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An fNIRS-based brain-machine interface for remote robot control

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Introduction

Patients with severe motor impairments (*e.g.*, 'locked-in' patients) may benefit from using brain-computer/machine interface (BCI/BMI) applications that could replace the patients' lost motor function.

Functional near-infrared spectroscopy (fNIRS), a portable, relatively easy-to-apply and safe functional-neuroimaging method, constitutes a promising BCI/BMI input modality. While fNIRS-based communication and computer control have been explored in several BCI studies[1-4], comparatively little research has been done in the context of fNIRS-based control of real (physical) robots.

Here, we developed and tested a BMI system for establishing control of a remote robot (located in 3-km distance) allowing its intentional navigation to one of four different target locations (*kitchen*, *charger*, *door*, or *work room*). For this purpose, we combined brain-based intentional encoding of the robot's target location based on brain hemodynamics (using differently timed motor imagery and fNIRS) and otherwise autonomous robot navigation.

Our successful proof-of-principle study demonstrates the general feasibility of fNIRS-based remote robot control in real-time.

Methods and Results

Encoding of robot-target location (*Figure 1*)

- performing 1× (single-trial approach) or 3× in a row (multi-trial approach) mental drawing for 10s during one of four consecutive time periods
- each time period corresponds to one of the four different robot target locations
- intention encoding guided by visual stimulation (presentation of dynamic map with robot target locations successively highlighted according to the encoding scheme)

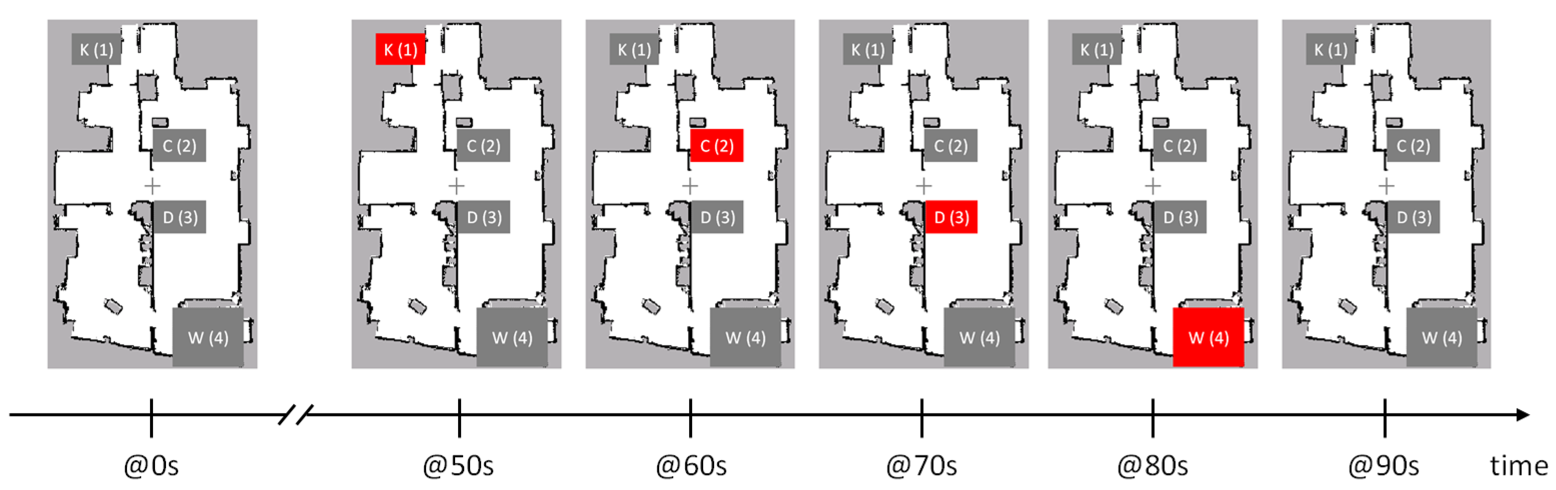

Figure 1. Visual guidance during intention encoding.
Participants encoded one of the four different robot target locations by performing the mental task during the time period in which the target location was highlighted (in red) in the dynamic visual display. *Remarks.* K(1) – kitchen; C(2) – charger; D(3) – door; W(4) – work room.

