

## BASIC SCIENCE

# Simultaneous Monitoring of Hemodynamic Response in the Pre-Frontal Cortex and Genital Organ During Sexual Arousal Using Near-Infrared Spectroscopy



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## ABSTRACT

**Background:** The monitoring of brain activity along with genital organ response to sexual stimulation can play an important role in understanding the under-lying mechanisms of sexual arousal as well as diagnosing erectile dysfunction. Several studies have observed brain activity corresponding to sexual stimuli, but only a few studies have shown a simultaneous measurement of brain activation and penile response.

**Aim:** To introduce near-infrared spectroscopy (NIRS) as a portable, easily implemented, and low-cost technique to simultaneously record brain activity and hemodynamics in the genital organ during sexual arousal.

**Methods:** Hemodynamic measurements of 15 healthy men were obtained using a home-built NIRS system. In the initial experiment, hemodynamics in the pre-frontal cortex (N = 10) were measured during visual sexual stimulation (VSS) and neutral visual stimulation (NVS) to identify brain activity related to sexual arousal. In the subsequent experiment, cerebral and penile hemodynamics were simultaneously measured (N = 5) using NIRS during VSS and NVS.

**Results:** The pre-frontal cortex showed activity related to VSS but not to NVS. Simultaneous measurements showed a corresponding increase of penile oxygenated and deoxygenated hemoglobin concentration indicating an increase of blood volume associated with sexual arousal in healthy men. An average response delay of 4 seconds was observed in the hemodynamic changes between the brain and genital organ.

**Conclusion:** In this preliminary study, we presented a NIRS system capable not only of detecting cerebral hemodynamic changes related to sexual arousal but also the simultaneous measurement of penile hemodynamics. We believe the NIRS system can be a potential technique to supplement the field of sexual medicine and can be expanded further to diagnose erectile dysfunction. **Kim E, Kim S, Zephaniah PV, et al. Simultaneous Monitoring of Hemodynamic Response in the Pre-Frontal Cortex and Genital Organ During Sexual Arousal Using Near-Infrared Spectroscopy. Sex Med 2018;6:234–238.**

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**Key Words:** Near-Infrared Spectroscopy; Hemodynamics; Pre-Frontal Cortex; Visual Sexual Stimulation; Erectile Dysfunction

## INTRODUCTION

The inability to attain adequate erection sufficient to perform intercourse, known as erectile dysfunction (ED), leads to a significant negative impact on the quality of life. A number of psychological disorders may contribute to ED such as stress, depression, and performance anxiety. Likewise, it can also be one of the earliest manifestations of an under-lying serious physical disease including diabetes, multiple sclerosis, or cardiovascular disorders. Thus, distinguishing between the psychological and organic origin of ED is a critical task for the clinician.

The normal sexual arousal involves a number of physiological responses among which penile erection is the most definitive

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response in the male body. It has also been shown that there is a neural response during sexual arousal, which could indicate a psychological role in the arousal process. Since the psychological aspect can be revealed by brain activity measurements, numerous studies have tried to understand brain function during sexual arousal. Results from these studies associate sexual arousal with many deep brain and cortical structures in normal healthy men<sup>1–3</sup> suggesting that sexual arousal is indeed a complex neural process. Most studies have employed positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) to observe brain response, along with plethysmography, pneumatic cuff, or the commercial device RigiScan (Timm Medical Technologies Inc, Eden Prairie, MN) to monitor penile tumescence and rigidity. However, even though PET and fMRI are established technologies to monitor brain activity during sexual arousal, they can be technically demanding and expensive. In addition, these modalities must be administered in a clinical environment, which could greatly influence psychological responses, especially for sexual arousal.

In this study, we propose to utilize a system that will enable the concurrent monitoring of cerebral and penile hemodynamics using near-infrared spectroscopy (NIRS). Being non-invasive, low-cost, and portable, NIRS is well-suited for hemodynamic response monitoring in a comfortable and natural setting. NIRS has become a widely used technique in the biomedical field, particularly for brain research.<sup>4</sup> In addition, NIRS can achieve higher temporal resolution, up to an order of milliseconds, compared to fMRI and PET.<sup>5</sup> Such high temporal feature could play an important role for comparison of the brain and genital organ hemodynamic response, and how it is affected by ED.

