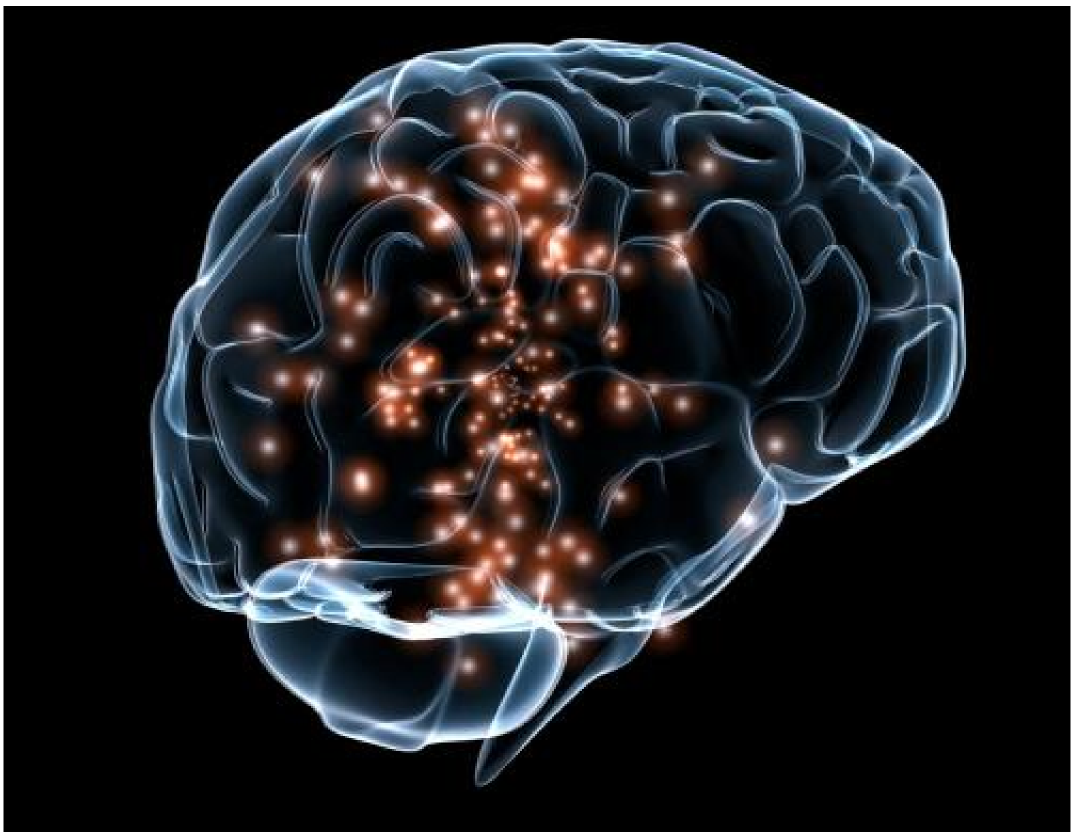
New unobtrusive electrode system for persistent brain-computer interface

March 25 2015, by Christopher Packham



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(Medical Xpress)—Noninvasive recording of electroencephalograms has applications in neurology, health and brain-computer interfaces. But existing technologies come with drawbacks that preclude their use for extended periods of time. The interface between the electrode sensor and the head have limitations including skin irritation, obtrusive wiring, cumbersome mechanical features, and often require complex, multistep preparation.

Now a research team has reported an unobtrusive, miniaturized electrode system that bonds to the complex curvature of the ear's auricle and the adjacent mastoid, using soft, skin-conformal materials. The electrical isolation of outer ear structures provides an effective point for reference/ground measurement electrodes. The system reported is durable, remaining bonded to the skin for periods of two weeks and withstanding normal activities such as vigorous exercise, showering, and swimming. It is unobtrusive to the user and requires minimal preparation for use in clinical study. The paper is published in the *Proceedings of the National Academy of Sciences*.

