Epilepsy & Behavior 51 (2015) 312–320

Contents lists available at ScienceDirect

Epilepsy & Behavior

journal homepage: www.elsevier.com/locate/yebeh

Proceedings of the Seventh International Workshop on Advances in Electrocorticography

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ARTICLE INFO

Article history:
Received 31 July 2015
Accepted 1 August 2015
Available online 29 August 2015

Keywords:
Electrocorticography
Brain–computer interface
Corticocortical evoked potentials
Brain mapping
Seizure termination
Neuroprosthetics
Subdural grid
Functional mapping
Subdural grid
Neurolinguistics

ABSTRACT

The Seventh International Workshop on Advances in Electrocorticography (ECoG) convened in Washington, DC, on November 13–14, 2014. Electrocorticography-based research continues to proliferate widely across basic science and clinical disciplines. The 2014 workshop highlighted advances in neurolinguistics, brain–computer interface, functional mapping, and seizure termination facilitated by advances in the recording and analysis of the ECoG signal. The following proceedings document summarizes the content of this successful multidisciplinary gathering.

1. Introduction

A. Ritaccio

The Seventh International Workshop on Advances in Electrocorticography (ECoG) took place on November 13–14, 2014, in Washington, DC. This meeting charted advances in established and novel investigatory domains. Poeppel's keynote address described ECoG-based experiments helping to define hierarchical linguistic structures as fundamental as words, phrases, and sentences. "Functional tractography" via ECoG-based corticocortical evoked potentials was summarized by its principal evangelist, Riki Matsumoto. Early observations in the chronic electrocorticography of patients with epilepsy were expertly described by Morrell. Manufacturing and implementation of customized electrode sheets fitted to the exact curvature of gyral and sulcal anatomy was outlined by Hirata. Advances in applicability and physician acceptance of functional mapping in neurosurgical decision-making were represented in the presentations of Ritaccio and Kamada. State-of-the-art presentations on brain–computer interface and basic ECoG neurophysiology rounded out this dense 2-day curriculum. The course directors thank the expert faculty for their participation and the editor of *Epilepsy & Behavior* for the privilege of a home for these proceedings.

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http://dx.doi.org/10.1016/j.yebeh.2015.08.002

2. Keynote address

2.1. Neural oscillations, speech, and linguistic structure building

D. Poeppel

Three problems in current research continue to capture much attention. The first challenge concerns how to develop a theoretically well-motivated and biologically sophisticated functional anatomy of the language processing system. This "maps problem" is a practical issue. As is true for other domains, language research needs fine-grained maps of the regions that underpin the domain; determining which techniques can be harnessed to build an articulated model remains difficult. Advances in imaging techniques and ECoG yield regular progress, but what constitutes the appropriate mesoscale remains debated (i.e., single cells are arguably too fine-grained a map, cortical fields at the "Brodmann scale" are almost certainly too coarse). Building on a dual-stream architecture for speech processing [1], it is argued that looking at these hypothesized regions and their internal structure constitutes a promising way to study an appropriate scale. The second, related challenge concerns the "parts list", or the set of primitives for language actually under consideration. What ontological commitments are likely to provide a plausible link to neurobiological infrastructure? This "mapping problem" constitutes a more difficult, principled challenge: what is the appropriate level of analysis and granularity that allows us to map between (or align) the biological hardware and the computational requirements of language processing [2,3]? The first challenge, the maps problem, addresses how to break down linguistic computation in space. The second challenge, the mapping problem, addresses how to break down language function into computational primitives suitable for biology. The third challenge, the timing problem, illustrates one linking hypothesis, breaking down the temporal structure of speech and language processing [4,5]. Human language is hierarchically structured, and mental representations of such structure are necessary for successful language processing. In speech, however, hierarchical linguistic structures, such as words, phrases, and sentences, are not clearly defined physically and must, therefore, be internally constructed during comprehension. How multiple levels of abstract linguistic structure are built and concurrently represented remains unclear. On the basis of magnetoencephalography (MEG) and ECoG experiments, we demonstrate that during listening to connected speech, cortical activity of different time scales is entrained concurrently to track the time course of linguistic structures at different hierarchical levels. Critically, entrainment to hierarchical linguistic structures is dissociated from the neural encoding of acoustic cues and from processing the predictability of incoming words. The results demonstrate syntax-driven, internal construction of hierarchical linguistic structure via entrainment of hierarchical cortical dynamics.

