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Early visual analysis tool using magnetoencephalography for treatment and recovery of neuronal dysfunction

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ABSTRACT

Functional neuroimaging modalities play an important role in deciding the diagnosis and course of treatment of neuronal dysfunction and degeneration. This article presents an analytical tool with visualization by exploiting the strengths of the MEG (magnetoencephalographic) neuroimaging technique. The tool automates MEG data import (in tSSS format), channel information extraction, time/frequency decomposition, and circular graph visualization (connectogram) for simple result inspection. For advanced users, the tool also provides magnitude squared coherence (MSC) values allowing personalized threshold levels, and the computation of default model from MEG data of control population. Default model obtained from healthy population data serves as a useful benchmark to diagnose and monitor neuronal recovery during treatment. The proposed tool further provides optional labels with international 10-10 system nomenclature in order to facilitate comparison studies with EEG (electroencephalography) sensor space. Potential applications in epilepsy and traumatic brain injury studies are also discussed.

1. Introduction

Clinical diagnosis of mild cognitive impairment (MCI), depression, traumatic brain injury (TBI), or dementia is performed by considering medical history followed by physical and psychiatric assessment. Neuroimaging modalities serve as an instrument to provide additional useful information to clinical diagnosis of neuronal dysfunction and degeneration. Conventionally, physicians recommend a magnetic resonance imaging (MRI) or Computed Tomography (CT) scan to examine anatomical connectivity, if they suspect any neuronal disorder, or they wish to investigate the extent of a head injury. However, metabolic diseases [1] and lesions [2] are better expressed by probing into functional connectivity. Functionally, brain is connected in such a way that neurons from different brain regions are synchronously activated to achieve a particular task. It has been noticed that this sort of connectivity exists in both resting-state and task state [3], generally termed as task-negative network (TNN) and task-positive network (TPN), respectively. TNN is also known as the default mode network (DMN). Functional connectivity is important to monitor recovery after any neurodegenerative illness or head injury [4]. The connectivity can be estimated by assessing active brain regions while performing a particular task or at rest.

Literature suggests that ventral medial prefrontal cortex (vmPFC) and posterior cingulate cortex (PCC) show considerable electromagnetic activity while at rest. Also, medial temporal lobe (MTL) is usually active during memory access during TNN state [5]. Functional connectivity can be measured by using neuroimaging modalities, such as functional magnetic resonance imaging (fMRI), Positron emission tomography (PET), Single-photon emission computed tomography (SPECT), functional near infrared spectroscopy (fNIRS), electroencephalogram (EEG) and magnetoencephalography (MEG). Usually, DMN connectivity is estimated by obtaining spontaneous scan (resting-state brain activity with eyes open or closed). The EEG and MEG could record brain activities at a higher temporal resolution. These modalities measure different features from the synchronization of neurons [6]. EEG is more sensitive to gyri, but also senses activity at the sulci to some extent. MEG, on the other hand, has a better ability to detect tangential dipole at the sulci [7].

Lee et al. have highlighted the need of standardizations across disciplines, and a single framework for inferring causality from EEG and MEG data [8]. Devising a formation of lead fields in order to compare MEG sensor space with EEG enables development of fusion strategies of

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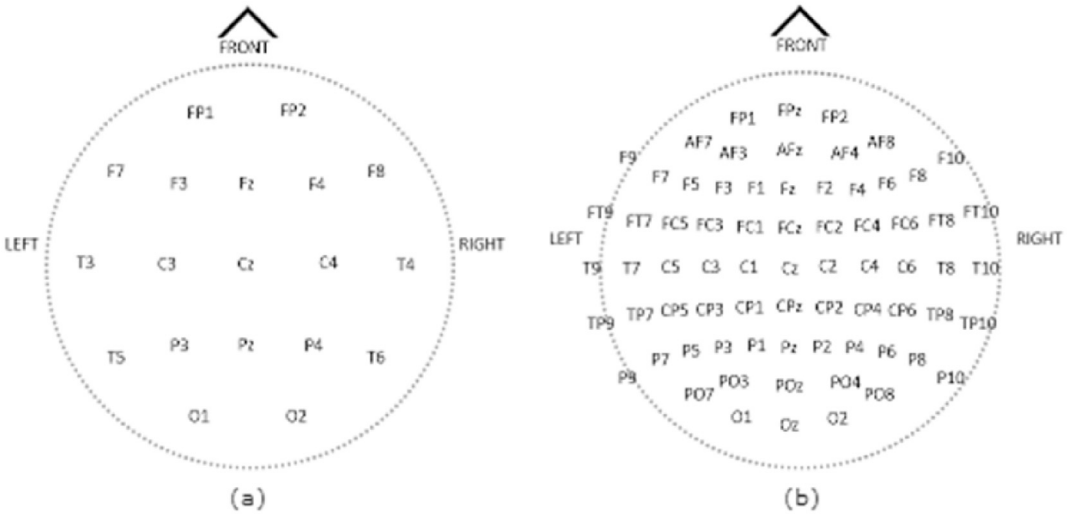

Fig. 1. (a) EEG electrode positions following international 10–20 system (b) Electrode positions following 10–10 system [FP=Pre-frontal, F=Frontal, T = Temporal, C=Central, O=Occipital, z = Midline].

