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Experimental investigation on the light transmission of a textile-based over-cap used in functional near-infrared spectroscopy

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ABSTRACT

Functional near-infrared spectroscopy as an optical (i.e., light-based) neuroimaging technique is susceptive to ambient light noise. In the daily task scenario experiments, light is required to monitor the movement of patients and to minimize the effect of this light on the results; the fNIRS optodes are covered with dark materials (e.g., a loose-fitting black shower-cap). In our laboratory, over-caps provided by NIRx (produced by EasyCap) have been used to eliminate this con-founder. However, there has been a demand to evaluate their performance by quantification. Thus, in this paper, the transmission of light through a fabric over-cap is investigated. The results revealed that the output signal of functional near-infrared spectroscopy could be contaminated significantly by the ambient light. Moreover, the noise varies due to the stretch that could be applied due to various head sizes. The changes in the amplitude of the signal, which relates to physiological responses, is about 1-2 % in continuous wave measurement while the result of the investigation notes that the transmission average in the samples varies from 8-46 percent depending on the stretching forces. Therefore, it is suggested that this kind of over-caps would be applied only in a dimmed environment, which is not applicable when subjects have mobility disorders. Under such conditions, other techniques to minimize ambient light should be practiced.

Keywords: DOI, fNIRS, Ambient light, Over-cap, Textile Material, Transmission

1. INTRODUCTION

The trend toward miniaturization and portability of functional near-infrared spectroscopy has paved the way toward portable cognitive monitoring researches. Therefore, everyday life situations can be studied with these instruments especially with the available off-the-shelf products that are commercialized by several companies such as NIRx Medical Technologies, Artinis, fNIRS Devices, Hitachi, Shimadzu, and Spectratech.[1]However, there is a concern about the reliability of the reported results and the employed techniques particularly whenever the comparison of results with positron emission tomography and functional magnetic resonance imaging is impracticable due to their bulkiness.[2,3]Therefore, the incorporation of confounding variables should be avoided during the experiment as well as eliminating these variables in the post-analysis. Removal of con-founders after gathering the raw data requires regression analysis, which is sometimes misleading especially in the intertwined problems and admittedly brain function monitoring.[4]One of these con-founders is the effect of ambient light that is intended to be avoided by over-caps that are provided by the producer of the fNIRS instruments.[5] The motivation of the experiment was to investigate the performance of textile-based over-caps that usually used in these systems.

Most previous publications use a cover material or perform the testing in a dimmed room to address the issue of ambient light.[6–9] However, a dimmed room would inhibit or make the experiment impractical in particular for testing the mobility of patients in a clinical setting. If continuous monitoring of the brain, using optical spectroscopy, would be applied as a clinical method, a more robust system with less sensitivity to ambient light is preferred. There have been approaches that are employed to reduce the effects of the ambient light including lock-in amplification of the signal, filtration of the signal by using high-pass filters and covering of the sensors with dark fabrics or clothes.[6,8]The last one is the typical adoption in many publications as well as commercial

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products and is the only method that can reduce the possibility of detector saturation. It should be noted that most DOI systems are based on a cap that resembles the EEG measurements with a similar arrangement of sources and detectors and they also use an over-cap to decrease the effect of ambient light.

The over-cap in DOI systems plays two simultaneous roles:[7, 10, 11] firstly, it applies constant pressure on the contact surface of optodes/detectors and the scalp to avoid motion artifacts. Secondly, it is intended to block the ambient light. The latter seems unclear since the near-infrared light is not only penetrating through the tissue but also can pass through fabrics.[12–14] Even a small amount of light transmission matters as the amount of change related to the physiological response in signal amplitude is as low as 1-2%.[15, 16]It should be emphasized that the passage of visible light through the fabrics also decreases the level of the signal to noise ratio (SNR) similar to the disturbance of the result by unwanted near-infrared noise. This is in particular due to the large spectral sensitivity of detectors that are used in most commercial DOI and fNIRS systems. As an example, the OPT101 is a detector that is used in several portable functional near-infrared imaging systems,[17, 18] and the detector has a broad spectral detection range within wavelength of 300 nm-1000 nm. This makes the detector susceptible to ultraviolet, visible and near infrared wavelengths. That may be the main reason why most of the textile-based caps and over-caps are provided in the black color as it may absorb at least the visual range of the light spectra. Thus it is demonstrated that dye color does not significantly alter the near infrared transmission through fabrics.[13] In this paper, we have investigated and evaluated the performance of one of these over-caps and its cap that are available commercially.

