CLASSIFYING EVENT RELATED POTENTIALS FOR VALID AND PARADOX REASONING

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Abstract: In this paper, a new methodology is presented for comparing the ERPs of Aristotle's "valid reasoning" and Zeno's "paradoxes". To achieve that, the ERPs of each such syllogism are grouped, by means of a new care-fitting approach. This consists of a) application of time-domain and amplitude scaling to one ERP and b) optimal fit of two ERPs via minimization of a properly defined error function. Next, the optimally fit ERPs, which form a group, are averaged to obtain an ideal representative for the valid and paradoxes reasoning separately. These ideal representatives manifest essential statistical differences per subject for a considerable number of electrodes (18 electrodes). The latter supports the assumption that the underlying mental processes of the valid and paradoxes reasoning are, indeed, different and this difference reflects upon the corresponding ERPs and, in particular, upon the introduced ideal representatives.

1 INTRODUCTION

One of the most advanced intellectual abilities of humans is the capacity to reason. Following Aristotle, the reasoning starts with a set of two statements such as "All men are mortal"; "All Athenians are men". Aristotle argued that these statements imply that "All Athenians are mortal" with absolute certainty. A series of relationships described by the predicative verb "are" and specified by the quantifier "all", constitute the inference and insure its validity (The revised Oxford Translation of Aristotle, 1995). Syllogistic reasoning has historically been the subject of active philosophic and psychological inquiry, but only recently, specific models of encoding and elucidating the underlying mechanisms have been proposed; however, the underlying processes are poorly understood (De Neys, 2006); (Rodriguez-Moreno and Hirsch, 2009).

In juxtaposition to this, Zeno the Eleatic, about 2500 years ago, conceived a number of paradoxes, based on the axiom of the unity and permanence of being (a fundamental principal of the doctrine of his teacher Parmenides). Zeno employed the method of indirect proof in his paradoxes consisting of three major steps: 1) a temporal assumption of a thesis that he opposed, 2) an attempt to deduce an absurd conclusion or a contradiction, thereby 3) the undermining of the temporary assumption. These paradoxes have always amazed philosophers and mathematicians, highly influencing subsequent research (Atmanspacher et al., 2004); (Caveing, 2000); (Simplicious. In Physica, 1882). Zeno's reasoning may be seen as akin to the cognitive illusions, which appear to violate the norms of rational thought only in philosophical speculation (Atmanspacher et al., 2004); (Strumia, 2007).

The nature of the mental processes induced by the paradoxes remains an open, very important research subject. Such research is not only of academic interest but also of great importance for clinical practice. From a cognitive viewpoint, it seems interesting to study the Zeno's paradoxes versus the Aristotelian deductive reasoning, using contemporary technology. The aforementioned, seemingly unrelated, notions appear to reflect certain deep, inherent cognitive mechanisms (Turner, 2007).

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Hence, the present research was designed to study healthy subjects engaged into two reasoning tasks, valid syllogisms versus paradoxes, adjusted to induce working memory (WM).

Contemporary neuropsychological views define WM as the capacity of the human subject to keep information 'on-line' necessary for an ongoing task (Baddeley, 1998); (Collette and Van der Linden, 2002). 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 (Miyake and Shah, 1999); (Glassman, 2000). Thus, WM incorporates, among others, a central executive system. Therefore, the present study, dealing with a sample of healthy adults, aims at determining if different patterns of electro-physiological activity exist, as reflected by event related potentials (ERPs). Each experimental condition and setting is adjusted, so as to induce working memory operation.

Event-related potential (ERP) techniques are known to be useful tools in the investigation of information processing and seem to be sensitive to subtle neuropsychological changes (Kotchoubey, 2006); (Kotchoubey et al., 2002); (Papageorgiou and Rabavilas, 2003); (Papageorgiou et al. 2004); (Beratis et al. 2009). The main goal of the present work is to provide direct evidence of association and/or dissociation of Aristotelian syllogistic reasoning and reasoning induced during the exposition to paradoxes. A comparative study of these activation patterns in Aristotelian and paradox-related reasoning could reveal critical aspects of reasoning processing, associated with perception, attention and cognitive behaviour. We note that these aspects are unobservable with behavioural methods alone.

