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Battlefield Acupuncture and Near-Infrared Spectroscopy–Miniaturized Computer-Triggered Electrical Stimulation of Battlefield Ear Acupuncture Points and 50-Channel Near-Infrared Spectroscopic Mapping

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ABSTRACT

Background: Battlefield acupuncture was developed in the course of researching a more-efficient auriculotherapy system for rapid relief of pain.
Objective: The aim of this study was to investigate possible changes in near-infrared spectroscopic (NIRS) parameters in the frontal area of the brain during electrical stimulation of battlefield acupuncture points.
Design and Setting: One channel recordings and, for the first time, 50-channel NIRS recordings were performed to obtain new insights into the possible cerebral effects of ear acupuncture.
Subjects: The test subjects were 11 healthy volunteers (8 female, 3 male; mean age ± standard deviation: 27.6 ± 4.6 years) and 1 subject for the 50-channel NIRS recording (female, age 24).
Intervention: Electrical ear stimulation was performed using a constant current 1 mA, with a duration of 1 ms at a frequency of 1 Hz.
Main Outcome Measures: The main outcomes sought were concentrations of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb) in brain tissue.
Results: There were no significant changes in the 1-channel measurement. Regional decreases of O_2Hb were seen in the frontal area in the 50-channel recordings, with a maximum within 100 seconds of stimulation onset.
Conclusions: Effects of the stimulation of battlefield acupuncture points in the brain are measurable.

Key Words: Acupuncture, Battlefield, Auriculoacupuncture, Multichannel Near Infrared Spectroscopy, Pain, Electroacupuncture, Cerebral Oxygenation (O_2Hb, HHb), Transcranial Monitoring

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INTRODUCTION

BATTLEFIELD ACUPUNCTURE WAS DEVELOPED by Niemtzow in 2001 in the course of researching a more-efficient auriculotherapy system for rapid relief of pain.[1] As Niemtzow stated in the first scientific description in 2007[1] ''the name *'Battlefield Acupuncture'* was probably influenced by the events of 9/11 with the destruction of the World Trade Center Towers in New York City by terrorists, and the assumption that this novel system could be eventually used on the military battlefield.'' In the meantime, this kind of ear acupuncture has also been investigated scientifically, and first results have been published in a joint article, with contributors from the Malcolm Grow Medical Center (Andrews Air Force Base, MD), the Helms Medical Institute (Berkeley, CA), and the TCM [Traditional Chinese Medicine] Research Center, Graz (at the Medical University of Graz, Graz, Austria).[2] In that article the first brain-function spectroscopic measurement during electrical stimulation of battlefield acupuncture points was described.[2]

Near-infrared spectroscopy (NIRS) is a non-invasive optical technique for assessment of functional activity in the human brain.[3] The technique uses an optical window in the near infrared (NIR) light spectrum identified by Jöbsis.[4] Within this spectral range ($\sim$ 630–1300 nm), light can penetrate the cranium and reach sufficient depth[5] to allow investigation of the metabolism in the cerebral cortex.[4] Typical applications include pharmacy and medical diagnostics, as well as neuroscience research.[3] NIRS has gained in importance in intensive-care medicine by providing a non-invasive method for the surveillance of cerebral oxygenation through the intact cranium.[4] Existing reports on the use of NIRS during acupuncture are mainly focused on 1-channel recordings. For a review of NIRS and acupuncture, see Litscher 2006.[6]

The goal of this study was to investigate possible changes of NIRS parameters in the frontal area of the brain in 11 healthy volunteers before, during, and after electrical stimulation of battlefield acupuncture points. In addition, for the first time, a multichannel (50-channel) NIRS recording was performed in 1 subject to demonstrate the limitations of 1-channel regional measurements and to obtain preliminary new insights into the possible cerebral effects of ear acupuncture. It has to be mentioned explicitly that this was the first investigation performed with a 50 NIRS–channel brain-function system in the field of acupuncture worldwide.

