NON CLASSICALITY IN MIND

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***Abstract*— Understanding the mechanisms of human decision making is of significant importance to the cognitive science. Today's motivation on artificial intelligence and machine learning has been focused on more humanoid machines. Classical machine learning algorithms are based on classical logic and probability. However, empirical evidence shows that human decision behavior reveals some non-classical aspects such as context effects, order effects or ambiguity aversion. Electroencephalography (EEG) is a well-known way to obtain and interpret the brain signals for diverse goals. This study presents standard EEG methods to obtain the data, then some methods will be briefly surveyed analyzing non-classical effects by using EEG data.

Keywords*— *EEG methods, Quantum non-locality, Cognitive systems

I. INTRODUCTION

THE underlying motivation for obtaining brain signals as a result of neural activity has been the need for diagnosis and treatment of brain dysfunctions, disorders and illnesses. The first extracted brain data was taken in 1875 by Richard Caton in Liverpool by a Galvanometer over the scalp of a subject with two electrodes. This was used to explain epileptic attacks by the observed electrical anomalies of the signals [1].

The existence of the brain EEG signals discovered Hans Berger by more powerful double Galvanometer [2, 3]. Berger declared the alpha rhythm as the main ingredient of EEG signals. He also discovered some relations between EEG signal variations and mental activities in his later studies.

Kornmüller signed out the importance of the positioning of electrodes and the multi-channel recordings [4]. In 1947 the American EEG society was founded and the first congress was held in London. The EEG studies are still in progress with the focus of clinical and data processing studies. Today, EEG recordings have been known as invasive and non-invasive recording integrated with computer systems. The obtained data is subjected to the advanced tools of many signal processing methods. EEG signals are obtained by secondary electrical fields generated by electric current flows between synaptic junctions of neural cells. Human head attenuates the EEG signals more than two orders of magnitude and the obtained EEG data consist environmental and internal noise.

Today, on one hand we witness the rapid development of artificial intelligence and machine learning, on the other hand we continue the effort on understanding the brain and human behavior. In this respect, the EEG data could provide an important information content as an empirical data. There is a huge literature on the human behavior violating the basic axioms of classical probability theory or depicting some non-classical effects [5, 6]. The well-known formulation for non-classicality or non-locality is Bell inequalities introduced by John Bell [7]. John Bell demonstrated that violations of Bell inequalities implies the non-classical behavior of quantum systems. A variant of these inequalities in the time domain are called Legget Garg inequalities proposed by Legget-Garg in 1985 [8]. These inequalities are sometimes called temporal Bell inequalities implies the non-locality in time.

In this article, we discuss brain rhythms and EEG signals. Then we review some studies analyzing the non-classicality of brain rhythms by investigating EEG data in terms of LG inequalities.

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Manuscript received May 15, 2017; accepted Jul 18, 2017.
Digital Object Identifier:

II. BRAIN RHYTMS

Brain defects could be diagnosed by careful analysis of EEG recordings. In our case, we will be interested in healthy subjects. There are five main distinguishable brain sourced waves change with wakefulness and sleep. The major frequency bands are alpha, theta, beta, delta and gamma waves.

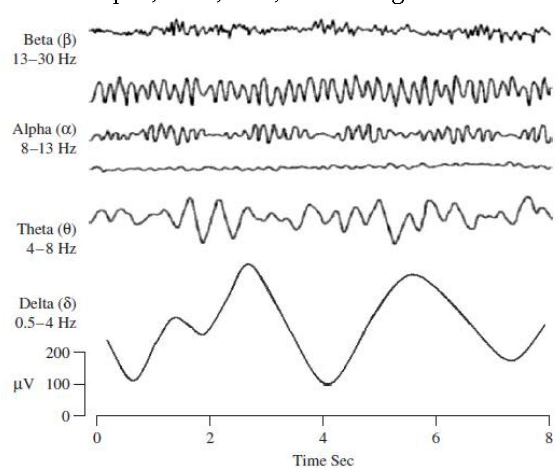

Fig.1. Typical brain rhythms, with descending frequencies. The delta wave is observed in infants or sleeping adults, the alpha wave is detected when there is no attention, and the beta wave shows up frontally and laterally.

Delta waves has the lowest frequency range which lies between 0.5- 4 Hz. These waves are associated with deep sleep and could be easily confused by artefact signals from the muscles. Theta waves has the have the frequency range 4-7.5 Hz and represent the consciousness shifts towards relaxation and unconsciousness. These waves would also be associated with mediation. Variation in the theta wave rhythms has been the subject of emotional studies [9]. Next band is the alpha waves lying within 8-13 Hz thought of representing awareness with low concentration. They have generally smooth or sinusoidal shapes and sharp shapes in rare situations. It's accepted that alpha waves show up in the posterior side of the head and cover a wide range of brain activity. In most cases, alpha waves are produced during the eyes closed but reduced during the eyes opened or a sound heard. The physiological impact of alpha waves is still under research [10].