2 METHODS

2.1 Participants

This study was approved by the Ethics committee of University Mental Health Research Institute (UMHRI). Thirty-one healthy subjects (aged 33.6 years on average, standard deviation: 9.1; 17 males) participated in the experiment. All participants gave written consent, after being extensively informed about the procedure. They all had normal vision and no one had neurological or psychiatric history.

2.2 Behavioural Procedures and the Four Different Classes of Questions

The participants were seated comfortably 1m away from a computer monitor in an electromagnetically shielded room. First, proper instructions were given to the participants together with a training test. The participants entered the formal experimental session, once they had fully comprehended the experimental task. The experiment was designed to validate two mental functions, one associated with "valid" syllogisms and another with "paradox reasoning". Two indicative examples follow:

A) Concerning the class "valid", the following statements were shown to each participant: "*All men are animals. All animals are mortal. Hence, all men are mortal.*"

B) Concerning the class "paradox", the following statements were shown to each participant: *"A moving arrow occupies a certain space at each instant. But, when an object occupies a specific space, it is motionless. Therefore, the arrow cannot simultaneously move and be motionless."* (The revised Oxford Translation of Aristotle, 1995).

Every such sequence of statements, forming a reasoning, appeared on the computer monitor accompanied by the question "true or false". The duration of the presented sentence was directly proportional to the letters involved in each sentence as described in Table 1.

Table 1: Units for magnetic properties.

Sequence of actions	Duration of actions
Valid or paradox sentence (visual presentation)	Duration according to the numbers of the letters in the sentences e.g. a sentence involving 92 letters presented 11,04sec
EEG recording	1000ms
Warning stimulus	100ms
ERP recording	1sec
Warning stimulus repetition	100ms
Response onset	Within 5sec
Period between response completion and onset of next sentence presentation	4-9sec

Then, the monitor screen went blank for 1000ms. Next, a sound warning stimulus of 65dB, 500Hz and 100ms duration was given, followed by the same warning stimulus after 900ms. Participants, after the second warning stimulus, were asked to judge each reasoning as either correct or incorrect. In addition, his/hers estimated degree of confidence in each trial was recorded as a number varying from 100 (absolutely certain) to 0 (not at all certain). Each class of the experiment contained 39 syllogisms.

To avoid habituation with the conditions of the test, the onset of the next sentence presentation varied from 4-9sec after completion of the previous oral response. A complete sequence of events in each experimental trial is shown in Table 1.

2.3 Experimental Setup and Recordings

A Faraday cage has been used to eliminate any electromagnetic interference that could affect the measurements; the mean field attenuation was more than 30dB. 30 scalp Ag/AgCl electrodes have been employed to record the electroencephalographic (EEG) activity in accordance with the International 10-20 system of electroencephalography (Jasper H., 1958). These electrodes are shown in a form of map in Figure 1. Two electrodes, attached to the two ear lobes, served for obtaining the reference potential.

Recordings higher than 75μV were excluded. Electrode resistance was kept constantly below 5kΩ. The amplifiers' bandwidth was 0.05-35Hz, to avoid interference with the 50Hz power supply signal. The evoked bio-potential signal was digitised at a sampling rate of 1Khz. The signals were recorded for 2000msec: 1000msec before the first warning stimulus (EEG) and 1000msec after that (ERP).

2.4 First Stage Processing of the Data

For each question and for each electrode separately, 2000 samples (expressed in μV) have been recorded in 2sec. We will employ for this subsequence of the data the symbol $S_{k,q,j}^{X}$ where subscript k runs through the electrodes, q through the 39 questions, j through the subjects and X determines the class; thus, $X \in \{V, P\}$ where V stands for "Valid reasoning" and P for "Paradoxes". In order to optimize the signal-to-noise-ratio (SNR) for each subject, each channel and each class of questions we have applied a rather standard method: a) For each question separately, we have averaged the values of the EEG, namely the data acquired in the 1000ms before the first sound stimulus. Thus, we have obtained quantities $a_{k,q,j}^{X}$, b) We have subtracted quantity $a_{k,q,j}^{X}$ from $S_{k,q,j}^{X}$, thus obtaining a translated version of $S_{k,q,j}^{X}$ for which we will employ the same symbol, c) We averaged the translated $S_{k,q,j}^{X}$ overall 39 questions, thus obtaining a mean curve $s_{k,j}^{X}$, d) We averaged the first 1000 values of $s_{k,j}^{X}$ and we have obtained quantity $a_{k,j}^{X}$, e) Finally, we have calculated the sequence $S_{k,j}^{X} = s_{k,j}^{X} - a_{k,j}^{X}$.