Participants and pre-training

- n = 5 (4 right-handed, all female, mean age = 28.8 years)
- short training of mental-task performance (right-hand mental drawing) and encoding of robot target locations

Experimental design/implementation

1. Localization of most-promising fNIRS-recording channel

- 1 short localizer run (6:50min)
- 50-s initial baseline period
- alternation between twelve 10-s mental-drawing and thirteen 20-s resting periods

2. Brain-based encoding of robot target location and robot feedback

- 50-s initial baseline period
- 4-8 multi-trial runs (encoding one robot target location each)
- 4-6 single-trial runs (encoding 4-6 robot target locations each)
- 20-40s resting periods separating individual encoding trials
- online decoding of participants' intentions during resting periods and immediate transfer of the command via the internet to the remote robot
- autonomous navigation of the robot (*Figure 2*; *TurtleBot 2*; Clearpath Robotics Inc., Ontario, Canada) to the target location
- participants traced the robot's navigation via real-time videoconferencing

fNIRS data acquisition

- NIRScout-816 system (NIRx Medizintechnik GmbH, Berlin, Germany)
- 8 light sources and 8 detectors covering large parts of the scalp above left-hemispheric sensorimotor cortex (*Figure 3*)
- equidistant optode positioning, 22 fNIRS-recording channels

Figure 2. Illustration of the *TurtleBot 2*.
(image obtained from www.clearpathrobotics.com)

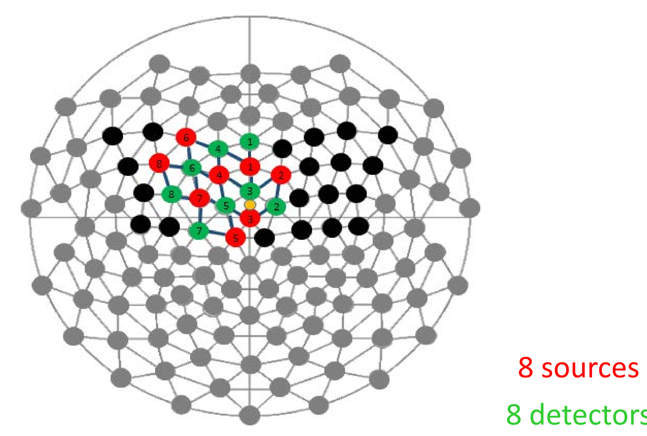

Figure 3. Equidistant fNIRS-optode setup.
(● Cz location according to the 10-20 system)

fNIRS-data analysis

Online analysis

- selection of most-promising fNIRS-recording channel (showing either clear oxy- or deoxy-hemoglobin changes during mental-task performance) for each participant individually by performing online general-linear-model (GLM) analysis
- decoding the participants' intention (*i.e.*, the robot's target location) by an experienced experimenter who visually inspected the fNIRS-signal time courses - focusing on either oxy- or deoxy-hemoglobin changes (depending on results of the localization procedure)

Post-hoc offline analysis

- intention decoding by performing GLM analysis employing four hemodynamic reference functions representing the four possible encoding periods
- calculation of multi-, single-, and overall single-trial decoding accuracies (the latter also incorporated the separate encoding trials of the multi-trial data as single trials) per participant and for the group

Online and offline analyses (including conversion to oxy- and deoxy- hemoglobin values and standard preprocessing) were performed using *TurboSatori* (v0.91; Brain Innovation B.V., Maastricht, the Netherlands).

