

Received April 5, 2020, accepted April 21, 2020, date of publication April 23, 2020, date of current version May 7, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2990095

Perspective-Taking in Blindness: An Event-Related Brain Potentials Study With the Continuous Wavelet Transform

CHARALABOS C. PAPAGEORGIU^{1,2}, GEORGIOS TH. KOUROUPETROGLOU³, (Member, IEEE),
XANTHI P. STACHTEA^{1,2}, PANOS C. PAPAGEORGIU⁴, (Member, IEEE),
ANTONIOS K. MAVROMATOS¹, GEORGE P. CHROUSOS⁵,
NIKOS K. LOGOTHETIS^{6,7}, AND ELEFThERIA TSALTAS¹

¹First Department of Psychiatry, Medical School, National and Kapodistrian University of Athens, Eginition Hospital, 11528 Athens, Greece

²Neurosciences and Precision Medicine Research Institute “Costas Stefanis” (UMHRI), University Mental Health, 11527 Athens, Greece

³Department of Informatics and Telecommunications, National and Kapodistrian University of Athens, 15784 Athens, Greece

⁴Department of Electrical and Computer Engineering, University of Patras, 26504 Patras, Greece

⁵First Department of Pediatrics, Medical School, National and Kapodistrian University of Athens, “Aghia Sophia” Children’s Hospital, 11527 Athens, Greece

⁶Department of Physiology of Cognitive Processes, Max Planck Institute for Biological Cybernetics, 72076 Tübingen, Germany

⁷Department of Imaging Science and Biomedical Engineering, University of Manchester, Manchester M13 9PL, U.K.

Corresponding author: Georgios Th. Kouroupetroglou (koupe@di.uoa.gr)

This work was supported in part by the European Union (European Social Fund—ESF), in part by the Greek national funds through the project: “THALIS-KAIKOS: Audio and Tactile Access to Knowledge for Individuals with Visual Impairments” through the National Strategic Reference Framework (NSRF) under Grant MIS 380442, and in part by the National and Kapodistrian University of Athens, Special Account for Research Grants.

ABSTRACT This study presents brain electrophysiological characteristics of perspective-taking for blind individuals ver. sighted ones, aiming to extend our knowledge on social concept formation with visual sensory modality loss. A blind and a sighted group instructed to consider the moral dilemmas therein from a neutral (observer), a morally positive or a negative stance, after the auditory presentation of Aesop’s fables. We recorded the basic emotions evoked by every stance in each fable, and the late positive potentials (LPP) component of Event-Related Potential detected with Continuous Wavelet Transform, believed to reflect the sustained attention and stimuli encoding processes. Blind participants demonstrated: i) significantly attenuated LPP amplitudes at distributed brain areas, particularly at leads T3, P4, O2, T6, Cz, Pz, CPz and CP4 (p values 0.026-0.003), ii) prolonged LPP latencies at parietal areas, at leads CP4 (p=0.009), Pz (p=0.019), and P4 (p=0.023), iii) shorter latencies at the frontal area (lead FPz, p=0.026) and iv) significantly shorter latencies at the right posterior centroparietal area under the negative than the positive condition (lead C4, p=0.009). Both groups exhibited higher LPP amplitudes under the morally positive, and lower under the negative condition located at the parietal areas (P3, p=0.001 and CPz, p=0.013). The relationships between behavior and LPP activation conform to the proposed generation and modulation of LPP. Our findings suggest that the visually deprived cortex may become more responsive to processes associated with perspective-taking, possibly through compensatory plasticity enabling cross-modal reorganization. Thus, the study introduces a novel model for accessing the sustained attention and stimulus-encoding processes underlying perspective-taking.

INDEX TERMS Event-related potentials, blindness, late positive potentials, continuous wavelet transform, perspective-taking.

I. INTRODUCTION

Loss of visual input leads to significant morphological and functional differentiation of the visual pathway structures

The associate editor coordinating the review of this manuscript and approving it for publication was Abdel-Hamid Soliman^{1b}.

in the brain of blind individuals compared to sighted ones. A growing body of evidence indicates that the visually deprived occipital cortex, far from remaining idle, facilitates a variety of non-visual perceptual and cognitive tasks. These tasks include lexical and phonological processing, selective attention, verbal memory, repetition priming, spatial,

object, and auditory discrimination, working memory, memory retrieval, and spatial navigation [1]–[5]. In this framework, recent research has also provided evidence indicating that the neural system of the congenitally blind exhibits plastic reorganization, contributing significantly to social cognition and perception of the emotions of others [6]. A process associated with social cognition is that of perspective-taking.

To the authors' knowledge, there is no published research of perspective-taking in either congenital or early-onset blindness.

Perspective-taking, i.e., the ability to assume the perspective of another individual, is considered as a basic process that supports human social interaction [7]–[9].

Perspective-taking is a top-down controlled process, essential for empathy, as one has to adopt another persons' psychological viewpoint in order to understand the others' emotional state [10]. It is then reasonable to expect that this process participates decisively in social communication and interaction mediating the acquisition and development of appropriate social behaviors such as helping and cooperation [11].

Furthermore, an association has been suggested between perspective-taking and Aesop's fables. We consider that a story schema allows a participant to identify, organize, and understand information regarding a character's mental state. This process provides useful information for evaluating the character's mental state and intentions. Also it leads to the comprehension of the development of events and judgment formation about them [12].

To measure the electrical activity of the brain related to various mental states, we used electroencephalogram (EEG) and recorded so-called Event-Related Potentials (ERP), i.e., large mean extracellular field potentials characterized by state and brain-region specificity. ERPs are a promising approach to the study of brain activity during information processing due to their high-resolution properties, as well as the fact that several evoked waveforms already had a firmly established interpretation, developed over many years of research.

In particular, the Late Positive Component (LPC), also mentioned as Late Positive Potential (LPP), is a positive-going ERP component that is an instantiation of the domain-general P300 component. [13]–[15]. Investigations consider that LPP reflects the syntactic [16] and semantic information processing [17], [18]. The LPP waveform, as a family of (late) positivities, reflects the effort involved in the updating of mental representation of what is communicated. This mental representation requires little effort if the existing representation integrates the incoming information, while it is effortful when there is a reorganization need for the existing representation. According to this view, the LPP amplitude is sensitive to semantic processing demonstrating enhancement in effortful conditions [19], reflecting sustained attention and stimulus encoding processes [20] in the field of empathy and enhanced attention to emotionally relevant stimuli [21]–[23]. Moreover, the LPP latency is a function of the onset and duration in the parsing processes [24], [25], i.e., it is under voluntary cognitive control [26], reflecting

a reciprocal codependency between the activity in the prefrontal and occipitoparietal cortex [20].

Given these considerations, the present study used Aesop's fables to generate perspective-taking processing by instructing participants to consider each fable from three standpoints: those of the narrator, of the victim, and the offender. While blind individuals or sighted controls were processing this material under these three stances, their brain activation patterns were examined using the recorded LPP-profiles.