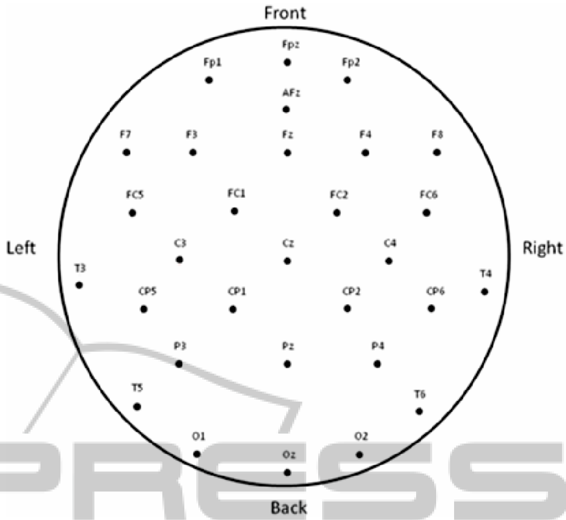

Figure 1: Map showing the position of the ERPs' electrodes.

3 A BRIEF DESCRIPTION OF THE INTRODUCED APPROACH

We have limited the obtained digital signal $S_{k,j}^{X}$ to the time interval (100,400]ms. We have decided to start from this restricted sequence, since the interval [1,100]ms refers to the EEG recordings previous to the first sound stimulus, while in the interval [301,1000]ms the Contingent Negative Variation (CNV) (Tecce, 1972); (Neumann et al., 2003) is dominant. The latter could obscure the analysis we have developed. We will employ for this restricted signal the symbol $R_{k,j}^{X}$, where, as always, $X \in \{V, P\}$ indicating the class of questions, k indicates the electrode number, except the ones attached on the ear lobes, and j the subject's cardinal number.

The basic notion behind the novel approach introduced here may be described as follows: Suppose there are causal functions, concerning the mental processes in hand, common to a group of persons. Then, one expects that this causality will reflect in the form of the digital signal $R_{k,j}^{X}$. Thus, we make the fundamental assumption that for each group of persons sharing the same mental behavior in "valid reasoning" and\or "paradoxes", there is a common underlying prototype curve $P_{k,j}^{X}$; in addition, we assume that the various signals $R_{k,j}^{X}$

corresponding to individuals belonging to this class, are noisy versions of $P_{k,j}^{X}$. Consequently, we have developed a method for classifying individuals according to their "valid reasoning" or "paradox understanding", consisting of the following steps:

Step 1 – We have defined a class of transformations applied to each signal $R_{k,j}^{X}$, in order to suppress causal discrepancies among signals, corresponding to specific differences in the various subjects' mental functions.

Step 2 - We have defined an error function indicating the similarity of two curves. This error function takes into proper account the transformations defined in step 1.

Step 3 – We have optimally fit curves $R_{k,j}^{X}$ using the results of step 1 and step 2, thus forming sub-groups of similar curves.

Step 4 – In each such sub-group, we have calculated a kind of "ideal representative", by proper averaging of the optimally fit curves $R_{k,j}^{X}$.

Step 5 – Finally, we have regrouped the individuals, by letting their digital curve $R_{k,j}^{X}$ fit the ideal representative, having a fitting error with the curve in hand, lower than a proper threshold.

4 THE NOTION OF THE ERPS' IDEAL REPRESENTATIVE FOR A CLASS OF SUBJECTS

In this section, we will give a more detailed analysis of steps 1 to 4, introduced in section 3:

Step 1 – To account for latency in the human response, we have performed time scaling in the domain of $R_{k,j}^{X}$. This is achieved by applying to a signal $x(t)$ the transformation given by $x(\lambda t)$, where t corresponds to time and λ is the scaling factor. When $x(t)$ is a digital signal, say $x(t_i)$, then the values of the signal in between the samples are unknown. Thus, $x(\lambda t_i)$ in practice is unknown; to circumvent this difficulty, we first interpolate the signal by ensuring continuity of it and its first derivative at the data points.