MATERIALS AND METHODS

Near-Infrared Spectroscopic Neuromonitoring

1-Channel Measurement Using NIRO 300. The NIRO 300 (Hamamatsu Photonics, Hamamatsu, Japan) measures changes in optical densities at wavelengths of 775, 825, 850, and 904 nm. The sensor contains a laser diode and three detectors placed at 4 cm from the source of emitting light. The sensor was placed so that a lateral margin of the sensor was at the midline of the right forehead of each subject, and the lower margin was 2 cm above the subject's eyebrow. The NIRO 300 uses the specially resolved spectrometer (SRS), which combines the multi-distance measurements of optical attenuation and makes it possible to calculate the absolute concentrations of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb) in brain tissue. The NIRO 500, the earlier model of the NIRO 300, monitored only changes in Hb concentration and the redox state of cytochrome oxydase with a modified Beer-Lambert equation.[3] In contrast with the modified Beer-Lambert equation, the values derived by SRS are not affected by differential path-length factors.[3]

50-Channel Measurement Using NIRScout 1624. For the multi-channel measurements, an optical neuroimaging system (NIRScout 1624, NIRx Medical Technology, Berlin, Germany) was used. The system is intuitively operated through a graphical user interface (GUI). The interface offers a range of automated procedures to assist an investigator to set up the measurement. Integrated system check procedures ensure instrument function and data integrity. The GUI displays measured data for all channels in real-time. An event synchronizer provides synchronization between the NIRS measurement and the external hardware used for the electrical stimulus presentation. The system has a sensitivity of < 1 pW NEP [noise equivalent power]; the dynamic range is 90 dB_{opt}, and the sensors consist of silicium photo-detectors. This device uses wavelengths of 760 and 850 nm, and the power is 10 mW per wavelength. The multi-channel system measures the change of O_2Hb and HHb in units of mM mm [m(mol/l)*mm] and consists of 16 light emitters and 24 photo-detectors. The distance between source and detector was 3 cm, and the sampling rate was set to 3 Hz. A specially designed electrode cap was used to apply the non-invasive optodes (optical electrodes) above the frontal and motor areas to each subject's intact skull (Fig. 1), resulting in a total of 50 measurement channels.

Subjects

After approval by the ethics committee of the Medical University of Graz (13-016, P-STIM), 11 healthy volunteers (8 female, 3 male) were included in the study. The mean age $\pm$ standard deviation (SD) was 27.6 ± 4.6 years (range 22–36). None of the subjects were taking medications and none had neurological or psychological impairments. All volunteers were informed about the nature of the investigation, as far as the study design allowed, and gave their written informed consent.

Experimental Setting and Acupuncture

The 11 volunteers were investigated in the laboratory of the TCM center of the Medical University of Graz in a half-