We hypothesized that perspective-taking calculation generated from Aesop's fables under conditions adjusted to engage Working Memory (WM) would yield an LPP component the dynamics of which could distinguish congenitally or early blind participants from sighted controls. Furthermore, we expected that perspective selection under the aforementioned experimental conditions would yield an LPP component, which discriminates between trials promoting the negative ('offender') vs. the positive ('victim') vs the self-referential perspective of the 'observer.'

II. METHODS AND MATERIALS

The Ethical committee of University Mental Health, Neurosciences and Precision Medicine Research Institute "Costas Stefanis," (UMHRI), Athens, Greece, approved the protocol of this study.

A. PARTICIPANTS

The experimental group consisted of 18 (11 male, 7 female) congenitally ($n=8$) or early blind ($n=10$) individuals, with a mean age of 32.66 ± 9 . The mean length of education was 15.55 ± 2.30 years. The control group included 17 sighted individuals (7 male, 10 female) with a mean age of 27.82 ± 5.02 years and mean length of education 16.58 ± 1.41 years. T-tests on age and length of education of the two groups showed no significant differences (age: $t=1.93$, $p=0.062$, education: $t=1.58$, $p=0.12$). Sighted participants had normal or corrected-to-normal visual acuity and reported no history of visual dysfunction. Inclusion criteria for all participants were the absence of medical, neurological, or psychological problems and the absence of pharmacological treatment. All participants were right-handed.

B. INSTRUMENTS

1) BEHAVIORAL INSTRUMENTS

a: AUDITORY STIMULI

Based on the Complete Fables of Aesop [27], we selected 15 of them for the creation of the auditory stimuli. These were translated to Modern Greek language and adapted to comparable text lengths. Their English back-translation from the Greek is given in the Appendix. The selected fables typically involve two main characters, one representing a negative ('offender') and the other a positive ('victim') perspective or moral stance. A third possible stance is the self-referential perspective of the 'observer.'

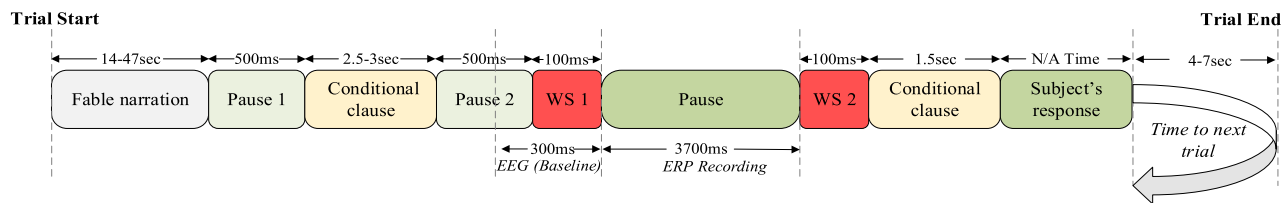


FIGURE 1. Flow diagram of recordings in each trial of the Aesop's fables procedure (BL: pre-trigger EEG baseline).

Auditory versions of the fables were created by a text-to-speech application, to ensure the neutrality of intonation. The narration times varied between 14 and 47 sec. After each fable narration, we have added a brief mute period (500 msec; see Procedures). Subsequent, we have added the presentation of a conditional statement (2.5 - 3.0 sec) instructing the participant to adopt one of the three possible moral stances: “If I took X’s position (‘offender’ or ‘victim’ or ‘observer’ . . .). Afterwards, we added another mute period (500 msec), concluded by an auditory warning stimulus (trigger: 100 msec, tone description). After 3700 msec, we have repeated the 100 msec warning stimulus, and the fable presentation was concluded by a final auditory prompt guiding the participant to evaluate his / her emotional response under the given stance: “I would feel . . .” (approximately 1.5 sec; see Table 1). We have used this sequence of the auditory components of the stimuli to engage working memory (WM) operation to allow the final response, i.e., the self-evaluation of the participant’s emotional state [28].

In order to cover the three possible moral stances, each fable was presented three times, to a total of 45 presentations or trials. The three presentations were differentiated only by the ‘If’ statement. The 45-item presentation sequence was pseudorandom concerning fable order and stance required in each of the three encounters of the fable, to avoid either consecutive exposures to a given fable or a fixed order of stance-taking. We used a fable example to explain to each participant the stance adoption requirement. To ensure the above comprehension, we provided two training presentations of fables before the onset of the testing (see Procedures).

b: RESPONSE MATERIALS

We prepared folders, each holding 45 separate pages corresponding to every one of the 45 fable encounters, ordered in the predetermined pseudorandom presentation plan. Pages were printed either conventionally for the sighted or in braille for the blind participants. Each page provided eight choices of emotional state (anger, disgust, sadness, surprise, joy, trust, anticipation, fear: A study [29] presented in a random order varying across pages, with a 9th choice of “none of the above” concluding the response choice sequence. The process of listening to a fable and making the required response to it had an average duration of approximately one min., resulting in a total session length of about 45 min.

2) ELECTROPHYSIOLOGICAL INSTRUMENTS

Electroencephalic (EEG) activity was recorded from 30 scalp electrodes based on the international 10-20 system of electroencephalography [30], referred to both earlobes. We recorded the electrophysiological signals using As/AgCl electrodes. Electrode resistance was constantly kept below 5 kΩ. We set the bandwidth of the amplifiers at 0.05-35Hz. We digitized the evoked biopotential signal with a sampling rate of 1 kHz.

C. PROCEDURES

1) BEHAVIORAL PROCEDURE

Table 1 and Figure 1 present the timeline of the behavioral and electrophysiological procedure. On the test day, a researcher provided verbal instructions to each participant and the procedure i.e., fable narration, the stance adoption requirement, and the response requirement. Specifically, he/she was informed that, at the end of each auditory presentation of a fable and after a brief pause, there would be a direction as to which stance he/she was to adopt. The participant would then have to assess his/her emotional state by choosing one of the nine response alternatives on the appropriate page of the response folder available and verbalize the chosen answer.

TABLE 1. Temporal sequence of the experimental procedure.

Sequence of events	Duration
Audio narration of Aesop’s fable	14 - 47 sec
Mute period	500 msec
Presentation of the conditional clause (“If I took the place of ‘offender’ or ‘victim’ or ‘observer’ . . .”)	2.5 - 3.0 sec
Mute period	500 msec
- No event	200 msec
- EEG recording (pre-trigger baseline: BL)	200 msec
- Warning (trigger) stimulus	100 msec
- ERP (post-trigger) recording	3.700 msec
- Length of electrophysiological recording: (Baseline + trigger + ERP)	4.000 msec
Warning stimulus repetition	100 msec
Completion of the conditional question (“I would feel . . .”)	1.5 sec
Emotion selection and response verbalization	Time as needed
Inter-trial interval (response completion to onset of next narration)	4-9 sec (random)

Both sighted, and blind participants were instructed to keep their eyes gently closed during narration in order to equalize the sighted and blind conditions and minimize eye movements and blinking. Blind and sighted participants alike were

instructed to open their eyes only when they were required to respond to the narration.

