Available online at www.sciencedirect.com

ScienceDirect

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

Original Research Article

A new approach for the classification of event related potentials for valid and paradox reasoning

C. Papaodysseus [a,*], S. Zannos [a], F. Giannopoulos [a], D. Arabadjis [a], P. Rousopoulos [a], X. Stachtea [b], C. Papageorgiou [b,c]

[a] School of Electrical & Computer Engineering, National Technical University of Athens, Greece
[b] University Mental Health Research Institute (UMHRI), Athens, Greece
[c] 1st Department of Psychiatry, National University of Athens, Medical School, Eginition Hospital, Athens, Greece

ARTICLE INFO

Article history:
Received 30 August 2015
Received in revised form
5 December 2015
Accepted 11 December 2015
Available online 31 December 2015

Keywords:
Event related potentials (ERPs)
Curve fitting
Valid reasoning
Paradox syllogism
Aristotle's reasoning
Zeno's paradoxes

ABSTRACT

In the present paper, a novel approach is introduced for comparing and classifying recorded ERP signals from subjects applying valid (Aristotle's) and paradox (Zeno's) syllogisms. In fact, the authors conceived and realized a corresponding experiment, as well as a new method for processing, fitting and classifying the corresponding captured ERP signals into groups according to their similarity. Subsequently, for each such group, an ideal curve that represents all signals of the group has been evaluated for valid and paradox reasoning separately. These ''ideal representatives'' manifest essential statistical differences per subject for a considerable number of electrodes (5 electrodes with 99% level of confidence, 14 electrodes with 95% level of confidence, 17 electrodes with 90% level of confidence). These results support the assumption that the obtained ideal representatives may indeed reflect essential differences in the underlying brain functions which generated the obtained ERPs. Equivalently, one may claim that the performed experiment and the associated results manifest statistically essential differences between the mental functions during valid and paradox reasoning.

1. Introduction

One of the most prominent intellectual abilities of the human brain, which so far characterizes the human kind, is the process of logical reasoning/syllogism. Historically, one of the first philosophers, if not the first one, who tried to analyze logical reasoning by the means of deduction was Aristotle. According to his analysis, the reasoning process starts with two statements, i.e. ''All men are mortal''; ''All Athenians are men''. These two statements, in Aristotle's approach, lead to the conclusion that ''All Athenians are mortal'' with absolute certainty [18]. We note that this Aristotle's syllogism, also known as valid reasoning, has been a very active, open field of research. Recently, a number of models have been proposed in order to encode and elucidate the underlying brain functions

* Corresponding author at: School of Electrical & Computer Engineering, National Technical University of Athens, Iroon Polytechneiou 9, Zografou 15773, Greece.
E-mail address: cpapaod@cs.ntua.gr (C. Papaodysseus).
http://dx.doi.org/10.1016/j.bbe.2015.12.004

associated with this type of reasoning; however, one may safely say that these brain functions are, by no means, fully understood [7,19].

On the other hand, about 2500 years ago, Zeno the Eleatic, extending ideas of his teacher Parmenides, conceived some paradoxes in order to elucidate contradictions of ''Common Sense'', as well as inconsistencies in the Pythagorean ideas of multiplicity and change. Zeno employed 3 major steps in order to manifest these contradictions and inconsistencies: (a) he temporarily adopted a thesis that he opposed, (b) he tried to deduce an absurd conclusion or contradiction in connection with it, (c) thus, he undermined the originally adopted thesis [5]. This approach is most commonly called ''a Zeno's paradox''. These paradoxes have always intrigued and puzzled philosophers and mathematicians and they largely influenced subsequent research [1,6,20].

The nature of the mental processes induced by the paradoxes has not been extensively studied and it is still an open research subject. The eventual results of such a research may be proven to be of considerable importance both from the Academic and Clinical point of view. More specifically, studying the brain functions which correspond to Zeno's paradoxes in contrast to mechanisms associated with Aristotle's valid reasoning may contribute in the understanding of the fundamental operation of reasoning into its extreme form [22]. In the present paper, the results of such a study are presented; the associated analysis employed, among others, principles and tools of Signal Processing, Pattern Recognition and Biostatistics.

