Title: Optical systems for assessing consciousness at the bedside: the past, present and future

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Structured Abstract:

Consciousness can be defined as the state of being awake and aware of oneself and one's surroundings. Even though determining if someone is awake is a relatively simple task, assessing awareness is not trivial. In clinical scenarios, patients are usually assessed against a neurological scale and the presence of awareness is measured by the ability to follow commands, either behaviorally or verbally. Because of this reliance on observable responses, a subset of patients who retain some cognitive function but are unable to follow commands are frequently misdiagnosed as suffering from impaired consciousness or what is clinically referred to as a disorder of consciousness (DOC). Previous work by Owen and colleagues showed using functional magnetic resonance imaging (fMRI) that some DOC patients are in fact aware and able to 'mentally' follow commands by performing a motor imagery task in response to commands (Owen et al., Science, 2006). This finding highlights the potential of neuroimaging techniques to provide an alternate means of assessing consciousness.

Although promising, there is a need to explore alternative techniques such as functional near infrared spectroscopy (fNIRS), an optical technique that is portable and inexpensive. Furthermore, brain regions associated with motor imagery can be interrogated by NIRS making it an ideal modality for bedside measurements. However, a major challenge with fNIRS is the signal contamination from the scalp which can potentially mask brain activity. One technique that can circumvent this issue is time-resolved (TR) fNIRS, which measures the time-of-flight of photons and provides a mean of isolating late photons that have a higher probability of reaching the brain. Our group has developed a TR-fNIRS system dedicated to measuring motor imagery activity and we were able to achieve a sensitivity of 93% in comparison to fMRI in healthy controls (Abdalmalak et al., BOE, 2017).

Given these promising results, the next critical milestone was to use our TR-fNIRS system as a brain-computer interface to establish rudimentary mental communication. One approach for mental communication is to use motor imagery as affirmation for questions. In 2017, our team tested this approach on a patient under intensive care at University Hospital (Abdalmalak et al., Neurophotonics, 2017). The patient was functionally locked-in i.e. completely paralyzed with very limited eye movements. The patient was asked a series of clinically relevant questions and the presence of eye movements provided a unique opportunity to validate our responses. Interestingly, the fNIRS responses were in full agreement with the eye responses.

In conclusion, our work highlights the potential of fNIRS as a portable tool to assess consciousness at the bedside. Future work will focus on assessing the feasibility of our system on a larger cohort of DOC patients, and implementing machine learning algorithms to improve the overall accuracy of our system.