After instruction, the participant was fitted with a cap of 30 scalp electrodes, stereo headphones, electro-oculogram (EOG) leads, and was comfortably seated in a Faraday chamber (2.5 x 2.5 m), with the response folder on a table before him/her. The researcher ensured by touch that no inordinate muscle tension was present on closed lids. Consequently, the researcher was seated outside the Faraday cage, near (1m) the participant, in front of the computer controlling the experimental procedure.

Verbal communication was possible through an intercom. The instruction was concluded by two trial runs of fable presentation and response, to ensure the participant clearly understood the procedure. Afterward, the 45-presentation series initialized. As mentioned above, the order of fable/stance presentation was computer-controlled according to a pseudorandom sequence. The researcher interfered with the process only by initializing each trial (fable narration) after recording the participant's verbal response to the previous one. As an example, the auditory presentation of the fable of the sick lion (see Appendix), in Presentation 1 of 3 would be followed by the direction "If I took the lion's position I would feel...": Choice from the response folder would follow and be recorded, then the researcher would instruct the participant to change page and close eyes so that the next trial could be initialized.

2) ELECTROPHYSIOLOGICAL PROCEDURE

In the course of the behavioral procedure, 200 msec after the presentation of the conditional clause ("If I took the place of ...) an EEG baseline was recorded for 200 msec. An auditory 'trigger' stimulus (100 msec) followed. Then ERPs were recorded for 3700 msec. Eye movements were also recorded using electrooculogram (EOGs). Recordings with EOGs higher than $75\mu\text{V}$ were rejected. In order to minimize other sources of artifacts, such as muscle contractions, participants had been instructed to remain relaxed as much as possible during the procedure. The total length of electrophysiological recording, including the pre-trigger baseline, trigger presentation, and ERP recording, was 4000 msec.

D. METHODOLOGY FOR ERP DETECTION WITH CONTINUOUS WAVELET TRANSFORM

We analyzed the experimental data by applying a wavelet-based algorithm using EEGLAB 13.5.4b [31], an open-source toolbox for MATLAB (Mathworks, Inc., Natick, MA, USA). This procedure enabled an accurate ERP detection in time, based on the continuous wavelet transform (CWT), which permits the accurate decomposition of EEG waveforms into a set of component waveforms allowing the isolation of all scales of waveform structure [32]–[35]. The CWT has a good time and frequency localization, which is ideal for ERP detection [36], [37]. This transform, denoted by $W_x(f, t)$, decomposes a signal time series, $x(t)$, into a set of basic functions $C_{\tau,s}(t)$, called wavelets.

Wavelets grow and decay in a bounded time period. Their energy is time concentrated, thus can be used as a perfect tool for the analysis of transient, non-stationary, or time-varying signals. According to this method, we choose first a mother wavelet to be convolved with the desired signal. In general, any number of waveforms can be considered a wavelet. Nevertheless, for biological signals, such as EEG, the waveforms contained in the wavelet must provide a biologically plausible fit to the signal being modeled. This fact showcases the importance of an appropriate choice of a mother wavelet in order to achieve accurate modeling. In our case, we chose the complex Morlet mother wavelet $\Psi(t)$ for the convolution step, which has been used with significant success in this process [38]. This convolution leads to a new signal $W_x^\Psi(b, a)$, where a is the scaling parameter of the wavelet, and b stands for the translation parameter. The confidence of this signal indicates the correlation between the EEG signal and the wavelet function. We note that the basic aim of the present study is to concentrate on the time domain analysis and the accurate localization of ERPs as enabled by the application of CWT.

In our study, we have implemented ERP detection with CWT by applying the following steps:

1. We first calculate the evoked potential via conventional averaging in each participant.
2. We choose a starting and ending value of scaling (a) or the complex Morlet wavelet to be convolved with the ERPs, and we set to 1 the initial value for the translation step (b).
3. We compute the correlation for the current value of scaling and for every translation, covering the whole signal.
4. We change the scaling according to an appropriate step, until we reach its maximum value.
5. We extract the wavelet coefficients obtained by analyzing and reconstructing the evoked potential.

The scalograms in Figure 2 presents an example of the applied CWT; each coefficient represents a degree of correlation between the original signal and the complex Morlet wavelet. Based on these coefficients, an appropriately scaled wavelet was selected to match the LPP component. In order to avoid a potentially false ERP detection, the derived wavelet is convolved with the EEG signals, only in the corresponding part of the EEG signal where the LPP component could be located (500-800 msec after the trigger onset). We extracted the ERP peak values, and the corresponding latencies for each participant, condition, and EEG channel. Figure 3 displays the grand average ERP waveforms obtained at lead T3 for the two compared groups for the Positive condition.

E. STATISTICAL ANALYSIS

The normality of distributions for each group of variables (amplitudes and latencies) dictated the applied statistical analysis. The Kolmogorov Smirnov test showed that both the amplitudes and latencies follow a normal distribution.

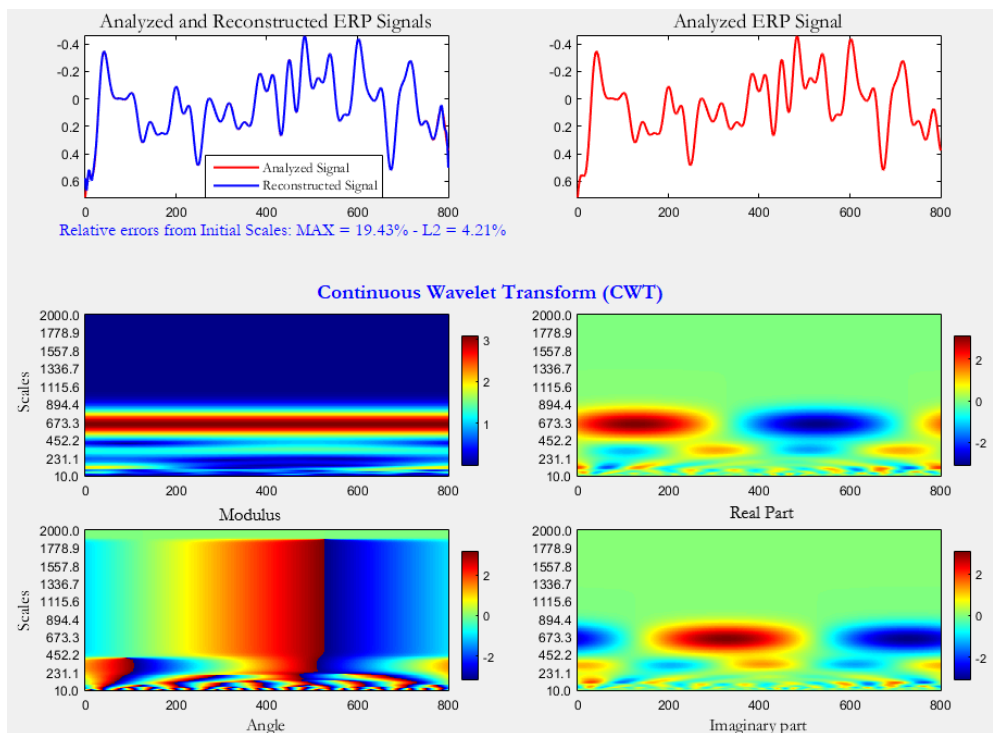


FIGURE 2. Mean valued ERP signal at lead T3 for the positive condition of the blind group.