Limitations of existing EEG systems

Conventional electrode systems are inhibited by a number of factors, including the use of gels to interface with the skin. After a single day of use, these electrodes show clear signs of elevated temperature; the gels exhibit a 50 percent reduction in volume due to evaporative drying, which adds noise to the signal acquired by the electrode. These sorts of limitations preclude its use in long-term studies or during extended periods of activity such as exercise.

By contrast, the new device is unobtrusive with excellent long-term adhesion. It includes mesh electrodes for data acquisition, ground, and reference on a soft elastomeric film. The connectors consist of filamentary serpentine traces arranged in a spatially varying design based on Peano curves in order to provide stretchability along longitudinal axes. The electrodes use a similar fractal layout. The epidermal electrode itself incorporates known biocompatible materials including silicone, gold and polyimide.

The effective modulus of the device is lower than that of the skin in order to conform to the contours of the ear and for maximum adhesion. It is the ability to adapt to these complex surface curves that provides the durability of the device, which is held to the skin with soft bonding from van der Waals interactions. The authors report that the complete device can be stretched up to around 50 percent. "These results suggest an ability to accommodate larger than average skin deformation, up to and including the maximum strains associated with the motion of the knee joint," they write.

Additionally, microscopy revealed no adverse effects from long-term application, including rashes, redness, or allergic reactions. The authors also report EEG measurement fidelity that compares favorably with conventional systems. The signal-to-noise ratio corresponds to the ratio of the signal power from the target to the noise power from the nontarget.

The authors successfully tested a number of use-case scenarios with the new device, including recording of EEG alpha rhythms over a two-week period. They recorded EEG spectrograms for frequencies between five and 15 Hz over 14 days, with no significant differences in the quality of recordings between days one and 14. "The slightly increased levels of background noise, especially on day 14, may arise from the buildup of naturally exfoliated dead cells on the skin surface," they write. These exfoliated skin cells were ultimately the limiting factor in the durability of the interface between the device and the skin.

The authors also conducted brain-computer interface experiments with subjects wearing the system, using a text-speller program. Subjects were asked to spell the word "computer" by looking at target letters that flickered at different frequencies. This flickering allowed a CCA-based classifier to determine the user's desired character. The authors report, "The averaged spelling rate is 2.37 characters per minute, which is only a factor of two to three times slower than a full cap system that uses 8-10 electrodes on the hairy scalp (4-7 characters per minute)."

In the future, the researchers hope to further model and study tripolar electrodes and to develop wireless communication and power supply systems without making the device more obtrusive to subjects.

More information: "Soft, curved electrode systems capable of integration on the auricle as a persistent brain–computer interface." *PNAS* 2015 ; published ahead of print March 16, 2015, DOI: 10.1073/pnas.1424875112

Abstract
Recent advances in electrodes for noninvasive recording of electroencephalograms expand opportunities collecting such data for diagnosis of neurological disorders and brain–computer interfaces. Existing technologies, however, cannot be used effectively in continuous, uninterrupted modes for more than a few days due to irritation and irreversible degradation in the electrical and mechanical properties of the skin interface. Here we introduce a soft, foldable collection of electrodes in open, fractal mesh geometries that can mount directly and chronically on the complex surface topology of the auricle and the mastoid, to provide high-fidelity and long-term capture of electroencephalograms in ways that avoid any significant thermal, electrical, or mechanical loading of the skin. Experimental and computational studies establish the fundamental aspects of the bending and stretching mechanics that enable this type of intimate integration on the highly irregular and textured surfaces of the auricle. Cell level tests and thermal imaging studies establish the biocompatibility and wearability of such systems, with examples of high-quality measurements over periods of 2 wk with devices that remain mounted throughout daily activities including vigorous exercise, swimming, sleeping, and bathing. Demonstrations include a text speller with a steady-

state visually evoked potential-based brain–computer interface and elicitation of an event-related potential (P300 wave).