Decoding results

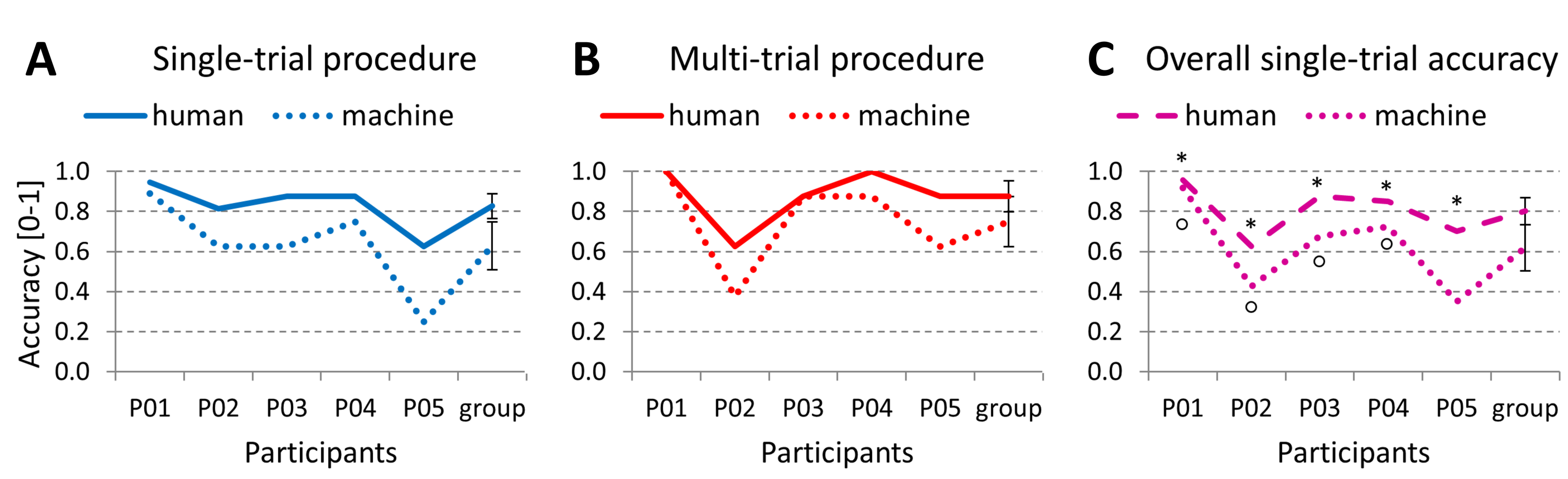

Figure 4. Individual and group decoding results.
The figure demonstrates the online- (continuous lines) and offline-obtained (dashed/dotted lines) results for experimenter (human) and automated (machine) decoding. Achieved accuracies are separately plotted for the single- (panel **A**) and multi-trial (panel **B**) encoding procedure. Panel **C** displays the overall single-trial accuracies. Asterisks (for human results) and circles (for machine results) indicate decoding performance significantly above chance level.

Conclusion

The suggested fNIRS-based BMI for remote robot control constitutes a promising approach which may allow disabled patients to (re-)engage in specific social activities. After further advancement (*e.g.*, increasing automated-decoding accuracy by employing multi-variate analysis) and more extensive validation, we will test the BMI system in motor-disabled patients.

References

1. Naito *et al.* (2007). A Communication Means for Totally Locked-in ALS Patients Based on Changes in Cerebral Blood Volume Measured with Near-Infrared Light, *IEICE Trans Inf Syst, 90*, 1028-37.
2. Gallegos-Ayala *et al.* (2014). Brain communication in a completely locked-in patient using bedside near-infrared spectroscopy, *Neurology, 82(21)*, 1930-2.
3. Sorger *et al.* (2016). Brain-based communication via online-decoded fNIRS signals, *fNIRS conference, 4th edition*, Paris, France.
4. Chaudhary *et al.* (2017). Brain-computer interface-based communication in the completely locked-in state, *PLoS Biol, 15(1)*, e1002593.

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