NIRS has been previously shown to be a reliable tool to measure penile hemodynamics and at the same time provide a more convenient and comfortable setting for the patient.<sup>6,7</sup> In contrast with the prevailing commercial device RigiScan, which measures penile tumescence and rigidity through loops bound to the stem and tip of the genital organ,<sup>8,9</sup> NIRS can provide vasculogenic information with a simple source-detector configuration in order to minimize the discomfort for the subject. Other methods have been applied to assess vascular involvement during penile tumescence including selective pudendal angiography, duplex Doppler ultrasonography, and cavernosometry.<sup>10,11</sup> However, they are limited by the expensive cost and complexity in methodology. The aim of this study is to introduce NIRS as a practical option for the studies of male sexual arousal by measuring the vasculogenic state during penile erection and the concomitant brain response. The authors hope that the study will lead to NIRS being utilized to assist in the proper diagnosis of ED.

## METHODS

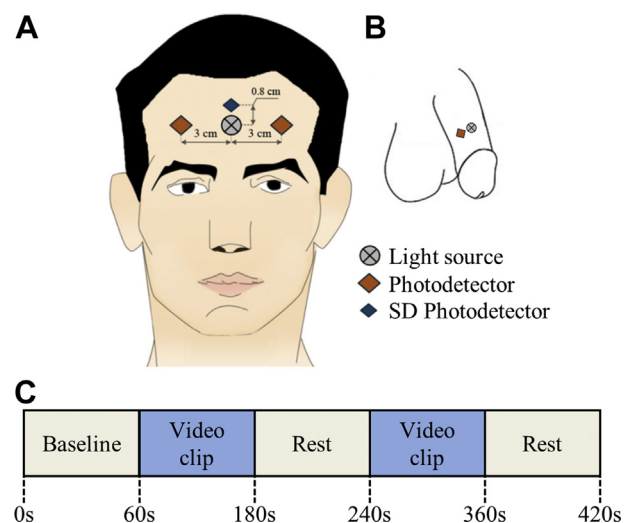
This study has been reviewed and approved by the Institutional Review Board of the Gwangju Institute of Science and Technology (20140319-HR-10-01-02). 15 Right-handed

healthy men (age  $24 \pm 3$  years) participated in the study. The subjects were recruited through university advertisements. Written informed consent was obtained from each subject prior to the experiment.

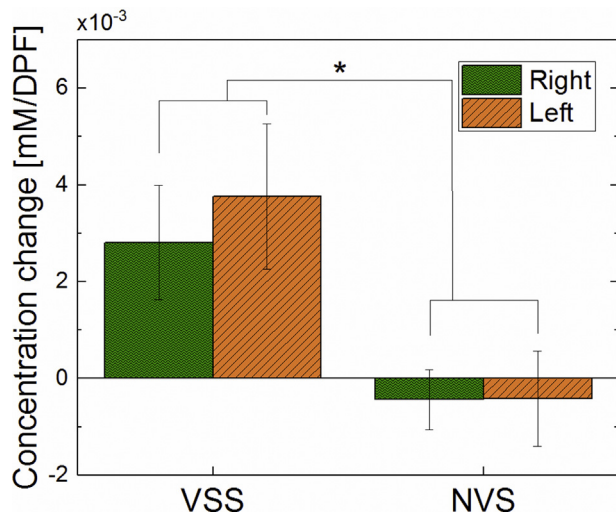
A home-built NIRS system described in a previous study<sup>6</sup> was used to measure cerebral and penile hemodynamics during visual sexual stimulation (VSS). In the first part of the experiment, hemodynamics from the pre-frontal cortex in 10 subjects were measured to identify the existence of a measurable change in signal related to sexual arousal. In the second part, the simultaneous change in hemodynamics in both the pre-frontal cortex and genital organ from 5 subjects were measured.

The NIRS probes consisted of a light source and detector, where a monolithic photodiode with single-supply transimpedance amplifier was used as a light detector (OPT101; Texas Instruments Inc, Dallas, TX). The light source was a light-emitting diode emitting wavelengths of 735 nm and 850 nm (L735/850-40D32; Epitex Inc, Kyoto, Japan). The 2 wavelengths from the light-emitting diode source sequentially illuminated the tissue, and the transmitted light was detected by the photodetectors. The complete cycle of data acquisition takes 0.25 seconds, for a temporal resolution of 4 Hz.