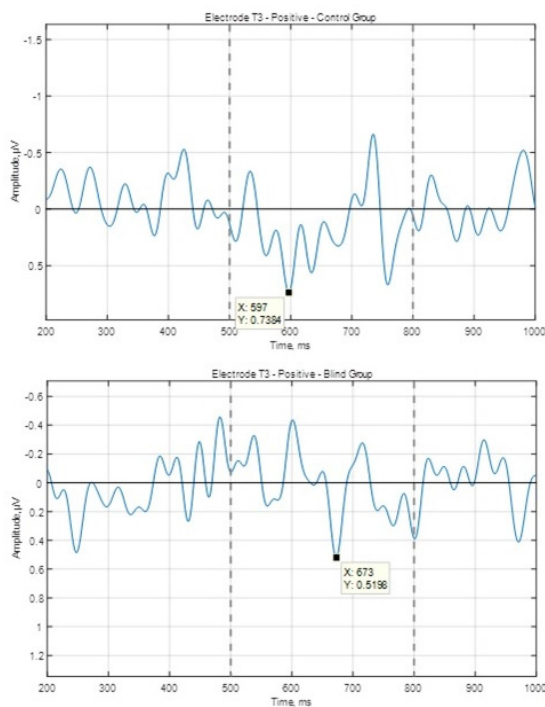


FIGURE 3. Grand ERP waveform in microvolts, for the Positive condition obtained for the control and blind groups at lead T3.

Normality was also examined by Box’s M test, which established multivariate normal distribution and ascertained the equality of the covariance matrices. This finding allows

the use of multivariate tests for the examination of overall group differences.

We applied one-way analysis of variance in order to estimate the group differences (i.e. blind vs controls) in behavioral performance and psychometric measures. Additionally, we used the Pearson correlation coefficients to assess the relationship between Plutchik’s emotional dimensions and the various ERP measurements. Results were considered significant at the 0.05 level.

III. RESULTS

A. ELECTROPHYSIOLOGICAL PERFORMANCE

Table 2 presents the comparison of LPP amplitudes in blind and control participants after repeated measures ANOVA, Group Effect. The analysis indicates that blind participants exhibited significantly attenuated amplitudes of the LPP component compared to controls at leads T3, P4, O2, T6, CZ, PZ, CPz, and CP4.

Table 3 presents the comparison of LPP amplitudes across moral stance conditions after repeated measures ANOVA (Condition Effect). The factor of Condition (neutral vs. positive vs. negative moral stance) produced statistically significant differences in two placements (leads P3 and CPz), with the Negative condition showing lower values than the Neutral and Positive ones. The difference was most pronounced on electrode P3, where the highest values of the positive condition and the lowest of the negative ones were noted. At the CPZ lead, there was also a statistically significant Condition effect with the Negative condition

TABLE 2. Comparison of LPP amplitudes in blind and control participants.

Mean values and standard errors of the LPP amplitudes in μV for blind and sighted participants, at the abductions where statistically significant differences were obtained ($p < 0.50$)					Partial η^2 (eta squared) values were large for all comparisons (suggested norms for partial η^2 : small = 0.01; medium = 0.06; large = 0.14)							
Electrode	Controls (n=17)		Blind (n=18)		SS	DF	MS	F	p	Partial eta-squared	Non-centrality	Observed power (alpha=0.05)
	Mean	SE	Mean	E								
T3	3.05	0.25	2.24	0.24	17.31	1	17.31	0.45	0.026	0.14	5.45	0.62
P4	3.67	0.37	2.20	0.36	57.22	1	57.22	0.07	0.008	0.20	8.07	0.79
O2	4.86	0.54	2.85	0.52	105.97	1	105.97	0.12	0.012	0.18	7.12	0.74
T6	3.90	0.47	2.33	0.45	64.06	1	64.06	0.73	0.023	0.15	5.73	0.64
Cz	2.25	0.24	1.47	0.23	15.85	1	15.85	0.55	0.025	0.14	5.55	0.63
Pz	3.01	0.30	1.68	0.29	46.30	1	46.30	0.14	0.003	0.24	10.14	0.87
CPz	2.14	0.22	1.39	0.22	14.84	1	14.84	0.80	0.022	0.15	5.80	0.65
CP4	2.58	0.23	1.64	0.22	23.07	1	23.07	0.48	0.006	0.20	8.48	0.81

TABLE 3. Comparison of LPP amplitudes across moral stance conditions.

Means and standard errors of LPP amplitudes (μV) at the abductions which produced statistically significant ($p < 0.50$) condition effects							Partial η^2 (eta squared) values were large for all comparisons (suggested norms for partial η^2 : small = 0.01; medium = 0.06; large = 0.14)							
Condition	Negative		Neutral		Positive		SS	DF	MS	F	p	Partial eta-squared	Non-centrality	Observed power (alpha=0.05)
Electrode	Mean	SE	Mean	SE	Mean	SE								
P3	2.06	0.29	2.57	0.20	3.06	0.29	17.49	2	8.74	7.46	0.001	0.12	9.35	0.77
CPz	1.33	0.19	2.02	0.23	1.95	0.21	10.30	2	5.15	4.67	0.013	0.12	9.35	0.77

TABLE 4. Comparison of LPP latencies in blind and control participants.

Mean values and standard errors of the LPP latencies (msec) for the blind and sighted groups, at the abductions where statistically significant differences ($p < 0.50$) were obtained					Partial η^2 (eta squared) values were large for all comparisons (suggested norms for partial η^2 : small = 0.01; medium = 0.06; large = 0.14)							
Group / Electrode	Controls (n=17)		Blind (n=18)		SS	DF	MS	F	p	Partial eta-squared	Non-centrality	Observed power (alpha=0.05)
	Mean	SE	Mean	SE								
FPz	670.69	16.13	618.46	15.68	71533	1	71533	5.39	0.026	0.14	5.391	0.616
P4	628.04	12.21	668.56	11.86	43056	1	43056	5.66	0.023	0.15	5.665	0.638
Pz	640.20	12.99	684.89	12.62	52390	1	52390	6.09	0.019	0.16	6.092	0.669
CP4	649.76	11.00	692.52	10.69	47943	1	47943	7.77	0.009	0.19	7.769	0.772

TABLE 5. Comparison of LPP latencies across moral stance conditions.