The recorded and processed electro-physiological activity is associated with event-related potential (ERP) techniques. These techniques are commonly used as they appear to be sensitive to subtle neuropsychological changes [11,12,16,15,4,3,23]. For this reason, the research presented here is based on an experiment during which the ERP signals of various healthy adults participants are recorded when these subjects applied valid and paradox reasoning. Special effort has been taken to induce the working memory (WM) of each participant during this experiment. Contemporary neuropsychological views define WM as the capacity of the human subject to keep information 'on-line' necessary for an ongoing task [2,6]. Accordingly, WM is not for 'memorizing' per se; it is rather in the service of complex cognitive activities, such as reasoning, monitoring, problem solving, decision making, planning and searching/shifting the initiation or inhibition response [13,8].

The main goal of the present work is to determine if different patterns of electro-physiological activity exist during Aristotle's valid reasoning in one hand and Zeno's paradoxes on the other. A comparative study of these activated patterns in Aristotelian and paradox-related reasoning could reveal critical aspects of reasoning processing, associated with perception, attention and cognitive behavior. We emphasize that these aspects are unobservable with behavioral methods alone.

2. A brief description of the introduced approach

A set of forty-five healthy subjects participated in an experiment, where each one of them was asked to verify or not the validity of a number of presented syllogisms. During this process, 30 scalp Ag/AgCl electrodes have been attached to each subject's scalp in order to record the electroencephalographic (EEG) activity in accordance with the International 10–20 system of electroencephalography [10]. These Event Related Potential signals (ERPs) were recorded for a 2000 ms interval and they have been digitalized at a sampling rate of 1 kHz. We have limited the obtained digital signal for each subject to the time interval (100,400] ms for reasons that we will present in the following Section 4, step 1. This restricted digital ERP signal is symbolized by $R^X_{k,q,j}$ where subscript k runs through the electrodes, q through the number of questions and j through the subjects; in order to explain superscript X, we must report that the aforementioned syllogisms are divided into two classes, one representing Aristotle's valid reasoning, where $X = V$ and another expressing Zeno's paradoxes, where $X = P$.

The basic ideas upon which the present study is based may be described as follows: suppose that there is indeed a class of common mental processes, which are activated when a person is asked to verify or not a valid or paradox syllogism. Then, one may expect that this causality will reflect in the form of the digital signal $R^X_{k,j}$. Thus, we make the fundamental assumption that for each group of persons manifesting the same mental behavior, if any, in respect to ''valid reasoning'' and/or ''paradoxes'', there is a common underlying prototype curve $\Pi^X_{k,j}$, where, this time, j runs through the different groups of persons. Moreover, we make the additional assumption that the various signals $R^X_{k,j}$, corresponding to subjects with similar mental response to valid or paradox reasoning, are noisy versions of the related $\Pi^X_{k,j}$. We further assume that the distortion of $\Pi^X_{k,j}$ that generates $R^X_{k,j}$ is due to two substantially different factors: (a) a causal one and (b) an erratic noise. The causal component of the distortion is associated with brain functions that do not affect the general shape of the signal $\Pi^X_{k,j}$; in fact, we assume that the most important such functions are (i) the intensity – amplitude of the emitted electromagnetic wave, reflected on the ERP amplitude and (ii) the speed of the subject's reaction. In order to account for these causal components, we apply suitable transformations on the ERP signal, while, in order to suppress the erratic component, we have developed a new approach that generates a good estimation of $\Pi^X_{k,j}$.

Therefore, in consistence with these assumptions, we have developed a method for classifying subjects according to their ''valid reasoning'' or ''paradox understanding'', consisting of the following steps:

Step 1 – A first stage processing of the data

Step 2 – We have defined a kind of amplitude scaling and time dilation or contraction, applied to each signal $R^X_{k,j}$ (Section 4, step 2), in order to suppress the aforementioned causal discrepancies among signals, corresponding to specific differences in the various subjects' mental functions.

Step 3 – In order to test similarity of two curves, we have defined a proper error function presented in Section 4, step 3. This error function takes into account the transformations defined in step 2 and it is practically independent of the prototype curve energy.

Step 4 – We formed subgroups of similar curves by optimally fitting curves $R^X_{k,j}$ using the results of steps 2 and 3. More specifically, we have momentarily set each $R^X_{k,j}$ to play the role