To account for differences in the ERPs amplitude, we perform scaling along the y-axis, in which case signal $x(t)$ yields signal $\alpha x(t)$.

The combined action of these transformations to a signal $x(t)$ yields signal $\alpha x(\lambda t)$.

At this point, we will briefly describe a quite standard approach used so far: a) One defines four time intervals in the domain (100,400], namely, the $I_{50} = [130,180]$ms, $I_{100} = [170,250]$ms, $I_{200a} = [250,350]$ms and $I_{200b} = [280,400]$ms. b) One computes the maximum of $R_{k,j}^{X}$ in the interval I_{50}; its value is often denoted by P_{50} and the point where maximum occurs by T_{50}. c) One computes the minimum of $R_{k,j}^{X}$ in the interval I_{100}; its value is often denoted by N_{100} and the point where minimum occurs by T_{100}. d) One computes the minimum of $R_{k,j}^{X}$ in I_{200a}; its value is often denoted by N_{200a} and its position by T_{200a}. e) One computes the maximum of $R_{k,j}^{X}$ in I_{200b}; its value is often denoted by P_{200b} and the point where maximum occurs by T_{200b}. f) One performs statistical tests for comparing i) the peaks' amplitudes and/or ii) the peaks' positions, among subjects, for each electrode separately.

The approach introduced in the present work is that all these actions must take place on the smoother and "normalized" curves we call ideal representatives. The term "normalized" is used to express the fact that curve fitting is performed after application of the aforementioned transformations. In addition, one can perform more statistical tests, which take into account each ideal representative.

Step 2 - Suppose that a signal $y(t)$ is the reference curve, while another signal $x(t)$ is subject to the transformations described in step 1. Suppose, moreover, that one wants to compare signals $y(t)$ and the transformed $x(t)$. Then, one may define the following fitting error ε:

$$\varepsilon(\alpha,\lambda) = \frac{1}{2}\int_{t_1}^{t_2}(y(t) - \alpha x(\lambda t))^2\, dt \qquad (1)$$

Evidently, when the signals are digital, then the integral is transformed to summation.

Step 3 - We optimally fit curves $y(t)$ and the transformed $x(t)$, by evaluating those scaling factors λ and α which minimize the aforementioned error function $\varepsilon(\alpha,\lambda)$. Fortunately, this error minimization has an analytic solution obtained by setting the gradient of $\varepsilon(\alpha,\lambda)$ equal to zero:

$$\frac{\partial\varepsilon}{\partial\alpha^*} = 0 \Rightarrow \alpha^* = \frac{\int_0^{t_2-t_1} x\big(\lambda(\tau+t_1)\big)\, y(\tau+t_1)d\tau}{\int_0^{t_2-t_1} x^2\big(\lambda(\tau+t_1)\big)d\tau} \qquad (2)$$

By substituting $\alpha^*$to $\varepsilon(\alpha^*,\lambda)$, we obtain:

$$\varepsilon(\alpha^*,\lambda) = \frac{1}{2}\left(\int_0^{t_2-t_1} y(\tau+t_1)^2 d\tau - \int_0^{t_2-t_1} \alpha^{*2} x^2\big(\lambda(\tau+t_1)\big)\, d\tau\right) \qquad (3)$$

$$\left.\frac{\partial \varepsilon}{\partial \lambda}\right|_{(\alpha^*,\lambda^*)} = 0 \Rightarrow$$

$$\frac{\partial}{\partial \lambda}\int_0^{t_2-t_1} x^2\big(\lambda(\tau+t_1)\big)d\tau = 0 \tag{4}$$

But, expanding the above integral we obtain:

$$\frac{\partial}{\partial \lambda}\int_0^{t_2-t_1} x^2\big(\lambda(\tau+t_1)\big)d\tau = \frac{t_2-t_1}{\lambda}x^2(\lambda t_2) - \frac{1}{\lambda^2}\int_0^{\lambda(t_2-t_1)} x^2(\tau+\lambda t_1)d\tau \tag{5}$$

and finally:

$$\left.\frac{\partial \varepsilon}{\partial \lambda}\right|_{(\alpha^*,\lambda^*)} = 0 \Rightarrow$$

$$\lambda^* = \frac{\int_0^{\lambda(t_2-t_1)} x^2(\tau+\lambda t_1)d\tau}{(t_2-t_1)x^2(\lambda t_2)} \tag{6}$$

