensor pad. The brain surface image is from the University of Washington, Digital Anatomist Project.[12] (B) Topographic images representing oxy-Hb contrasts across self- and other-referential processing.

TABLE 28.1 Multilevel Analyses Contrasting Prefrontal Activity Across the Self- and Friend-Referential Conditions

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
b	.06	.12	.10	.00	.00	.02	.14	.14	.07	.14	−.03	−.10	.04	−.11	−.02	.03
SE	.05	.05	.04	.09	.05	.08	.05	.06	.05	.06	.05	.10	.05	.08	.05	.05
t value	1.39	2.62**	2.76**	−.05	.02	.24	2.93**	2.32*	1.31	2.44*	−.57	−1.06	.87	−1.39	−.32	.56

Note: Unstandardized regression coefficients represented by *b*s and corresponding standard errors by *SE*s. $^{**}P<.01$, $^{*}P<.05$.

RESULTS

Data was analyzed with multilevel regression models.[13] We estimated random intercept models using the method of maximum likelihood, an unstructured covariance matrix, and the "between–within" method of estimating degrees of freedom. We estimated separate models for each channel across the fNIRS sensor pad. A dummy code contrasted activity in the self- and friend-referential conditions (friend = 0, self = 1). Results are shown in Table 28.1 and Fig. 28.2B. As expected, channels covering the anterior frontal pole and corresponding to the MPFC exhibited preferential activity in the self condition relative to the friend condition. Results also indicated preferential activity for the self condition in channels covering left lateral prefrontal regions.

DISCUSSION

The advancement of any scientific discipline depends in part upon the development of new methods. The present findings illustrate the utility of fNIRS for social neuroscience, showing its ability to recover well-established patterns of prefrontal activity when participants made self- and other-referential judgments. In keeping with previous fMRI studies,[3,8] participants exhibited greater activity in regions corresponding to the MPFC when rating trait adjectives with respect to themselves relative to adjectives with respect to their friends. Self-referential judgments were also associated with preferential activity in left lateral PFC regions. This finding is consistent with previous studies, suggesting the role of the left lateral PFC in the retrieval of autobiographical information during self-referential judgments.[8] These results thus provide initial evidence that fNIRS can be used to examine types of phenomena of interest to social neuroscientists.

Given these promising results, we can reflect upon the ways in which fNIRS may be best used to advance social neuroscience research. In addition to large-sample "brain-mapping" research (that is, traditional neuroimaging research in which the neural correlates of various social psychological phenomena are examined), fNIRS may be particularly useful for studies adopting a "brain-as-predictor" approach.[14] Studies adopting the brain-as-predictor approach have the goal of understanding how specific neurocognitive processes mediate ecologically valid outcomes, and accordingly use measures of task-related neural activity to predict real-world behaviors. For decisive results, however, large samples of participants are required, especially when task-related measures of neural activity are intended as variables that statistically mediate the relations between social psychological variables on the one hand and objective behavioral outcomes on the other. In this regard, fNIRS has distinct advantages relative to more expensive imaging methods.

Of course, like all methodologies fNIRS has clear limitations. Most saliently, it limits researchers to measuring neural activity at the surface of the cortex; but most, if not all, social psychological phenomena have key underpinnings in deeper cortical and subcortical structures. A related limitation of fNIRS is its lower spatial resolution relative to fMRI, which can assess neural activity in the order of square millimeters. For these reasons, fNIRS is optimally deployed in studies that target, on an a priori basis, specific operations of the outer cortex. Researchers can partially sidestep these limitations by coupling fNIRS technology with other methods, especially in protocols that capitalize on the portability of some fNIRS systems for naturalistic recording of brain activity.[7] Notwithstanding these limitations, the present results provide support for the idea that fNIRS is a promising method that can be effectively used to examine key topics within social neuroscience.

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