



Can electrocorticography (ECoG) support robust and powerful brain–computer interfaces?

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A commentary on

Long-term asynchronous decoding of arm motion using electrocorticographic signals in monkey.

by Zenas C. Chao, Yasuo Nagasaka and Naotaka Fujii (2010). *Front. Neuroeng.* 3:3.

Brain–computer interfaces (BCIs) use brain signals to communicate a user's intent (Wolpaw et al., 2002). Because these systems directly translate brain activity into action, without depending on peripheral nerves and muscles, they can be used by people with severe motor disabilities. Successful translation of BCI technology from the many recent laboratory demonstrations into widespread and valuable clinical applications is currently substantially impeded by the problems of traditional non-invasive or intracortical signal acquisition technologies.

Non-invasive BCIs use electroencephalographic (EEG) activity recorded from the scalp (Birbaumer et al., 1999; Pfurtscheller et al., 2000; Wolpaw et al., 2002; Millan Jdel et al., 2004; Wolpaw and McFarland, 2004; Blankertz et al., 2007; McFarland et al., 2008). While non-invasive BCIs can support much higher performance than previously assumed (Wolpaw and McFarland, 2004; Müller and Blankertz, 2006; McFarland et al., 2008, 2010), such performance typically requires extensive user training and can also be variable. Intracortical BCIs use action potential firing rates or local field potential activity recorded from individual or small populations of neurons within the brain (Serruya et al., 2002; Taylor et al., 2002; Carmena et al., 2003; Shenoy et al., 2003; Santhanam et al., 2006; Donoghue et al., 2007; Velliste et al., 2008). Signals recorded within cortex may encode more information and might support BCI systems that require less training than EEG-based systems. However, clinical implementations

are impeded mainly by the problems in achieving and maintaining stable long-term recordings from individual neurons and by the high variability in neuronal behavior (Shain et al., 2003; Donoghue et al., 2004). Despite encouraging evidence that BCI technologies can serve useful functions for severely disabled individuals (Kübler et al., 2005; Hochberg et al., 2006; Nijboer et al., 2008), these issues of non-invasive and action potential-based techniques in acquiring and maintaining robust recordings and BCI control remain crucial obstacles that currently impede widespread clinical use in humans.

In consequence, a critical challenge in designing BCI systems for widespread clinical application is the identification and optimization of a BCI method that combines good performance with robustness. In the current absence of robust techniques to extract high-fidelity signals from EEG or to record activity from within the brain over prolonged periods, the use of electrocorticographic (ECoG) activity recorded from the cortical surface could be a powerful and practical alternative. ECoG has higher spatial resolution than EEG (i.e., tenths of millimeters vs. centimeters, Freeman et al., 2000; Slutzky et al., 2010), broader bandwidth (i.e., 0–500 Hz, Staba et al., 2002, vs. 0–40 Hz), higher amplitude (i.e., 50–100 μ V maximum vs. 10–20 μ V), much greater signal-to-noise ratio (Ball et al., 2009), and far less vulnerability to artifacts such as EMG (Freeman et al., 2003). In addition to these superior general characteristics, a number of human studies (Schalk et al., 2007; Ball et al., 2008; Pistohl et al., 2008; Sanchez et al., 2008; Waldert et al., 2008; Gunduz et al., 2009; Kubanek et al., 2009) have recently shown that ECoG can provide information about movements that far exceeds that provided by EEG. Other studies (Leuthardt et al., 2004; Wilson et al., 2006; Schalk et al., 2008) demonstrated that this information in ECoG can be used to provide

one- or two-dimensional BCI control with little training. In summary, these (predominantly human) studies have produced great excitement for ECoG recordings, because they demonstrate that ECoG can provide information about movements and other aspects of behavior that is in aspects relevant to BCI performance on par with, and can even exceed, the information provided by single-neuron recordings.

While these studies demonstrated ECoG's impressive capabilities, and while several other studies suggested that ECoG may have long-term robustness (Loeb et al., 1977; Bullara et al., 1979; Yuen et al., 1987; Pilcher and Rusyniak, 1993; Margalit et al., 2003), concrete quantitative evidence for ECoG's long-term stability has been missing. The recent study by Chao et al. (2010) provided this critical piece of information. This study evaluated ECoG-based decoding of hand position and arm joint angles during reaching movements. Data were recorded in two monkeys over a period of several months. This study confirmed and extended the previous finding that local field potentials recorded from the surface of the brain can be used to accurately decode different kinematic parameters of limb movements. More importantly, it also provided two other pieces of information. First, the authors showed that decoding performance does not significantly degrade with time, which suggests that the signal-to-noise ratio of ECoG recordings is robust over many months. Second, the authors also showed that there is no negative correlation between decoding performance and the time between model generation and model testing, which suggests that the neural representations that encode kinematic parameters of reaching movements are stable across the months of study.

In conclusion, the study by Chao and colleagues is of critical importance to the whole field of BCI research. It justifies previous excitement for ECoG recordings, and

more forcefully suggests a realistic trajectory toward robust, powerful, and widespread clinical applications of BCI technology.

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Received: 10 May 2010; accepted: 27 May 2010; published online: 24 June 2010.

Citation: Schalk G (2010) Can electrocorticography (ECoG) support robust and powerful brain–computer interfaces? *Front. Neuroeng.* 3:9. doi: 10.3389/fneng.2010.00009
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