2. MATERIAL AND METHODS

2.1 The Experimental Setup

The non-homogeneous nature of the woven fabrics and their diversity present some challenges in measuring the light transmission of fNIRS' caps and over caps. Firstly, the repeatability of the trial should be secured and the second challenge relates to applying ample light to the fabric without saturating the spectrometer, and finally, the beam of light should be wide enough to grant an averaging evaluation rather than the effect of a single strand of the woven fabric. To our knowledge, there is not any specific standard protocol for this type of measurement. Therefore, a setup with these characteristics was designed and a fabric holder was fabricated, which is presented in Fig.1. A halogen lamp as the light source with a filament temperature of 2700 K (AVALIGHT-HAL-S-IND), which illuminates from visible to the near-infrared range (wavelength of 360-2500 nm), was applied. The selected source sets up an illumination with the wavelength spectrum which is comparable to the lab and outdoor condition of fNIRS-based researches. An optical fiber (QP400-2-VIS-BX) was employed to form the track between the source, a fabric holder, and a spectrum. The fabric holder was composed of two lenses, which widen the light beam to shape a spot size of about 10 mm and converge the transmitted light to the fiber. Then, the acquired light was delivered to the input of a spectrometer by the second fiber (AvaSpec-2048-USB2). The spectrometer operates in the range from 200 nm to 1100 nm with the slit No. of 500 and grating of 300 lines/mm. The sampling rate of the spectrometer was set at 15s with 100 times averaging. The 100 nm of the low end of the spectra was omitted due to the susceptibility of the applied spectrometer to noise in that part. The location of the lenses in x and y directions (in the plane perpendicular to the cross-section depicted in Fig.1 was alignment via four screws that are located in the lens housing of the fabric holder. The optical fibers can also be adjusted at the focal point by manipulation of the connection point in the z-direction. These tuning screws were used to peak the amplitude of the transmitted light before measuring the samples without saturation. At least five measurements evaluated the repeatability of the experiment for each fabric sample, and the results were incorporated with the confidence interval relating to the setup. Each repetition of the repeatability test involved disassembling, the assembling of the sample holder and remarking of the errors.

2.2 Samples

Several samples from a commercially available over-cap given by NIRx (S/N C07582) was chosen for this experiment and to evaluate the degree of its effectiveness, and the necessity of its use, the light transmission of a simple cap was also investigated. In contrast to over-cap, the NIRx provides different caps for various head size. So, it is assumed that they would not be stretched and therefore the measurements for the caps are only done in an unstretched condition. The thickness of the fabrics is about 0.30.05 mm.

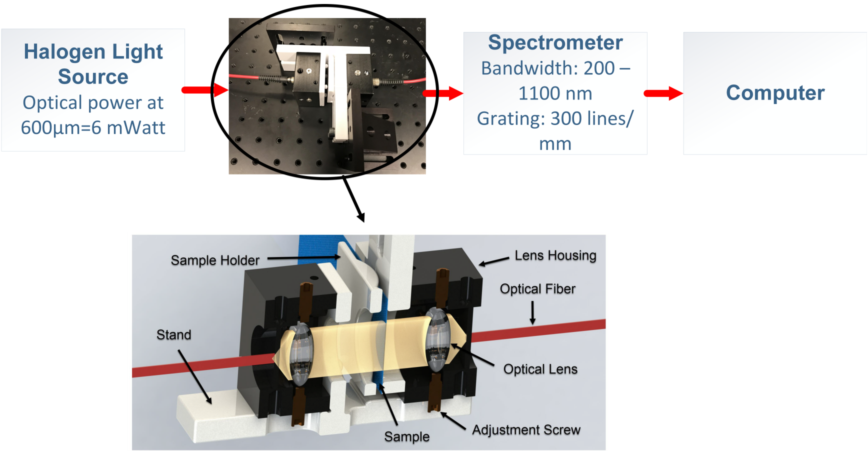

Figure 1. The Experiment setup to investigate the light transmission of textile-based over-caps and caps used in functional imaging using diffuse optical spectroscopy. The setup has the required degree of freedom to adjust light.

2.3 Environmental Monitoring

Texas Instruments CC2650STK monitored the temperature and humidity of the lab. The temperature in the laboratory was around 21C, and the humidity was approximately 80%.

2.4 The Stretch Effect on the Light Transmission

The samples were measured in three conditions, unstretched, partial stretched by 15 N force, and stretched by 30 N force. The amount of force was roughly estimated as the textile may have an anisotropic behavior to the applied external forces. Homogeneity of the textile in the measuring area was inspected visually, and also identifying any alterations in the material or its shape due to the external forces. The amount of the applied external forces did not permanently change the form of the textile; thus, the measurements are repeatable and show a trend.