The placement of the probes in the forehead and genital organ are shown in Figure 1A, B. The head probe had a source-detector separation distance of 3 cm, which provides a penetration depth sufficient to observe a signal from superficial hemodynamics and also cortical areas. Therefore, a shorter channel of 0.8 cm was used to detect hemodynamic change within superficial layers and later the short channel data were suppressed from the longer channel to isolate the critical activation. The head probes were attached by the experimenters using double-sided adhesive  $20 \times 8$  disks (BioSemi Instrumentation, Amsterdam, The Netherlands), which allow adequate fixation of probes without



**Figure 1.** The location of near-infrared spectroscopy probes: on the forehead (A) and genital organ (B). C, Time of procedure for the experiments. SD = short distance.

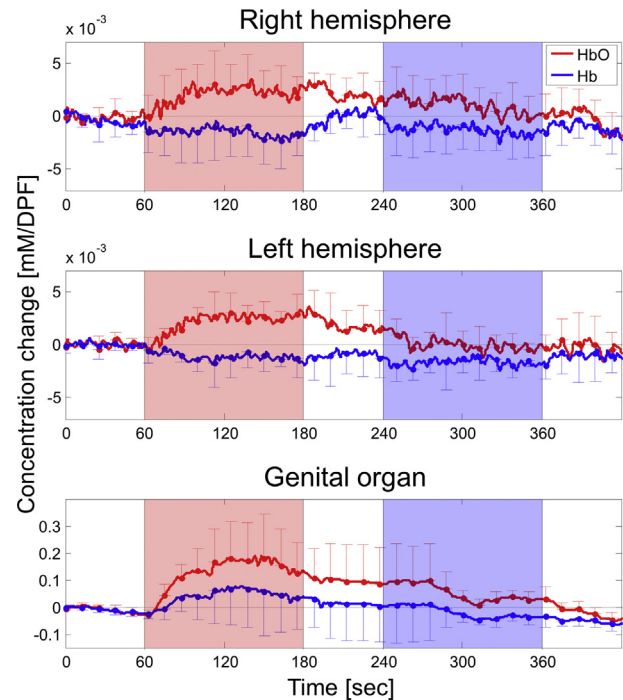


**Figure 2.** Average concentration change in cerebral hemodynamics between the end and beginning of stimulation ( $N = 10$ ). A significant difference (\*) in hemodynamics was found between visual sexual stimulation (VSS) and neutral visual stimulation (NVS). No significant difference was found between the right and left hemispheres for both cases. DPF = differential pathlength factor.

discomfort to the subject. The penile NIRS sensor was affixed by the subjects themselves to the right medial side of the genital organ using medical tape. Prior to this, the subjects were instructed on how to attach the probe properly to the genital organ. After confirming a stable signal for the 2 probes, the experimental protocol was remotely controlled by the experimenter in a separate room. The probes for the genital organ were designed with a source-detector separation of 1 cm to provide a penetration depth enough to monitor hemodynamic changes from the corpus cavernosum.<sup>6</sup>

The schematic diagram for the protocol of the experiments is shown in Figure 1C. To reduce the number of motion artifacts, the subjects were instructed to sit motionless in a comfortable chair and to focus on a monitor. 2 Different video clips were shown preceded by a black screen with a white cross. To highlight brain activity from sexual arousal rather than simple visual stimulation, video clips featuring an erotic episode (VSS) and a neutral video featuring nature (neutral visual stimulation [NVS]) were shown to the subject. In the first experiment, the order of the VSS and NVS were randomized between the 10 subjects to make a clear distinction between the hemodynamic responses from both visual stimulations. In the second experiment, the VSS was shown before NVS. The erotic clip included sexual intercourse between a man and a woman. During the resting periods, the subjects were asked to focus on their breathing in order to return their heart rate to a normal state. The duration and sequence of the clips were kept unknown to the subjects to prevent pre-mature arousal and/or daydreaming.

Light intensity attenuation was converted to changes in oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (Hb) concentration by applying the modified Beer-Lambert law.



**Figure 3.** The average hemodynamic changes during the simultaneous measurement ( $N = 5$ ) (1-sided error bars represent SD). Periods of visual sexual (red region) and neutral visual (blue region) stimulation. DPF = differential pathlength factor; HbO = oxygenated hemoglobin; Hb = deoxygenated hemoglobin.