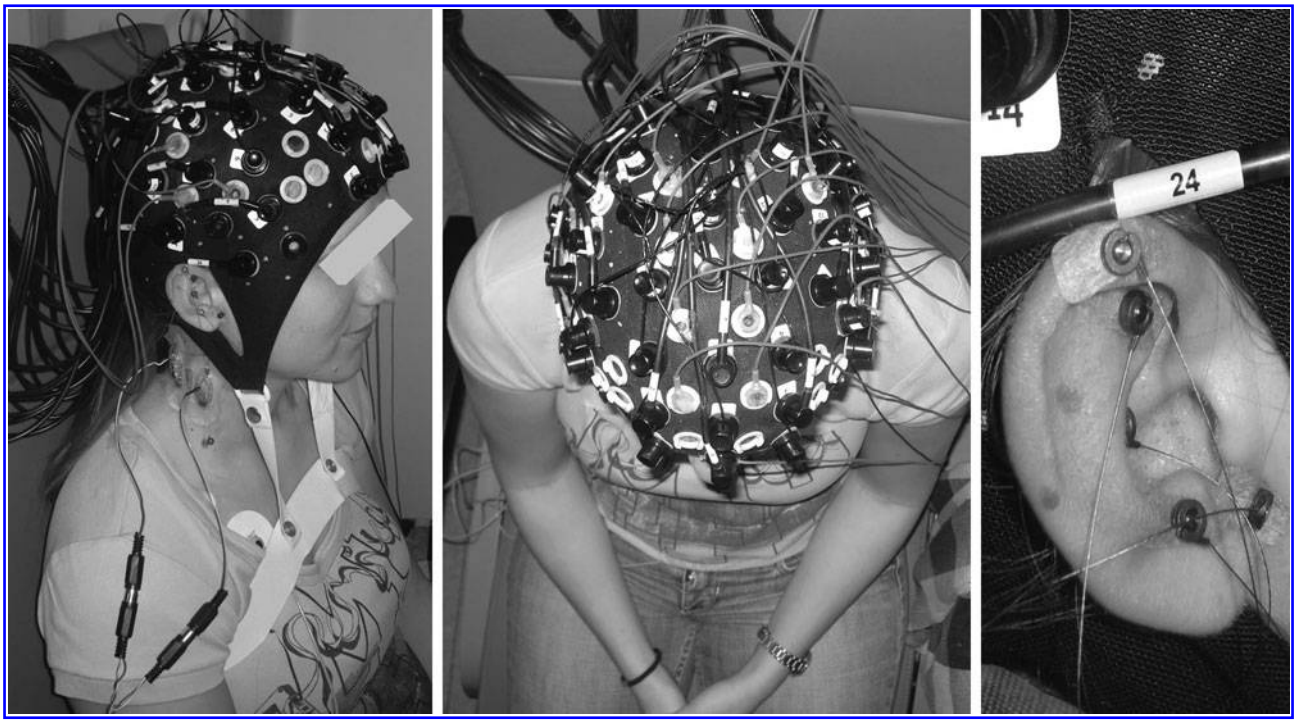

FIG. 1. Healthy volunteer during the 50-channel near-infrared spectroscopy experiment at the Graz University of Technology, Graz, Austria. *Left:* The electrical stimulators behind the ear can be turned on or off from outside the chamber. *Middle:* View from above. *Right:* Positions of the battlefield acupuncture points.