Beginning from a point $t_c = \frac{t_1+t_2}{2}$ of the x - signal time domain optimal time-scaling λ^* and amplitude – scaling α^* are computed via:

$$\lambda^* = \frac{2T}{t_2-t_1}, \tag{7}$$

$$T : \frac{1}{T}\int_{t_c-T}^{t_c+T} x^2(\tau+t_c-T)d\tau = x^2(t_c+T) \tag{8}$$

$$\alpha^* = \frac{\int_0^{t_2-t_1} x\big(\lambda^*(\tau+t_1)\big)\, y(\tau+t_1)d\tau}{\int_0^{t_2-t_1} x^2\big(\lambda^*(\tau+t_1)\big)d\tau} \tag{9}$$

Step 4 - Consider anyone of the digital curves $R_{k,j}^X$ and let it be the reference curve as in steps 2 and 3. Moreover, consider all other sequences $R_{k,i}^X$ for the same class X and the same electrode k. We let all these curves be transformed and optimally fit to the reference sequence, by the methods described in steps 1, 2 and 3 above. The corresponding fitting error is expected to follow a chi-square distribution X^2, a fact not rejected by the performed related Kolmogorov-Smirnoff test (α=0.01). If two ERP curves are noisy versions of the same ideal curve, then one expects that, statistically, the related error will be pretty close to zero. Therefore, we choose the upper point ε^T of the 5% left tail of the above X^2 distribution to be an acceptable threshold for this error. In other words, if a transformed curve $R_{k,i}^X$ optimally fits to the reference curve with a fitting error smaller than ε^T, then we may reasonably assume that these curves belong to the same group. In this way, to each reference curve $R_{k,j}^X$, we have associated a group of corresponding data sequences.

Next, we choose the group with the greater number of optimally fit curves and we use, for the corresponding reference curve, the symbol $Y_{k,1}^X$ (subscript k is the electrode number and subscript 1 stands for the group's cardinal number). For the transformed curves, optimally fit to $Y_{k,1}^X$, we employ the symbol $X_{k,i,1}^X$, where the additional subscript i indicates the corresponding transformed curve.

We repeat this process for all groups having more members than 10% of the individuals sample size, thus obtaining corresponding reference curve $Y_{k,m}^X$ and transformed $X_{k,i,m}^X$.

Consider any reference curve $Y_{k,v}^V$ and the transformed curves $X_{k,i,v}^V$ optimally fit to $Y_{k,v}^V$, where, superscript V stands for "valid reasoning". Then, for each sample point in (100,400]ms, we average the values of $X_{k,i,v}^V$ and $Y_{k,v}^V$ simultaneously, obtaining a mean curve denoted by $M_{k,v}^V$. If the assumption that there is a causal underlying process for all members of this group is correct, then one expects that the averaging process will reduce the overall noise. Hence, digital curve $M_{k,v}^V$ is a better representative of the mental process of "valid reasoning" for all members of the group in hand (Figure 2).

We repeat this process for all groups of the paradox reasoning, thus obtaining a class of corresponding "ideal representatives" $M_{k,v}^V$.

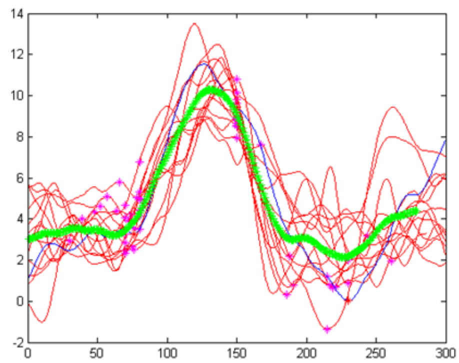

Figure 2: An ERP's ideal representatives with very low error, supporting the authors' assumption about an underlying common mental behavior per group.