Means and standard errors of the LPP latencies in msec and the abductions with statistically significant condition effects where ($p < 0.50$)							Partial η^2 (eta squared) values were large for all comparisons (suggested norms for partial η^2 : small = 0.01; medium = 0.06; large = 0.14)							
Condition / Electrode	Negative		Neutral		Positive		SS	DF	MS	F	p	Partial eta-squared	Non-centrality	Observed power (alpha=0.05)
	Mean	SE	Mean	SE	Mean	SE								
O1	613.47	13.05	654.84	15.69	662.08	15.39	48096	2	24048	0.51	0.035	0.10	7.022	0.636
P4	614.81	16.35	657.86	13.76	672.23	14.12	62439	2	31220	0.07	0.021	0.11	8.139	0.704

showing lower values than both the Neutral and Positive conditions.

Table 4 presents the comparison of LPP Latencies in blind and control participants (Repeated measures ANOVA, group effect). Blind participants demonstrated prolonged LPP latencies at leads P4, PZ and CP4 compared to Controls, with significantly shorter than control latencies at the FPz lead.

Table 5 presents the comparison of LPP latencies across moral stance conditions (Repeated measures ANOVA, Condition Effect). At leads O1 and P4, prolonged LPP latencies were noted in the Neutral and Positive conditions compared to the Negative one.

Table 6 presents the comparison of LPP latencies in blind and control participants across conditions (Repeated measures ANOVA, Group x Condition interaction effect). A single statistically significant interaction effect was noted, at the C4 electrode: blind participants were faster in the Negative condition compared to healthy controls. This finding was reversed in the Positive condition.

B. BEHAVIORAL PERFORMANCE

The behavioral responses of the blind and sighted groups did not reveal major differentiations, with two exceptions. Specifically, during the positive condition of the

TABLE 6. Comparison of LPP latencies in blind and control participants across conditions.

Means and standard errors of LPP latencies (msec) at the abduction C4 which produced a statistically significant ($p < 0.50$) interaction effect							Partial η^2 (eta squared) values were large for all comparisons (suggested norms for partial η^2 : small = 0.01; medium = 0.06; large = 0.14)							
C4 Condition/ Group	Negative		Neutral		Positive		SS	DF	MS	F	p	Partial eta-squared	Non-centrality	Observed power (alpha=0.05)
	Mean	SE	Mean	SE	Mean	SE								
Controls (n=17)	680.00	21.20	670.12	26.62	617.18	21.63	87428	2	43714	5.001	0.009	0.13	10.00	0.796
Blind (n=18)	610.72	20.60	692.94	25.87	686.89	21.02								

TABLE 7. Behavioural comparison between the two groups (regarding the basic emotion of sadness).

Sadness in positive condition of perspective taking	N	Means	SD	-95%	+95%
Controls	17	2.352941	1.497547	1.582974	3.122909
Blind	18	1.500000	0.923548	1.040730	1.959270
All Groups	35	1.914286	1.291862	1.470516	2.358056

perspective-taking, the controls exhibited statistically significant expression of the emotion of sadness as compared to blind participants ($F=4.16$, $p=0.049$), see Table 7. In contrast, during the self-referential condition, the blind participants expressed the emotion of Joy significantly more often than the controls ($F=5.30$, $p=0.027$), see Table 7.

1) RELATIONSHIPS BETWEEN AMPLITUDES OF LPP AND THE BASIC EMOTION ACCORDING TO PLUTCHIK’S THEORY IN THE BLIND GROUP

During the positive condition of the perspective-taking:

(i) Positive relationships: with sadness localized at centroparietal areas, in particular in CPz ($r=0.531$, $p=0.023$) and Pz leads ($r=0.489$, $p=0.039$), with fear localized at anterior temporal area T3 lead ($r=0.560$, $p=0.014$), with trust localized at occipital area Oz lead ($r=0.655$, $p=0.003$), with the choice “none of the above” localized at central area Cz lead ($r=0.569$ and $p=0.014$).

(ii) Negative relationship: with disgust at posterior temporal area T6 lead ($r= -0.523$, $p=0.026$).

During the self-referential condition of the perspective- taking:

(i) Positive relationships: with sadness localized at occipito-parietal areas, O2 ($r=0.473$, $p=0.047$) and P4 ($r=0.536$, $p=0.022$) leads, with anticipation localized at centroparietal areas, specifically at CPz ($r=0.487$, $p=0.040$), Cz ($r=0.727$, $p=0,001$), and P4 ($r=0.495$, $p=0,037$) leads.

(ii) Negative relationships: with surprise localized at anterior temporal area at T3 lead ($r=-0.656$, $p=0,003$) and parietal area at lead P4 ($r=-0.492$, $p=0.038$).

During the negative condition of the perspective-taking:

(i) Positive relationships: with trust localized at occipital area at Oz lead ($r=0.581$, $p=0.011$).

(ii) Negative relationships: with trust localized at parietal areas, Pz lead ($r= -0.555$, $p=0.017$), with the choice ‘none of the above’ localized at centroparietal areas, in particular,

TABLE 8. Behavioral comparison between the two groups (regarding the basic emotion joy).

Joy in Self-referential Condition of perspective-taking	N	Means	SD	-95%	+95%
Controls	17	0.941176	0.966345	0.444327	1.438025
Blind	18	2.722222	3.044871	1.208043	4.236401
All Groups	35	1.857143	2.427088	1.023409	2.690877

at P4 ($r= -0.580$, $p=0.024$) and CP4 ($r= -0.681$, $p=0.002$) leads.

2) RELATIONSHIPS BETWEEN THE AMPLITUDES OF THE LPP AND THE BASIC EMOTIONS OF THE PLUTCHICK’S THEORY IN THE CONTROL GROUP

During the positive condition of the perspective-taking:

(i) Positive associations: with the joy localized at occipital area lead O2 ($r=0.585$, $p=0.014$), with the anticipation localized at parietal area P4 lead ($r=0.646$, $p= 0.005$).

(ii) Negative associations: with the choice ‘none of the above’ localized at occipital area O2 lead ($r= -0.519$, $p=0.033$).

During the self-referential condition of the perspective- taking:

(i) Positive associations: with the disgust localized at anterior temporal area T3 lead ($r=0.486$, $p=0.048$), with the trust localized at parietal area P4 ($r=0.635$ $p=0.006$) and Pz ($r=0.51$, $p=0.036$) leads.

During the negative condition of the perspective-taking:

(i) Positive associations: with the sadness localized at the parietal areas P3 ($r=0.561$, $p=0.019$) and Pz ($r=0.681$, $p=0.003$) leads.