3. RESULTS AND DISCUSSION

The result of the transmission measurement of cap and over-cap samples is presented in Fig.2 and Fig.3. The number of measurements in each state is limited to five repetitions. Therefore, the distribution of error is contemplated as student's t-distribution rather than normal distribution. The number of iteration seems to be enough and the results are representative, as the results confirm the modest change in the trend that does not affect the interpretation. The error bounds in each state are presented based on the 2.75 times standard deviation, which exhibits the confidence interval of 95% upon the repetition of the experiment.

As shown in Fig.3, the change in the amplitude of the transmission does not linearly vary with the force and this stem from the fact that textile-based materials exhibit mechanical hyper-elastic characteristics. The observation that emerge from the data comparison is that the transmitted photons through the pores mainly contribute to the transmission and this was verified by Canal, 2011[13] that also showed fabrics usually have a transmission higher than 30% within near-infrared range. The difference between the sizes of gaps correlates with the poor transmission performance of the over-cap (Fig.4). The graph highlights that not only the combination of over-cap, and cap does not shield the ambient light but also the stretch modifies the behavior of over-cap and therefore, the outcome of the DOI systems would be affected by different head sizes. This may cause incorrect interpretation on account of comparison nature of the DOI systems. This means that DOI does not provide any absolute measurements, but their signals have been compared between different areas of the brain and different subjects. These results reveal that the contamination of the signal with ambient light is inevitable with textile-based over-cap with a thickness below 0.5 mm. Moreover, the added thickness of the over-cap results in the rigidity of the material. The rigidity limits their application for different head size. Therefore it is logical to conclude that the effectiveness of this fabric over-caps is limited to dimmed environments and in case of using the over-cap in bright ambient light, considerable modification of their transmission properties is required. Considering the use of commercialized DOI as a standard device for clinical investigations, connectivity of physical activities with brain signals and brain computer-interface, This is a critical issue especially with the applied automatic increase in the gain of the amplifier which could result in the intensification of noise rather biosignals.

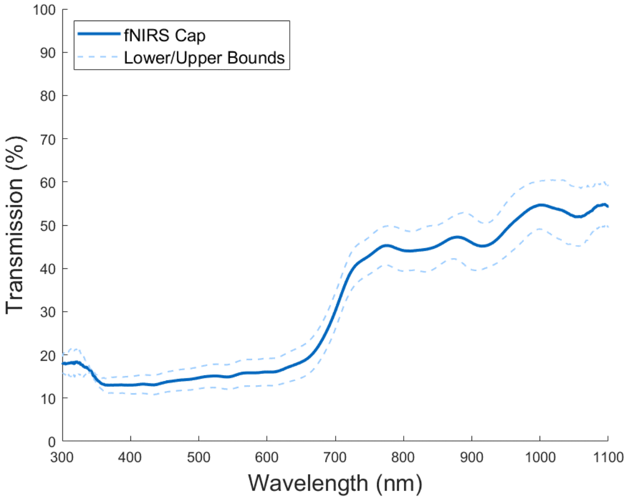

Figure 2. Light transmission of the cap.

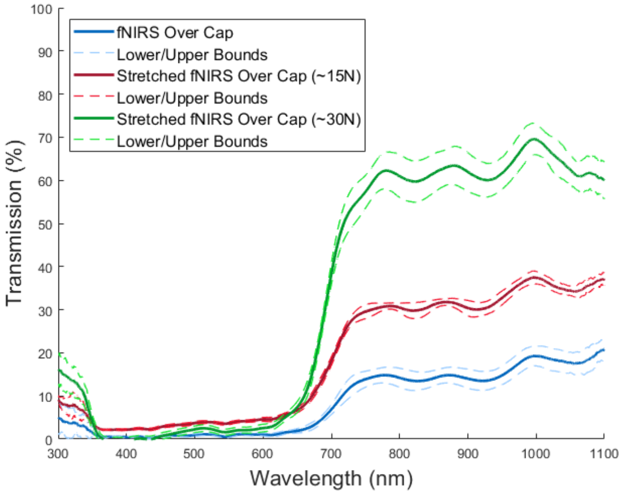

Figure 3. Light transmission of the over-cap measured in three states: unstretched, partial stretched by 15N force, and stretched by 30N force.

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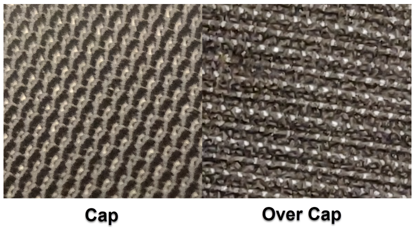

Figure 4. The image of the unstretched-fiber arrangements of the over-cap and fiber arrangements of the Cap. It seems that the gaps play a significant role in the light transition.

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