5 STATISTICALLY SIGNIFICANT DIFFERENCES IN "VALID REASONING" AND "PARADOXES" IDEAL REPRESENTATIVES

We have applied the approach introduced in Section

4 to the data sequences $R_{k,j}^{V}$ corresponding to the subjects' responses to the valid syllogism questions in one hand and to the subjects' responses to paradoxes questions $R_{k,j}^{P}$, on the other. In this way, we have divided the entire class of sequences $R_{k,j}^{V}$ into, occasionally overlapping, sub-groups, for each electrode separately. The same was achieved for the sequences $R_{k,j}^{P}$. From each such sub-group, we have evaluated a representative curve which, we have called "ideal representative" of the group in hand. Then, we proceeded to step 5, described below:

<u>*Step 5*</u> – We let $M_{k,1}^{V}$ play the role of the reference curve of group 1 and we optimally fit all data sequences $R_{k,j}^{V}$ to it by application of steps 1 to 4. In this way, we obtain the final group of subjects, whose ERPs associated with "valid reasoning", are similar to the ideal representative (Figure 3). We would like to emphasize that this action offered a larger group of well fitting curves than that in Step 4 for each electrode, when the same error threshold was used. Equivalently, the number of subjects with similar "valid reasoning" ERPs is, as a rule, increased, when the smoother curve $M_{k,1}^{V}$ is used as a reference curve instead of the corresponding $R_{k,j}^{V}$. This further supports the assumption that there is a common underlying brain behavior among all members of each group.

We have repeated the same process for all sub-groups of valid reasoning ERPs with analogous results. Namely, we have considered curve $M_{k,2}^{V}$, i.e. the ideal representative of the second group, and we let it play the role of the reference curve of the second group. Subsequently, we have considered all ERPs not belonging to the first group and we let it optimally fit $M_{k,2}^{V}$ with the same method, error function and error value as in the previous steps. Keeping the error threshold fixed, we have attributed to the second group with ideal representative $M_{k,2}^{V}$ a specific curve, as far as "valid reasoning" is concerned. After completing the attribution of ERPs to the second group of individuals, always for the same electrode k, we have proceeded in forming the representative $M_{k,3}^{V}$ and so on. In this way, finally, we have selected the smaller class of disjoint groups covering the entire set of $R_{k,j}^{V}$ for each electrode separately. Thus, to each individual who performed the test and for each electrode separately, we have attributed a unique ideal representative $M_{k,n}^{V}$, namely the ideal representative of the group to which his/her "valid reasoning" ERP has been attributed.

The same procedure has been applied to the class of "paradoxes" ERPs $R_{k,j}^{P}$ for each electrode separately. Thus, we have obtained a minimum class of paradox ideal representatives $M_{k,n}^{P}$, together with a maximal set of $R_{k,j}^{P}$ optimally fit to it, covering the entire set of paradox ERPs. Consequently, each individual, for each electrode k separately, has been attributed to a specific sub-group, having a concrete ideal representative $M_{k,n}^{P}$, where n is the cardinal number of the specific distinct sub-group.

Eventually, statistical tests have been applied for each electrode separately, in order to check possible statistical differences between the brain functions that take place during "valid" and "paradox" reasoning. These statistical tests have been performed in a subject-wise manner as follows:

We have considered an arbitrary subject, say A_1 and let us suppose that his/her ERP, captured by the electrode k, associated with "valid reasoning" has been classified to the mth group with ideal representative $M_{k,m}^{V}$; let us, also, assume that the same subject and in connection with the same electrode, has been classified to the nth group of "paradoxes" having ideal representative of the related ERPs, the digital curve $M_{k,n}^{P}$.

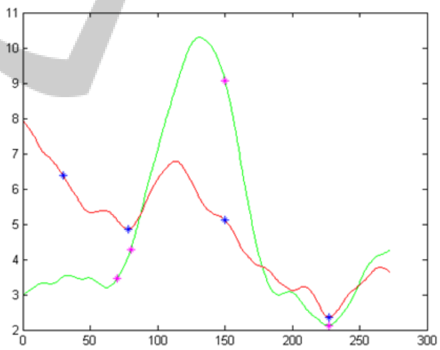

Figure 3: Ideal representatives manifest essential statistical differences, supporting the assumption that corresponding differences exist in the underlying mental processes of "valid syllogism" and "paradox reasoning".