(ii) Negative associations: with the surprise localized at anterior temporal area T3 lead ($r= -0.656$. $p=0.003$).

3) RELATIONSHIPS BETWEEN THE LATENCIES OF THE LPP AND THE BASIC EMOTIONS ACCORDING TO PLUTCHIK’S THEORY IN THE BLIND GROUP

There were not noticed any association in the positive condition of perspective-taking.

During the self-referential condition of the perspective-taking: (i) Positive associations: with the joy localized at parietal area Pz lead ($r=0.505$, $p=0.032$), with the sadness localized at parietal area Pz lead ($r=0.515$, $p=0.029$), with the anger localized at occipital area O1 lead ($r=0.474$,

$p=0.046$), with the disgust localized at central area C4 lead ($r=0.543$, $p=0.020$), with the choice 'none of the above' localized at the occipital area O1 lead ($r=0.533$, $p=0.023$).

4) RELATIONSHIPS BETWEEN THE LATENCIES OF LPP AND BASIC EMOTIONS ACCORDING TO PLUTCHIK'S THEORY IN THE CONTROL GROUP

During the positive condition of the perspective-taking:

(i) Positive relationships: with the surprise localized at occipito-parietal areas O1 ($r=0.550$, $p=0.029$) and Pz ($r=0.564$, $p=0.018$) leads.

During the self-referential condition of the perspective-taking

(i) Positive association: with the fear localized at parietal area Pz lead ($r=0.493$, $p=0.044$).

(ii) Negative association: with the joy localized at the orbitofrontal area FPz lead ($r=-0.507$, $p=0.087$), with the trust localized at the orbitofrontal area FPz lead ($r=-0.528$, $p=0.029$).

During the negative condition of the perspective-taking:

(i) Positive associations: with the anger localized at parietal area P4 lead ($r=0.565$, $p=0.018$).

(ii) Negative associations: with the choice none of the above localized at the parietal area Pz lead ($r=-0.509$, $p=0.037$).

IV. DISCUSSION

A. ELECTROPHYSIOLOGICAL PERFORMANCE

Blind participants exhibited significantly attenuated LPP amplitudes compared to controls at leads T3, P4, O2, T6, CZ, PZ, CPZ, and CP4. They also demonstrated prolonged LPP latencies at the P4, PZ, CP4 leads compared to controls, with significantly shorter than control latencies at the FPZ lead.

The neural efficiency hypothesis postulates that clever (qualified) participants exhibit inferior (more efficient) brain activation than less qualified participants on cognitive tasks of low to moderate difficulty [39], [40]. On the other hand, the amplitude modulations of LPP are believed to reflect the sustained attention and stimulus encoding processes [20], which serve to inform understanding of another's behavior [41]. Based on the above, our results are compatible with the view that blindness is accompanied by increased efficiency in handling sustained attention and stimuli encoding. This view is in agreement with observations that the visually deprived cortex becomes responsive to a wide variety of non-visual sensory inputs. Specifically, studies have revealed a role of the visually deprived cortex in facilitating a variety of cognitive processes including lexical and phonological processing, working memory, verbal memory and memory retrieval, repetition priming, spatial, object and auditory discrimination, selective attention, as well as spatial navigation [1]–[5]. The efficient interaction of congenitally blind individuals with the environment is most likely mediated by both supramodal brain organization and cross-modal brain plasticity.

Supramodal brain organization (SBO) refers to the capacity of distinct cortical areas to process information without support from the sensory modality, which carries that information to the brain. SBO would advance sensory information towards a more abstract, possibly 'conceptual,' representation. At the same time, the absence of vision gives rise to a structural and functional reformation within "visual" brain areas, a phenomenon known as cross-modal plasticity. The cross-modal synergy of the occipital cortex in individuals with visual impairment represents an adaptive compensatory mechanism that contributes to the processing of non-visual inputs. Supramodality and cross-modal plasticity appear to be the "yin and yang" of brain development: supramodal is what takes place despite the lack of vision, whereas cross-modal is what happens because of lack of vision [42]–[44].

The pattern of results on LPP latencies revealed group divergence, where the blind exhibited significant prolongations at right temporoparietal leads compared to sighted controls. At the same time, they manifested significantly shorter latencies at frontal leads. Understanding these findings would be facilitated by consideration of the view that latency variations of the LPP waveform reflect the time needed to complete the processes which have triggered the LPP. Hence, these results appear to be an effect of a hybrid between the general loss hypothesis and the compensatory plasticity hypothesis in the congenitally blind [45]. These components of this hybrid might act in accord to provide a balanced adaptation with the demands of the environment. The general loss hypothesis [46], [47] predicts that early sensory deprivation and the lack of visual experience during postnatal brain development induces a generalized degradation of sensory functions. Accordingly, a person with blindness would be impaired in the adjustment of other senses and, therefore, would be unable to form a map of the surrounding space. However, most findings of the last decade favor the alternative complementary hypothesis of compensatory adaptation. This hypothesis proposes that the brain deprived of one sensory modality shows massive reorganization, adapting to sensory loss by recruiting the deafferented cortex to process information from preserved modalities leading to superior abilities [48], [49].

We note that, although blind individuals appear to make more efficient use of their spared modalities under certain circumstances, superior performance is not the dominant state in the blind. Poorer performance after the absence of visual activations in the early or late blind conforms to the general loss hypothesis. Future studies providing insight into the temporal dynamics of the brain networks involved might help the dissociation, or the integration, of these two theoretical views [45], [50].

The present results have also shown that LPP amplitudes were differentially deployed in judgments carried out under the assumption of different perspectives with the highest values emerging under the positive condition and the lowest under the negative condition. Both the blind and the sighted participants exhibited this pattern of differences,

which appear to involve temporoparietal areas. The pattern may be explained by the functional characteristics of the LPP waveform. Psychophysiological studies suggest that LPP is a sensitive index of emotional reactivity and regulation. In this sense, both the amplitude and the latency of LPP might be a consistent measure of emotional reactivity and regulation. Convergence evidence indicate that attenuated LPP is induced by deceptive relative to truthful responses [51], [52]. These authors suggested that the inhibition of truthful response in conjunction with the enhancement of cognitive load in order to make ready the deceptive responses would be responsible for this result.

It is noteworthy that the LPP latency variation patterns in blind participants across the three perspective stances examined in this study revealed significantly shorter latencies under the negative stance compared to the positive one. Previous studies demonstrated that, compared to sighted controls, congenitally blind individuals are better in detecting negative emotions from body odors [53] and prosody [54]. A negative stimuli signal threat usually requires an immediate behavioral adaptation in order to cope with a potentially dangerous situation [55], [56]. Hence, it is reasonable to suppose that congenitally blind individuals are better in identifying ecologically important emotions [54]. This is congruent with the view that, under congenital visual deprivation, phylogenetically older forms of interacting with the world gain importance. Indeed, the evolutionary perspective and social neuroscience maintain that evolution has promoted a range of adaptation mechanisms facilitating the survival of the individual within a social group. Amongst these, all-important are those who support moral judgment, especially the deep sense of uneasiness and aversion to harming another [57], [58].