Beta waves constitutes the range of 14-26 Hz which are known as usual waking rhythm. These waves are associated with active thinking, high-level attention. A beta wave frequency level could be enhanced during a panic case. The brain waves with frequency above 30 Hz correspond to gamma waves. These waves generally lies within 30-45 Hz and their detection is rare. Their presence indicates certain brain diseases. Fig.1 demonstrates the aforementioned brain rhythms with corresponding frequency ranges.

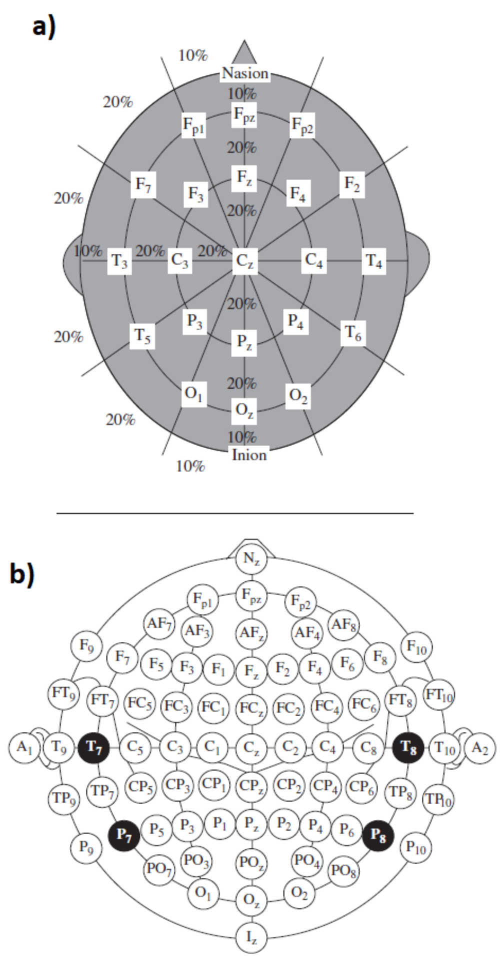

Fig. 2. Typical brain rhythms, with descending frequencies. The delta wave is observed in infants or sleeping adults, the alpha wave is detected when there is no attention, and the beta wave shows up frontally and laterally [11].

Effective signal bandwidth is restricted to around 100 Hz and a 200 Hz sampling frequency is generally sufficient for sampling EEG signals. The international federation of societies for EEG has recommended the conventional electrode setting for 21 electrodes. As in Fig.2 [11] the even electrodes are on the right side and the odd ones are on the left. In this system, more number of electrodes can be placed in between the above electrodes with equidistance. As in Fig.2b, C_1 is placed between C_3 and C_z on the left side.

In some cases, only single channel EEG recording may be sufficient. For example, C_3 or C_4 electrodes have convenient placements for the movements of the right and the left fingers respectively. In some other applications such as human-computer interfacing, a few numbers of electrodes might be selected from the conventional setting system.

III. BISTABLE PERCEPTION

It's been proposed that the characteristics of quantum theory can be used for exploring the dynamics of the systems outside physics [12]. One example is a bistable perception of human which has been an interesting topic since the report of Necker [13]. As depicted in Fig. 3, only one perspective over two possible perspectives perceived at a time.

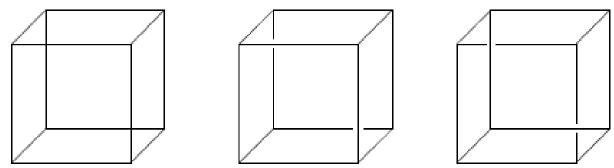

Fig. 3. Necker cube (leftmost) and the corresponding two possible representations.

Under continuous time evaluation the perspectives of ambiguous figures switches in an uncontrollable manner. There are various studies reported extracting EEG data taken by ambiguous figures stimuli [14, 15].

Generally, experiments held by middle aged subjects pressing a button during the percept reversal. Atmanspacher modelled this bistable perception phenomena by a quantum model violating LG inequalities [16]. The proposal based on the Necker-Zeno model reported in 1977 by Misra&Sudarhan [17]. According to Atmanspacher proposal, mental states described by described by a two state quantum system. The random switches between the two states of the system describes by a unitary operator$U(t)$. They also consider a realistic time scale in the order of ms in terms of mental states. Piantoni *et.al.* demonstrated a bistable perception example highlighting the alpha power by using EEG record [18]. According to the results, high alpha power associated with the long and stable perceptual representations. On the other hand, during the reversal of perceptions low alpha power recorded. It's pointed that alpha rhythm power can predict the unstable occurrence of perception with the same stimuli.

IV. CONCLUSIONS

In this review, EEG studies and unstable perceptual effects simply surveyed. Processing EEG data has been developed as a mature field of research with more than 60 years' experience. Now the EEG data has been the subject of an intense research beside the diseases and diagnosis. Particularly by the idea to use the EEG data in order to understand human behavior, the field remains accessible for psychologists trying to understand non-classical behaviors and ambiguities of humans. Here, we conclude that alpha power would be a fair point of study particularly to understand the bistable perception or similar non-classical decision-making mechanisms.

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