3. Clinical

3.1. Probing functional networks with cortical stimulation

R. Matsumoto

A better understanding of seizure networks as well as the mechanisms involved in human higher cortical functions requires a detailed knowledge of neuronal connectivity. In the last decade, single-pulse stimulation has been highlighted in the field of epilepsy surgery to probe functional and seizure networks as well as to evaluate epileptogenicity. This technique is "old" in a sense that the original attempt to record the direct cortical response (DCR) from the immediate adjacent cortices in animals was performed in the early 20th century by Adrian [6], and "new" in that its clinical application has expanded with multichannel intracranial recording in the last decade owing to the development of digital electroencephalography (EEG) equipment. Although limited to the invasive presurgical evaluations with chronic implantation of intracranial electrodes, single electrical pulses (duration: 0.3 ms, frequency: 1 Hz, alternating polarity: 1–12 mA) are directly applied to the cortex, and evoked cortical potentials (corticocortical evoked potentials, CCEPs) are recorded from adjacent and remote cortical regions by averaging the electrocorticogram time-locked to the stimulus onset (20–30 × 2 trials). In contrast to diffusion tractography, the CCEP technique has an advantage of tracking the interareal connectivity physiologically, providing directional as well as temporal information. Clinically, CCEP or "functional tractography" is highly practical because it can be done (*i*) easily with an online averaging technique in a short time (less than a minute or two for each stimulus site), (*ii*) without the cooperation of patients, and (*iii*) with minimal chance of provoking seizures.

The CCEP method has been introduced in the extraoperative setting to probe the dorsal language network [7], cortical cognitive motor network [8], and lateral parietofrontal network [9] and complemented the findings obtained by the diffusion tractography (e.g., the arcuate fasciculus, superior longitudinal fasciculus, and frontal aslant tract) by providing their detailed cortical destinations. The CCEP connectivity investigations have expanded in the last several years, and worldwide collaboration warrants the establishment of a comprehensive CCEP connectivity standardized map as a reference for noninvasive connectivity studies. Evaluating the state/task-dependent dynamic change of the connectivity is another interesting topic in the academic field.

Reflecting its high practicality, intraoperative "system" mapping is one of the most significant clinical applications. Corticocortical evoked potential has been recently applied to intraoperative language and cortical motor network mapping [10,11]. During both general anesthesia and awake craniotomy, single-pulse stimulation has been successfully applied to Broca's area to probe and monitor the integrity of the dorsal language pathway for brain surgery of tumors around the arcuate fasciculus. After the language white matter bundle, i.e., the arcuate fasciculus, was defined by 50-Hz stimulation, single-pulse stimulation was applied to trace its connections into the language-related cortices (Fig. 1). Judging from the latencies and distribution of CCEP and subcorticocortical evoked potential (SCEP) in the anterior and posterior language areas, the eloquent subcortical site was shown to connect directly with the two cortical language areas. Combined 50-Hz and 1-Hz white matter stimulations under awake craniotomy would be a promising method to probe the function and cortical targets of the large white matter bundles involved in higher brain functions such as language for each individual patient.

3.2. Implantation of intracranial electrodes causes subacute changes in clinical seizures and in the electrocorticogram

M. Morrell

A common clinical observation in patients being evaluated for epilepsy surgery is that seizures may be less frequent immediately after implantation of intracranial electrodes [12,13]. This "implant effect" has been variously attributed to anesthesia, the craniotomy, or the mechanical effect of electrodes. Two randomized controlled trials (RCTs) of brain stimulation for adjunctive treatment of medically refractory partial seizures reported a seizure reduction after implantation of intracranial electrodes but before stimulation was delivered. The seizure reduction after implant was of similar magnitude (initially about 25%, then waning over time) and duration (at least 3 months) in both studies despite different intracranial targets [14,15].

One of these RCTs was conducted with a responsive neurostimulator that provides chronic ambulatory electrocorticographic (ECoG) sensing, detection, and recording, as well as stimulation in response to detections of specific physician-identified ECoG patterns (RNS System, NeuroPace, Mountain View, CA). Data from 126 patients who were implanted with the RNS System and who had at least 100 scheduled ECoG samples obtained over a minimum of 1 year were analyzed to assess monthly changes in raw and normalized overall power, as well as power in specific frequency bands. Over 100,000 ECoG samples (typical