II) We define a measure of difference of the two brain functions (V and P) for subject A_1, a properly selected distance of the two digital curves $M_{k,m}^{V}$ and $M_{k,n}^{P}$. In fact, for any point (i) of the common domain of the curves $M_{k,m}^{V}$ and $M_{k,n}^{P}$, we compute the signed difference d_i of the value of the two curves at this point. Then, if N_1 is the number of points of the common domain of curves $M_{k,m}^{V}$ and $M_{k,n}^{P}$, we define quantities

$$\mu_1 = \frac{\sum_{i=1}^{N_1} d_i}{N_1} \quad (10)$$

$$S_1 = \sqrt{\frac{\sum_{i=1}^{N_1}(d_i - \mu_1)^2}{(N_1 - 1)}} \tag{11}$$

and

$$t_1 = \frac{\mu_1 - M_k^{V,P}}{S_1 / \sqrt{N_1}} \tag{12}$$

where $M_k^{V,P}$ is the theoretical mean value of the difference of the representative curves of groups m (for "valid reasoning") and n (for "paradoxes"), where subject A_1 belongs for the electrode in hand.

III) We make the plausible assumption that if the ideal representatives $M_{k,m}^V$ and $M_{k,n}^P$ differ significantly, one may assume that the underlying brain functions associated with "valid reasoning" and "paradoxes", do indeed differ. On the other hand, if the two digital curves $M_{k,m}^V$ and $M_{k,n}^P$ do not manifest essential differences, one must deduce that the ERPs do not reflect differences of these mental processes, as far as electrode k is concerned.

IV) To quantify the analysis stated in (III) above, we have proceeded as follows:

First, we have stated the assumption that the signed differences d_i defined in (II), belong to a normal distribution, an assumption verified by the Kolmogorov-Smirnoff test (α=0.01). Then, quantity t_1, defined in step (III), follows a Student distribution with (N_1-1) degrees of freedom.

Moreover, if we make the hypothesis H_0 that the two brain functions (V and P) do not generate differences in the corresponding ideal representatives, then, $M_k^{V,P} = 0$. Thus, the value of t_1 is well defined and, hence, the validity of H_0 can be tested, for subject A_1 and electrode k.

V) We repeat the aforementioned procedure for all subjects and all electrodes. For each electrode separately, we apply either Bonferoni test or geometric distribution methods to decide if the ideal representatives of the various groups manifest statistically significant diversification of the two mental processes (V and P).

Application of the method in 31 subjects to which both the tests of "valid reasoning" and "paradox syllogism" have been applied, indicated that essential statistical differences exist in 18 electrodes, as shown in the map of the Figure 4.

6 CONCLUSIONS

In the previous analysis, the ERPs of "valid reasoning" on one hand and of "paradox syllogism" on the other have been grouped by optimally fitting the corresponding digital curves. The related new curve fitting method accomplishes: a) time domain and amplitude scaling to one of the two curves and b) optimal determination of these scale parameters, so as an introduced error function is minimized. After grouping the various subjects' ERPs, for each electrode separately, the authors have evaluated a kind of a mean curve, assumed to be a good representative of the corresponding "ideal" mental process' ERPs. Next, the subjects' ERPs have been regrouped by letting each ERP's curve optimally fit the proper ideal representative with the minimum fitting error. Finally, statistical tests per electrode and per subject's ideal representative have been performed, indicating statistically significant differences in 18 electrodes.

The fact that "valid reasoning" ERPs in one hand and "paradoxes" on the other, optimally fit the corresponding ideal representatives with very low error, supports the authors' assumption about an underlying common mental behavior per group, well expressed via the ideal representatives (Figure 2). At the same time, the fact that, per subject, there is a considerable number of electrodes, for which the ideal representatives manifest essential statistical differences, supports the assumption that differences do exist in the underlying mental processes of "valid syllogism" and "paradox reasoning" (Figure 3). Thus, future research will aim at more precise determination of these causal behavioral functions and the relation of the ERPs valid and paradox ideal representatives with each subject's mental state.

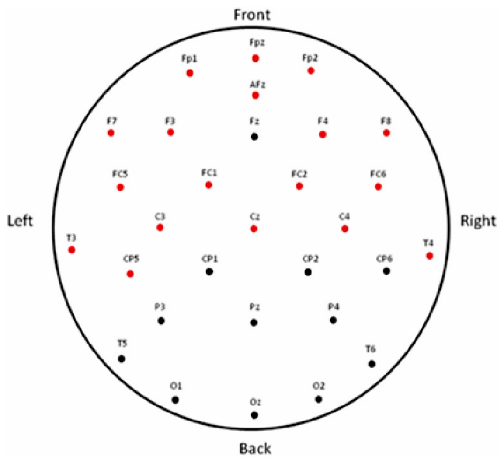

Figure 4: Map showing the 18 electrodes in red, for which the introduced method offered statistically significant differences between the mental processes of "valid reasoning" and "paradox syllogism".

