Maastricht University

Shedding light on motor-independent communication

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6 Knowledge Valorization

Communication with others through speech is fundamental to our human experience and general well-being. The overarching goal of the field of research, in which this thesis is situated, is development of alternative means of communication for patients who have lost the means to communicate naturally. Patients suffering from the so-called ’locked-in’ syndrome (LIS) are almost completely paralyzed while at the same time being awake and aware. One possible solution to this clinical problem can be found in motor-independent communication through a brain-computer interface (BCI). A BCI uses voluntarily evoked brain signals for communication, without relying on peripheral nerves and muscles to produce speech (Wolpaw et al., 2000).

The three studies in this thesis aimed to develop and validate straightforward, robust, efficient and cost-effective communication paradigms that can be tailored to individual users and eventually be used in daily life. A relatively new neuroimaging method, namely functional near-infrared spectroscopy (fNIRS) was used to measure signal changes in the brain. FNIRS is a relatively easy-to-apply, inexpensive, safe and portable technology (Irani, Platek, Bunce, Ruocco, & Chute, 2007; Scholkmann et al., 2014). In **chapter 2**, participants imagined drawing to answer “yes” or merely rested to answer “no”. In **chapter 3**, participants imagined drawing to answer “yes” or imagined walking through their house to answer “no”. In both studies, roughly half of the participants were able to communicate using the binary BCI. In **chapter 4**, a small group of participants used a four-choice BCI with a single mental task (mental drawing). All six participants could communicate using the fNIRS-BCI via three sensory modalities (visual, auditory and tactile) across three consecutive days.

The scientific impact on the short-term is clear as **all three empirical chapters** were peer-reviewed and published in scientific journals. **Chapters 2 and 3** were presented to a scientific audience via oral and/or poster presentation (see conference contributions). Many methodological novelties – with the aim of improving fNIRS-BCI methodology, especially increasing fNIRS-signal quality or enhancing decoding accuracy – were explored in these works. For example, in **all chapters** novel temporal and spatiotemporal answer-encoding paradigms were developed and tested. Furthermore single-channel answer decoding and the effect of different types of optode-holders were explored as well as the influence of participants' physical features on signal quality. In **chapter 3**, spatial navigation imagery was used for the first time in the context of fNIRS-based motor-independent communication. Each of these separate innovations can influence communication BCI's in the short- and long-term. Outside the field of communication BCI's, such as brain-robot or neurofeedback applications, the three novel answer encoding paradigms (**chapter 2-4**) have a clear applicability. For the whole field of fNIRS, the methodological developments presented in this thesis, such as the use of an fNIRS suitability questionnaire in **chapter 3**, pave the way for more robust data collection. Lastly, this work has potential to inspire other disciplines, such as neuroenhancement, neurofeedback or brain-based gaming applications, as well as influence industrial and technical developments, such as advancements in fNIRS hard- and software.

Given that the field of research of this thesis is relatively applied, the societal implications for healthcare and quality of life of affected patients are obvious. Restoration of the possibility to interact with one's surrounding is essential to LIS patients psychological well-being. Despite losing all physical autonomy, appropriate assistive technology can enable cognitive/mental autonomy (Lulé et al., 2009). Although the work in this thesis involved healthy participants, the potential clinical application has been a topic of focus. In **all empirical chapters,** participants' subjective experience was recorded, as a BCI should be comfortable and easy to use. In **chapter 4,** the performance of the BCI was tested over three consecutive days, as patients need a BCI that works not only once but continuously. A BCI should also perform outside the laboratory, *i.e.*, in the real world, so two participants used the BCI in a cafeteria. Moreover, three sensory encoding modalities were explored to include potential users with modality-specific disabilities (*e.g.*, blindness). In the short-term, clinical studies involving affected patients can use the knowledge obtained in this thesis to further improve usability of clinical fNIRS-BCIs. In the long-term, use of fNIRS-BCIs to communicate in daily life can hopefully become a reality, with the **three chapters** being a step in this direction. Establishing fNIRS-BCIs as a viable option for patients implicates more patients could find a suitable BCI, as the group of LIS patients is heterogenous. For example, patients that have involuntary movement or suffer from seizures of spasms can often not benefit from EEG-based BCIs (Nijboer, Plass-Oude Bos, Blokland, van Wijk, & Farquhar, 2014). Moreover, the knowledge obtained in this work is not merely potentially beneficial to LIS patients. Several patients groups can directly benefit from the current work. An fNIRS-BCI can be a valuable option for patients who have some remaining muscle control (*e.g.*, vascular or traumatic brain injury) but in which motor function is easily exhausted. As discussed in **chapter 2**, a simple yet robust binary BCI could serve as a diagnostic tool in patients with a disorder of consciousness (*i.e.*, unresponsive wakefulness syndrome or minimally conscious state). Even patients without motor dysfunction could benefit from the knowledge obtained. For example, neurofeedback therapy aims to put brain activity related to behavior, emotion and/or cognition under volitional control of the subject, to then change/adapt said behavior, emotion and/or cognition. Neurofeedback is typically performed using electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) but use of fNIRS as neurofeedback signal is on the rise. The knowledge in this work, for example our focus on channel-of-interest and/or signal-of-interest and reports on the location of mental task-related brain activity, can be directly applied to fNIRS-neurofeedback research. In the long term, it might become possible that fNIRS-neurofeedback ameliorates symptoms in patients who had a stroke (through modulation of motor regions) or suffer from ADHD, autism or social anxiety (through modulation of prefrontal regions) (Kohl et al., 2020).

To inform and involve future target groups about the research findings, BCI information sessions and workshops can be organized. Possible end-users could be invited via existing patient organizations. The approach being ideally user-centered, meaning a patient in need of a BCI is the starting point. Given the patient-specific needs and clinical profile, several BCI systems and encoding modalities are tested and even adapted to his/her needs (Käthner, Kübler, & Halder, 2015; Schreuder et al., 2013).

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