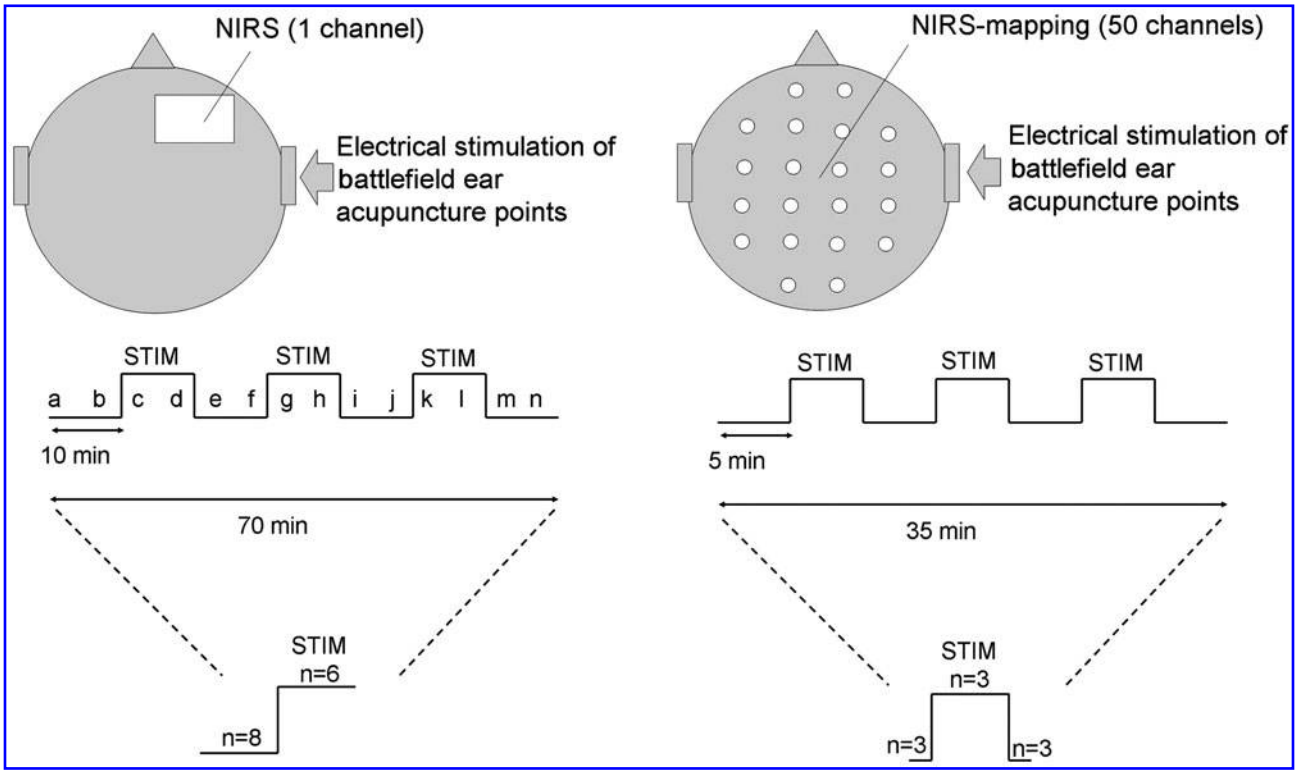

FIG. 2. Measurement procedure. *Left:* Study design for the 11 persons investigated at the Medical University of Graz, Graz, Austria. There are six 5-minute stimulation (STIM) phases (c, d, g, h, k, and l) and eight 5-minute resting periods (a, b, e, f, i, j, m, and n). *Right:* The study design for the volunteer investigated at Graz University of Technology, Graz, Austria, using the same stimulation equipment. Analysis was performed for three 5-minute stimulation periods. Min, minutes; NIRS, near-infrared spectroscopy.

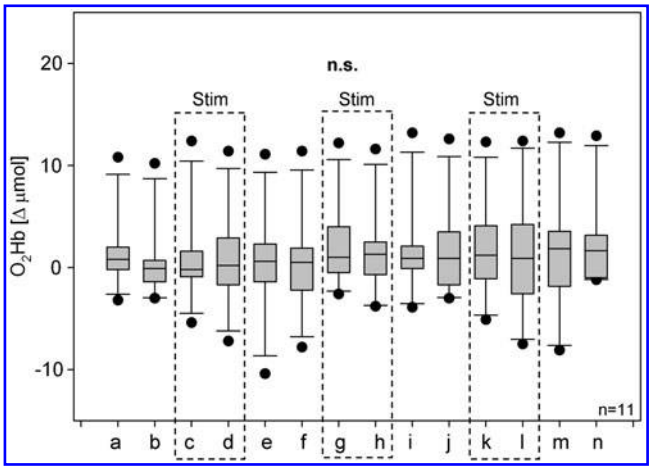

FIG. 3. Insignificant changes (in μmol) of oxyhemoglobin (O_2Hb) with (c, d, g, h, k, and l) and without (a, b, e, f, i, j, m, and n) electrical stimulation of battlefield acupuncture points, recorded with the 1-channel system. The horizontal lines in the boxes show the medians, the ends of the boxes define the 25th and 75th percentiles, and the error bars indicate the 10th and 90th percentiles. n.s., not significant.

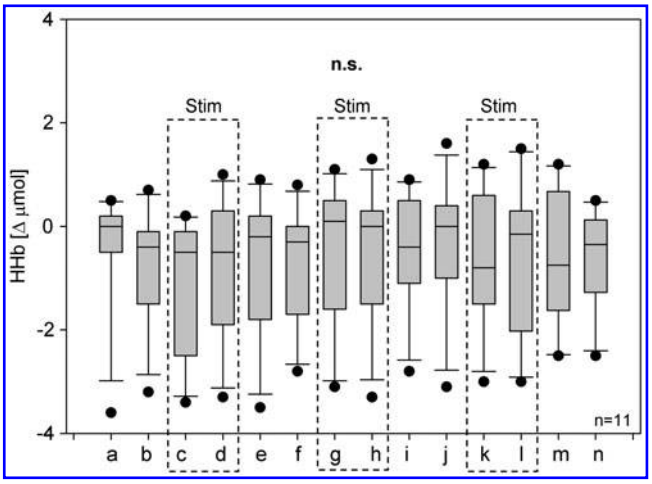

FIG. 4. Insignificant changes (in μmol) of deoxyhemoglobin (HHb) with (c, d, g, h, k, and l) and without (a, b, e, f, i, j, m, and n) electrical stimulation of battlefield acupuncture points, recorded with the 1-channel system. For further explanations, see Fig. 3. n.s., not significant.

sitting position. Fourteen 5-minute periods of averaged data before (a, b), during (c, d, g, h, k, l), between (e, f, i, and j), and after (m and n) stimulation were compared (Fig. 2, left).