Heart pulsation and respiration signals were removed from the NIRS data by utilizing a Butterworth low-pass filter with cutoff frequency at 0.6 Hz. The hemodynamic changes from the superficial layer were suppressed from the forehead channels by scaling and subtracting the short-distance probe signal from the long-distance probe signals over the entire measurement.<sup>12</sup> The changes of HbO and Hb concentration in brain and genital organ were compared during the 2 different visual stimulations.

## RESULTS

The averaged hemodynamic changes at the end of the visual stimuli compared to the beginning of stimuli for all subjects in the first experiment monitoring only the cerebral hemodynamics ( $N = 10$ ) is shown in Figure 2. A statistically significant difference was found between VSS and NVS ( $P < .01$ ,  $\alpha = 0.01$ ) but not between the right and left hemispheres ( $P > .05$ ) using a 2-tail paired Wilcoxon test.

The averaged hemodynamic response in the pre-frontal cortex and genital organ during the simultaneous measurement ( $N = 5$ ) are shown in Figure 3. The temporal profiles of cerebral hemodynamics in the simultaneous measurement was not notably different from the preceding independent measurement. The pre-frontal response during VSS shows a dramatic increase in HbO and a less intense decrease in Hb in the pre-frontal cortex compared to baseline. The change in cerebral hemodynamics during VSS accompanies an increase in both HbO and Hb in the

genital organ indicating an increase in the blood volume associated with a successful penile erection. The onset of the penile response was observed to lag by an average of  $4 \pm 1.5$  seconds from the onset of cerebral hemodynamic change during VSS. When the VSS ended, both cerebral and penile hemodynamics begins to wane, with cerebral HbO and Hb trending toward a baseline state, while the total blood volume in the genital organ decreases. Initiation of the NVS shows a minimal response in both cerebral and penile hemodynamics.

## DISCUSSION

In this study, NIRS offers the concurrent measurement of brain activity and penile response to sexual stimulation providing not only the condition of the penile vasculature and brain function but also directly associates their responses to sexual arousal. Using NIRS, we were able to identify hemodynamic changes in the pre-frontal cortex related to VSS. The hemodynamic changes in the pre-frontal cortex can be described by an increase in HbO and a corresponding decrease in Hb. This hemodynamic pattern can be explained by neurovascular coupling and thus can be identified as a measure of neural activity indicating that the pre-frontal cortex was activated during VSS. Moreover, the neutral video clip did not cause significant changes of hemoglobin concentration as opposed to VSS, indicating that the pre-frontal cortex is highly activated in response to sexual arousal rather than visual stimuli. The study does not imply the direct involvement of the pre-frontal cortex in triggering penile erection. However, the pre-frontal cortex is known to be involved in higher cognitive processes including sexual desires<sup>13</sup> and is under-activated in patients with major depression,<sup>14</sup> making this a notable feature in identifying psychological ED.

During the simultaneous measurements, all subjects demonstrated a penile response to sexual arousal characterized by an increase in the concentration of both HbO and Hb resulting from an increase in the total blood volume. The dramatic increase of total blood volume triggered by sexual stimulation is associated with a healthy penile erection, while the insufficient change in blood volume might indicate vascular ED.<sup>7</sup> The delay between responses in the brain and genital organ is a normal physiological response, meaning that sexual arousal was first initiated in the brain and successfully manifested in the genital organ. A prolonged time delay between the responses could be indicative of some neurological disorders.<sup>15</sup>

Considering the future implementation of this technique in a medical setting, where the simplicity to administer a procedure has great impact, we decided to record hemodynamic changes only from the pre-frontal lobe. However, NIRS can be easily expanded into measuring the whole cortex.<sup>16</sup> The major shortcoming of NIRS in detecting cerebral hemodynamics is the high contamination of systemic hemodynamic changes within superficial layers of the head that reduce the accuracy of NIRS to detect brain activity. To address this issue, we applied an

additional channel with a short distance between source and detector, which records the hemodynamics mostly from superficial layers (scalp and skull). The technique allows us to suppress the physiological noise and extract cortical signals that are related to the stimulation task.

## CONCLUSION

In this preliminary study, our results have shown that NIRS is a useful tool to conveniently observe the hemodynamic changes that the brain and body undergo during sexual stimulation using a single system. In future studies, we plan to expand the population of the current work to include a larger number of subjects including patients with different cases of ED with the aim to enhance the diagnosis of ED.

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