REFERENCES

1995. *Prior Analytics, The complete works of Aristotle. The revised Oxford Translation.* Vol., 1., NJ: Princeton University Press. Chichester, West Sussex. pp. 39-113.

De Neys W., 2006. Dual processing in reasoning: Two systems but one reasoner. In *Psychological Science.* 17: 428-433.

Rodriguez-Moreno D., Hirsch J., 2009 Mar. The dynamics of deductive reasoning: an fMRI investigation. In *Neuropsychologia*. 47(4): 949-61.

Atmanspacher H., Filk T., Römer H., 2004. Quantum Zeno features of bistable perception. In *BIOLOGICAL CYBERNETICS,* Vol. 90 no. 17: 33-40.

Caveing M., 2000. Greek Thought. A guide to classical Knowledge. Brunschwig J. & Lloyd E. R. G. The Belknap Press of Harvard University Press, London, pp.783-795.Simplicious. In *Physica*., 1882. 2 vols. Ed. Hermann Diels. Berlin, 18

Strumia A., 2007. Complexity seems to open a way towards a new Aristotelian-Thomistic ontology. In *Acta Biomed.* 78 Suppl 1:32-8.

Turner W., 2007. Zeno of Elea: Where Space, Time, Physics, and Philosophy Converge An Everyman's Introduction to an Unsung Hero of Philosophy. In *Western Kentucky University: Honors College Capstone Experience/Thesis Projects. Paper 111.*

Baddeley A., 1998. Recent developments in working memory. In *Curr Opin Neurobiol,* 8: 834-838.

Collette F., Van der Linden M., 2002. Brain imaging of the central executive component of working memory. In *Neurosci Biobehav Rev,* 26:105-125.

Miyake A., Shah P., 1999. *Models of Working Memory.* New York: Cambridge University Press.

Glassman R.B., 2000. A "theory of relativity" for cognitive elasticity of time and modality dimensions supporting constant working memory capacity: involvement of harmonics among ultradian clocks? In *Prog Neuropsychopharmacol Biol Psychiatry,* 24:163-182.

Kotchoubey B., 2006. Event-related potentials, cognition, and behavior: a biological approach. In *Neurosci Biobehav Rev.* 30(1): 42-65. Review.

Kotchoubey B., Lang S., Bostanov V., Birbaumer N., 2002. Is there a mind? Electrophysiology of unconscious patients. In *News Physiol Sci.*17:38-42. Review.

Papageorgiou C. C., Rabavilas A. D., 2003. Abnormal P600 in obsessive-compulsive disorder. A comparison with healthy controls. In *Psychiatry Res.* 119:133-43.

Papageorgiou C., Liappas I., Ventouras E., Nikolaou C., Kitsonas E., Uzunoglu N., Rabavilas A., 2004. Long-term abstinence syndrome in heroin addicts: indices of P300 alterations associated with a short memory task. In *Progress in Neuropsychopharmacology & Biological Psychiatry.* 28:1109-1115.

Beratis I. N., Rabavilas A., Nanou E. D., Hountala C., Maganioti A. E., Capsalis C. N., Papadimitriou G. N., Papageorgiou C., 2009. Effect of initiation-inhibition and handedness on the patterns of the P50 event-related potential component: a low resolution electromagnetic tomography study. In *Behav Brain Funct.* 5:51.

Jasper H., 1958. The ten-twenty electrode system of the international federation. In *Electroencephalogr Clin Neurophysiol,* 10:371-375.

Tecce J. J., 1972. Contingent negative variation (CNV) and psychological processes in man. In *Psychological Bulletin* 77 (2): 73–108.

Neumann N., Kübler A., Kaiser J., Hinterberger T., Birbaumer N., 2003. Conscious perception of brain states: mental strategies for brain–computer communication. In *Neuropsychologia.* 41(8): 1028-36.