The volunteer undergoing investigations with the 50-channel NIRS system (female, age 24) was sitting in a specially designed chamber at the Graz University of Technology laboratory and was observed by biomedical engineers and 2 medical doctors, both of whom were experts in TCM. This volunteer met the same inclusion criteria as the 11 volunteers described above. The experimental setting for this subject is shown in Figure 2 at the right.

Ultrathin permanent needles (P-Stim, Biegler GmbH, Mauerbach, Austria) were applied to the battlefield acupoints (Cingulate Gyrus, Thalamus, Omega 2, Shenmen, and Point Zero; Fig. 1, right) in each subject.[1] Two generators located behind the ear produced electrical stimulation impulses, which were transferred via the needles to the battlefield acupuncture zones on one ear (Fig. 1, left). The wires were connected to the needles by snapping conductive plastic rings over the needles. Electrical stimulation (P-Stim, Biegler GmbH, Mauerbach, Austria) was performed using a constant alternating (AC) current of 1 mA; impulse duration was 1 ms, stimulus frequency was 1 Hz.[2] The stimulators were electronically modified so that they could be turned on or off from outside the chamber in which the volunteer was sitting.

Statistical Analysis

Data were analyzed using SigmaPlot 11.0 software (Systat Software Inc., Chicago, IL). Graphic presentation of results uses box-plot illustrations. Testing was performed via one-way repeated measures analysis of variance (ANOVA). The criterion for significance was $p < 0.05$.

RESULTS

1-Channel NIRS System

Figures 3 and 4 show box-plot illustrations of changes in O_2Hb and HHb (averaged values of 5 minutes each). There was no significant difference between the stimulation phases and the non-stimulation periods. In addition, a comparison of the grand average of 6 stimulation phases versus 8 non-stimulation phases (Fig. 2) also did not show significant differences.

50-Channel NIRS System

Figure 5 shows the results of the topographical presentation of the 24-year-old volunteer. To facilitate comparison with the 1-channel system, only the 12 channels in the frontal area are shown (Fig. 5, A and B). The maximum decrease of O_2Hb occurred in channel 4, within 100 seconds of electrical stimulation onset (Fig. 5 [B, C, and D]). Similar to the 1-channel measurements, the data in Fig. 5 (B, C, and D) reflect the grand average of all stimulation phases (Fig. 2). In this person, the other channels showed similar, yet less-pronounced, trends.

DISCUSSION

Acupuncture is one of the oldest methods of TCM known to humanity. This ancient Asian healing method developed through extensive observation and clinical testing over the last 4000–5000 years as a system of medical theory and praxis, which is different from Western medicine. Over the