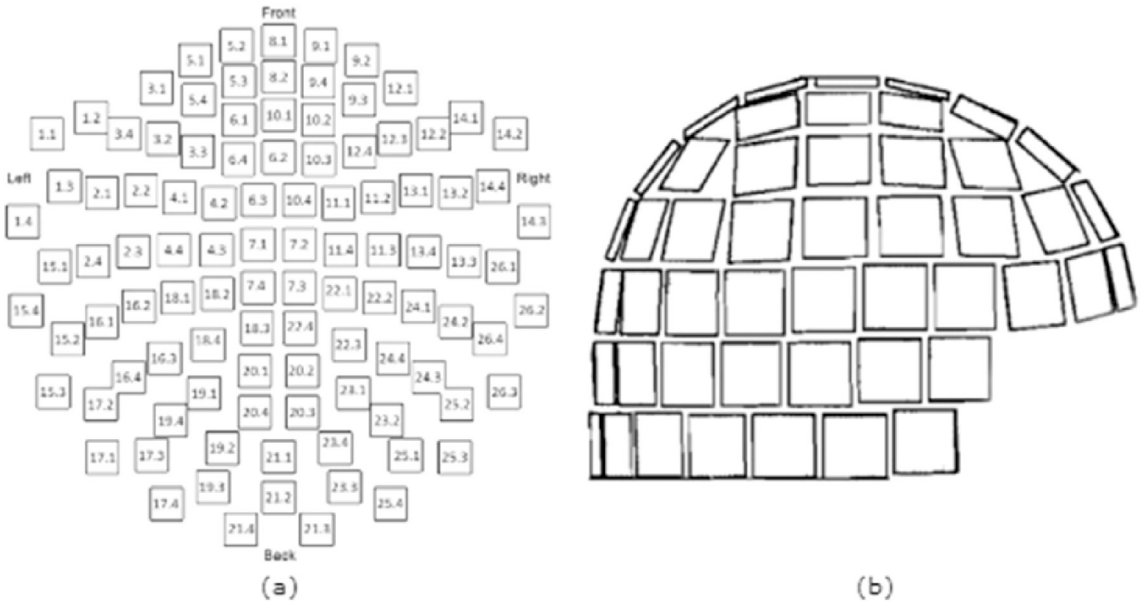

Fig. 2. (a) Sensor space of MEG as defined by vendor Elekta (b) Sensor distribution on MEG Dewar [13].

both modalities [9]. Literature reports that a combination of these two modalities gives a higher accuracy and sensitivity than any of them used alone, because MEG is more sensitive to sulci, whereas EEG is sensitive to gyrial activity [9,10]. EEG instruments comply to well-known international standard to specify location of scalp electrodes, for instance, international 10–20 system consists of 19 electrodes in its sensor space [11], as shown in Fig. 1(a). Modern EEG systems use 64, 128 or more electrodes and their placements are based on enhanced conventions, such as 10-10 system of electrode positioning, as shown in Fig. 1(b). On the other hand, due to technological difference of MEG sensor coils, different vendors may have different spatial spread of MEG sensors. Moreover, the MEG sensor labels are not as elaborative as EEG.

MEG bears the highest temporal resolution with a reasonable spatial resolution, making it suitable for functional connectivity visualization and analysis. Due to its spatiotemporal strength, MEG has been applied to locate sources in auditory, somatosensory and motor area [12]. MEG is completely non-invasive and comparatively convenient to examine patients suffering from neuronal dysfunction or injury. For MEG systems, the sensor space is specified by individual vendors due to distinct design constraints; for instance, 26 locations of various sensor groups are defined over the whole brain using 102 MEG triple-coil sensors (Elekta Neuromag Oy, Helsinki, Finland) as shown in Fig. 2.

Although, both MEG and EEG electrodes are set over the scalp in order to record brain activity, yet MEG carries several advantages over EEG apparatus. The bio-electromagnetic difference between the two modalities has been studied by many, and it has been established that EEG is susceptible to extracellular volume currents, usually generated by postsynaptic potentials [14]. Such a volume conduction issue is not significantly detected in magnetic signals, because multiple field components tend to nullify each other within a spherical volume conductor. This phenomenon enhances the sensitivity of MEG to superficial cortical activity, hence enabling localization of deep brain sources.

Typically, the data acquired from the MEG sensors is processed using data analysis software, which is usually supplied by the vendors alongside their systems. However, due to limited and very distinct focus of these software applications (typically shipped freely by vendors with

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