The loci of the obtained differences are distributed at occipital and temporoparietal areas. The emergence of a common pattern in blind and sighted participants at occipital areas supports the notion that the visual cortex in the blind complies with the existence of supramodal areas within the visual cortex, capable of processing information conveyed by different sensory modalities [44].

By considering altogether the findings regarding the statistically significant differences both of the amplitudes and latencies, it has been shown that these are mainly located at temporoparietal areas (see Figure 4). It is noted, however, that exception are the FP2, and O1 leads concerning the differences of amplitudes. The temporoparietal topography of the LPP suggests the ‘repair’ of the integration of syntactic and semantic information [17] in the updating of mental representation of what is being communicated as it is reflected by the LPP waveform [19]. In this regard, it is reasonable to bear in mind that studies concerning the neural basis underlying the LPP effect indicates that the middle temporal gyrus and the posterior portion of the temporal cortex are part of the circuit supporting processes reflected by the LPP waveform [59]–[61].

In contrast to this, the observed locations at the orbitofrontal and occipital regions might be understood by

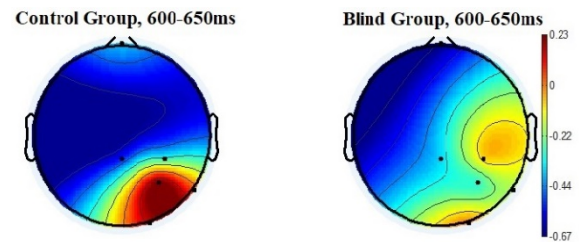


FIGURE 4. Spatio-temporal ERP patterns concentrated at leads P4, Pz, CP4, O2, and T6, as obtained at different time periods for the control and blind groups.

considering the aforementioned view that the LLP effect to emotion has been explained by a ‘reciprocal codependency between activity in prefrontal and occipitoparietal cortex’. [20]. Moreover, an alternative explanation concerning the significance of the observed distribution regarding the differences of the LPP amplitude and latencies may be better understood by taking into account the possible implication of the neural network involved in the theory of mind (i.e., conceiving the perspective of others) considering that the perspective-taking of others was the cornerstone of our experimental design [62], [63].

B. BEHAVIORAL PERFORMANCE

The observed behavioral findings seem to be consistent with studies indicating that blind individuals have difficulty posing emotional expressions [64]. Although the compensatory plasticity hypothesis suggests that blindness associates with compensation for the loss of vision through more efficient use of the spared modalities [45], [65]. In this sense, provided that sadness is associated with more systematic and deliberate processing whereas happiness is associated with more heuristic processing, [66], [67] it is tempting to hypothesize that in the present study the blinds based on more heuristic adaptive processes and less systematic and deliberate processing.

Pleasant basic emotions (such as joy and trust) and unpleasant (such as sadness, fear, disgust, and anger) elicited enhanced LPP for both compared groups, i.e., blinds and controls. An exception was the relationship between the emotion disgust with the LPP at the posterior temporal location during the positive perspective taking and the emotion trust with the LPP at parietal during the negative perspective-taking.

Generally speaking, the obtained sites of LPP activation as correlated with the basic emotion conform in spatial topography to those proposed for generation and emotional modulation of LPP. Indeed, ERP experiments in humans [68]–[70] consistently found enhanced Late Positive Potentials evoked by highly arousing unpleasant and pleasant stimuli. This phenomenon is a product of both an automatic facilitation of perceptual activity, as well as post-perceptual processing under cognitive control. The reciprocal codependency between activity in the prefrontal and occipitoparietal areas could explain this phenomenon [16].

Consequently, blind participants, compared to controls, exhibit analogous patterns of correlations of the LPP

activation and the expressed emotions. However, the sensory loss may hinder their social perception skills when processing some subtle emotions such as disgust or trust or when the extraction of simultaneous semantic information is required. We can justify this view by the fact that blindness reduces access to relevant sources of social information [71].

The positive association between the latency of the LPP and the pleasant (joy) and unpleasant basic emotion (sadness, anger, disgust) during the self-referential condition in the blind group appears to be consistent with previous investigations [72]. Moreover, this is an indication that longer response time may arise from uncertainty during an effortful correction. In line with this view, the controls exhibited similar patterns (i.e., positive associations) with the emotions surprise, fear, and anger during the positive, self-referential, and negative conditions of the perspective-taking, respectively. The exception to this consists of the fact that the controls showed positive emotions, joy, and trust during the self-referential condition, while exhibited negative associations between the latency of LPP and these emotions. A possible explanation for this finding might be the notion that the ability to integrate multimodal social cues correlates efficiently with measures of perspective-taking and emotional reactivity. Based on this evidence, we expect that sensory loss to hinder the perspective-taking skills of the blind participants [73].

Complementary information was obtained by the analyses that identified correlations between the variable ‘none of the above choice’ and the LPP activation elicited during the three conditions of the perspective-taking. The observed correlations appear to reflect activations that correspond to the Default Mode Network (DMN) operation. Indeed, the DMN is preferentially activated when individuals’ social tasks involve affective and introspective processes. These findings appear to be compatible with the notion that ‘the brain of the blind undergoes not only a local functional reorganization of the occipital cortex and DMN but also a reorganization of the cortical network as they adapt to the non-visual environment’ [74].

C. LIMITATIONS

A limitation of this study concerns the localization of ERP source generators, as multiple source configurations on the scalp may result in similar voltage fluctuations (the well-known “ill-posed” problem). Spatial resolution is therefore poor. However, ERP methodology has an excellent temporal resolution, allowing fine-grained temporal evaluation of the time-course of cognitive task-relevant operations.

V. CONCLUSION

We have presented an investigation on perspective-taking in congenital blindness based on Event-Related Potentials’ Detection with Continuous Wavelet Transform. This exploratory study, based on a set of fables with moral - emotional connotations, yielded evidence that the visually deprived cortex may become responsive to processes associated with perspective taking, probably mediated

by compensatory plasticity and cross-modal reformation. To conclude, we would like to underline that our study harnessed an ancient approach to social teaching towards the development of a novel model with the potential of expanding our understanding of crucial aspects underlying the complex link between emotion and cognition.

As in the present study, we focused exclusively on the time domain analysis and the accurate localization of ERPs enabled by the application of CWT, our ongoing research efforts include the analysis of the brain oscillations in the frequency domain between the groups of blind and sighted participants in various conditions.

Future studies may further investigate the functional and neural mechanisms underlying emotion processing in blind individuals by considering a larger variety of emotional stimuli, as well as testing individuals with acquired blindness later in life.