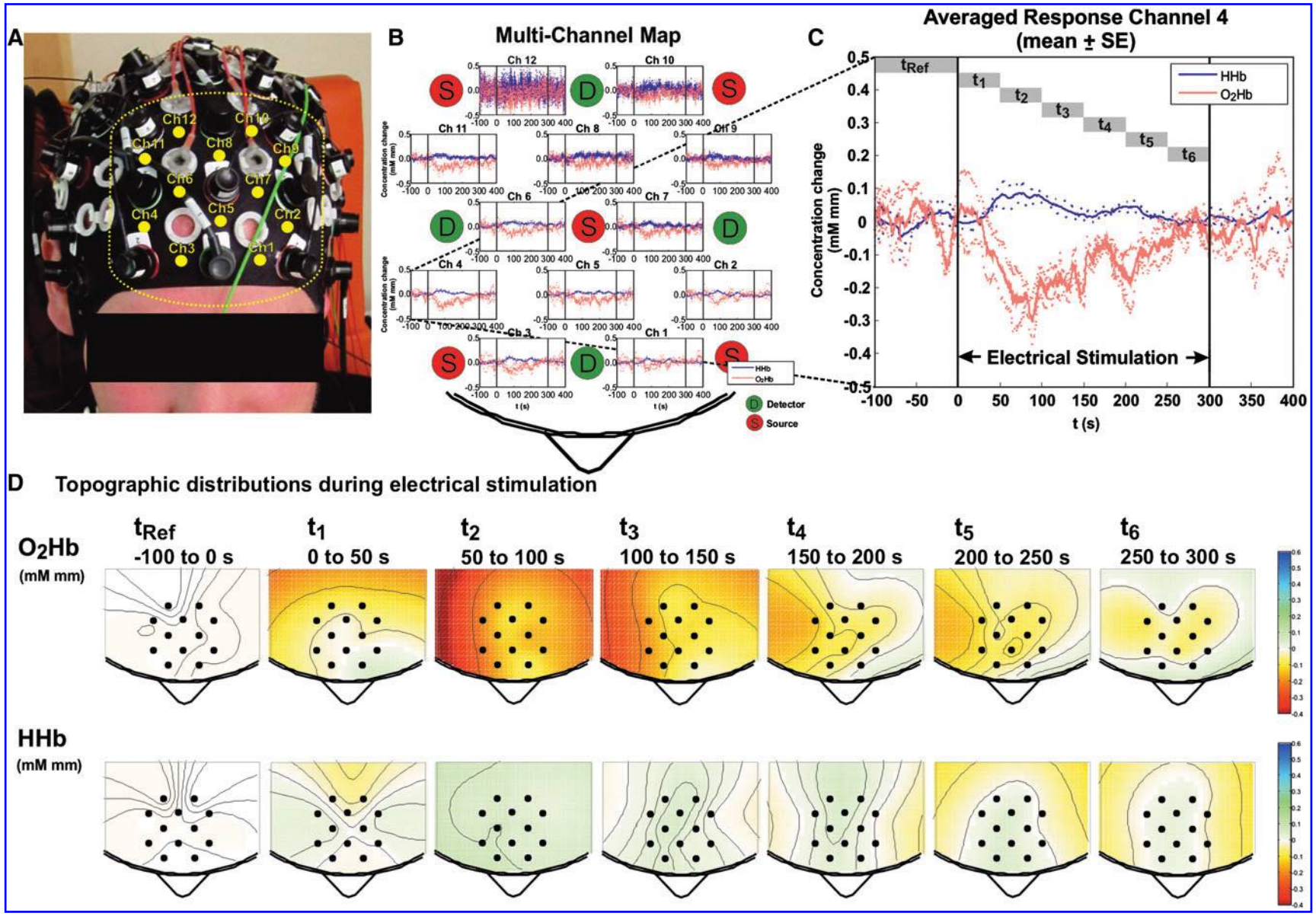

FIG. 5. First 50-channel near-infrared spectroscopy (NIRS) measurement at the Graz University of Technology, Graz, Austria. (**A**) Electrode cap with detectors and emitters for recording NIRS parameters. The 12 channels presented in the multi-channel map in (**B**) are numbered (Ch1–Ch12). (**B**) Concentration changes of oxyhemoglobin (O_2Hb; pink) and deoxyhemoglobin (HHb; blue) on a map. (**C**) Averaged responses (mean ± standard error [SE]) of channel 4 before, during, and after electrical stimulation of battlefield acupuncture points. **D.** Color-coded topographical distribution of O_2Hb (top) and HHb (bottom) before and during stimulation. Note that the maximum decrease of O_2Hb occured 50–100 seconds (s) after stimulation onset (t_2).

past 30 years, acupuncture has gained increased popularity in modern health care and is increasingly supported among scientific investigators.

It is well-known that acupuncture can be applied to treat various diseases related to the central nervous system. In this context, autonomic and cerebral hemodynamic changes induced (e.g., by electroacupuncture) are of special interest.[7] However, as of this writing, there is no scientific publication of research in the field of ear acupuncture available using high-resolution optical functional NIRS mapping of the human brain.[8]

From the historical point of view, in 1978, Chen and Erdmann[9] were the first to study the effects of acupuncture using oxygenation investigations with implanted microelectrodes in the rat brain. The NIRS method was used by Litscher et al. at the Medical University of Graz (formerly University of Graz, Faculty of Medicine) for the first time in 1997 in healthy adult volunteers.[10] The results have been published in English in 1998.[11] Thereafter, several further studies dealing with NIRS and acupuncture (different modalities) were published by Litscher et al.[2,12–18] In the year 2004, the first clinical results concerning NIRS and acupuncture were published,[19] and Széles and Litscher then provided further NIRS results of electrical punctual ear stimulation.[20,21] The present article confirms the first results of changes of NIRS parameters described in a previous battlefield acupuncture study using a 1-channel system[2] and provides new insights in topographical views using a 50-channel recording system from the Graz University of Technology for the first time in 1 person.

Acupuncture is supposedly based on energy metabolism. Here, cerebral metabolism definitely plays an important role.[6] Non-invasive, continuous single, and multichannel monitoring of regional cerebral oxygenation was not possible in the past. The NIRS method can sensitively determine changes in oxygenation proportions in cerebral vessels. Villringer and Dirnagl, in 1997,[22] and, in the meantime, many other researchers were able to prove that changes in NIRS parameters existed during cognitive processes and were able to show that these alterations did not originate from circulation of the scalp. They did these things by performing simultaneous laser-Doppler microcirculation measurements.

The NIRS method has primarily been used in scientific research in combination with specific stimulation techniques in experimental and clinical situations. By 1993, Kato et al.[23] showed that NIRS parameters changed specifically above the occipital region during visual stimulation. Meek et al.[24] also documented specific regional, marked NIRS changes after visual stimulation in 10 volunteers within the occipital region. Takahashi et al.[25] went one step further: In 2000, they published a study in which they used 24-channel NIRS imaging with a 9-cm^2–sized area with integrated optodes to investigate the visual cortex. Five volunteers were given visual stimuli for 20 seconds. The determined 1-channel measurement results were confirmed. In the literature there are a number of studies on motoric,[26] olfactory,[27] acoustic,[28] and direct electrical thalamic[29] stimulation in children and adults in connection with NIRS monitoring. All of these studies came to the same conclusion: NIRS is able to register very small changes competently in cerebral hemodynamics that occur as a response to different functional stimulation.

Studies by the research team at the Medical University of Graz on battlefield acupuncture point stimulation and NIRS provided signs that electrical stimulation of these points can alter NIRS signals over the frontal area.[2] However, in the first part of the present study, there were no significant changes within a group of 11 healthy volunteers. It is very interesting that, with a multichannel measurement using a similar stimulation procedure, one can demonstrate frontal changes clearly in NIRS parameters as the current authors had already proven and written about in an article on battlefield acupuncture.[2]

In general, the changes in NIRS parameters are unspecific, and an isolated decrease in saturation does not reveal whether the cause lies in an increase in cerebral oxygenation or in a decrease in cerebral blood flow.[6] Thus, not only the extent of oxygen supply is shown, but the interaction between oxygen supply and oxygen demand is also reflected.[19] This is possible because the venous portion of the cerebral vascular system (~75 %) mainly dominates the measurement zone. The portion of the arterial (~20%) or capillary (~5%) flow regions are, respectively, less dominant in the measurement zone.[30]

Based on these facts, changes resulting from decreased or increased oxygenation can be determined. Which regulative mechanisms are present is still unknown and the current study design did not allow conclusions on the underlying mechanisms. However, an increased utilization of oxygen resulting from stimulation induced neuronal activation (e.g., from changes in membrane potentials or releasing of neurotransmitters) is conceivable.[19]

CONCLUSIONS

The great experience of the current study group in the experimental and clinical use of the NIRS method (operating room,[3] intensive care unit,[3,31,32] acute mountain sickness,[33,34] hyperbaric chamber,[3,35] and acupuncture [2,3,6,10–21]) allow the supposition that dynamic changes in NIRS parameters reflect very small changes in cerebral oxygenation.

The NIRS results presented in this article underline the importance of the brain in acupuncture research. Even though the preliminary results do not allow uniform evaluation, they provide new information: The effects of the stimulation of battlefield acupuncture points in the brain are measurable.

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DISCLOSURE STATEMENT

No competing financial interests exist.

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