Moreover, developing a deeper understanding of the nature of the emotion modulated LPP during a perspective-taking associated with stories telling is promising. Research demonstrates that reading literature improves the capacity to identify and understand other’s subjective emotional and mental states, including empathic concern. In this sense, Pinkes argued that the increase of literacy during the humanitarian revolution during the 18th century contributed to the expansion of empathy to humanity [7], [75], [76].

DATA AVAILABILITY

All data considered in the context of this paper are available upon request for non commercial research purposes.

APPENDIX

Translations of the adapted Aesop’s fables used in the study.

THE MONKEY AND THE CAMEL

Someday, the forest animals organized a great feast, during which the Monkey stood up and danced. Having entertained the animal company, he sat down amidst cheers. The camel envied monkey the applause and, wishing to receive the same acclaim, stood on his hind legs, and started to dance. Nevertheless, he danced in such a ridiculous and clumsy way that the animals rushed angrily and kicked him out of the feast.

THE NORTH WIND AND THE SUN

The North Wind and the Sun were arguing over who was the stronger. Suddenly they saw an approaching traveler. “I see a way to settle our dispute. Whoever of us can make that traveler take off his cloak shall be regarded as the stronger”. “You begin,” said the Sun and retired behind a cloud. The North Wind began to blow as hard as he could upon the traveler, but the harder he blew, the closer the traveler wrapped his cloak round him, till at last, the North Wind had to give up. Then the Sun came out and shone in all his glory upon the traveler, who put off his cloak, feeling too hot.

THE TWO FROGS

Two frogs were once neighbors. One of them dwelt in a deep pond far removed from people while the other dwelt in a ditch with some water next to a busy road. The former warned his friend to change abode and invited him to come and live by him, saying that he would enjoy greater safety and ample food. The latter frog rejected the invitation saying that he could not leave the place to which he had been accustomed. Unfortunately, some days later, a big wagon passed through and crushed the poor frog under its wheels.

THE TWO CRABS

One fine day two crabs came out of their home to take a stroll on the sand. “Child,” said the mother, “you walk very ungracefully. You should get used to walking straight ahead gracefully rather than walking sideways.” “You are right, mother,” said the young one, “set the example yourself, and I will follow you.”

THE TREE AND THE REED

“Well, little one,” said a huge tree to a reed that was growing at its foot, “why do you not plant your root deeply in the ground so that you can grow taller like me?” “I am contented with my lot,” said the reed. “I may not be so grand, but I feel more safe.” “Safe!” sneered the Tree. “Who could uproot me or make me bend to the ground?” Nevertheless, it would soon have to regret its boasting, for a strong wind arose which tore it up from its roots, and cast it, a useless log, on the ground. On the other hand, when the storm had passed, the reed bending to the force of the wind, soon stood upright again..

THE FOX AND THE LION

A fox saw a lion imprisoned in a cage. It stood next to him and started reviling him. The lion said: “It is not me whom you revile but this misfortune which has befallen me.”

THE SICK LION

An old Lion, unable to procure his food through violence, decided to procure it through guile. It lay down in his den, pretending to be sick and made sure his sickness became publicly known. The other animals started arriving to express their compassion, but the lion devoured them. After many animals disappeared, the Fox, who understood the lion’s ruse, stood outside his den at a safe distance and asked him how he was. “So and so,” replied the lion. “But why don’t you come in for a chat?” “Because I see many footprints entering your den, but none leaving it,” the fox answered.

THE SCORPION AND THE FROG

The Scorpion and the Frog met on a riverside, and the scorpion asked the frog to carry him across. The frog questioned then: “How can I be sure that you will not sting me?” and the scorpion answered: “Because if I do, I will die too.” The frog, satisfied by the answer, agreed to take him across, but

in midstream, the scorpion stung the frog. The latter started to paralyze and, while sinking, managed to ask in a muffled voice, “Why?” “Because it is in my nature to do so...” the scorpion answered.

THE FOUR OXEN AND THE LION

A Lion used to prowl for food in a field in which four Oxen pastured. Many a time, it tried to attack them, but whenever it came near, they turned their tails to each other so that the lion would always meet the horns of one of them. Finally, the oxen started quarreling among themselves, and each went off to pasture alone in a separate corner of the field. Then the Lion attacked them one by one and soon killed all four.

THE FOX AND THE GOAT

By an unlucky chance, a fox fell into a deep well from which he could not get out. A goat passed by and asked the fox what he was doing down there. “Oh, have you not heard?” said the Fox, “there is going to be a great drought, so I jumped down here in order to be sure to have water nearby. Why don’t you come down too?” The goat considered this advice and jumped down into the well. But immediately, the fox jumped on his back and then on his long horns and managed to jump out of the well. “Good-bye, friend,” said the Fox, “and remember in the future not to take account of the advice of someone in difficulties.”

THE FOX AND THE MONKEY

The Fox and the Monkey were traveling together. While passing by a cemetery, the monkey told the fox: “Do you see all these monuments? They were made in honor of my ancestors, who were citizens of great fame”. The fox answered: “You chose the most appropriate participant for your lies since you are sure that none of your ancestors will refute them.”

THE GOATHERD AND THE GOAT

A goatherd was looking for a stray goat to return it to his flock. He whistled and sounded his horn in vain. The goat paid no heed to the summons. Finally, the Goatherd threw a stone and broke the goat’s horn. However, he begged the Goat not to tell his master about that. The Goat replied, “Why, you silly fellow, I will say nothing. My horn will speak for itself”.

THE FOX AND THE LION

A fox entered into a partnership with a Lion. Each undertook his proper duty following his nature and strength. The Fox would spot and point out the prey; the Lion would spring upon it and seize it. The Fox soon became jealous as the Lion would snatch “the lion’s share” and said that he would abandon the partnership and capture the prey on his own. The next day he attempted to snatch a lamb from the fold, but he fell prey to the huntsmen and hounds.

THE BOY AND THE PASSER-BY

A boy bathing in a river was in danger of drowning. He called out to a passing traveler for help but, instead of holding out a

helping hand, the man stood by and started scolding the boy for his imprudence. “Oh, sir!” cried the youth, “help me now and scold me afterward”.

THE CAMEL AND THE ARAB

An Arab camel-driver, having loaded his camel, asked it which it would prefer: going uphill or downhill. The poor beast replied, not without a touch of reason: “Is it that the level way through the desert is closed?”

ACKNOWLEDGMENT

The authors gratefully thank Dr. Demetrios Tsonos, Department of Informatics and Telecommunications, National and Kapodistrian University of Athens for his support on the development of the experimental procedure. The authors would also gratefully thank Dr. Emmanouil A. Kitsonas, Technical Director, Eugenides Foundation, and Alexandros Pantazis Electrical Engineer for their technical support and insightful comments.

REFERENCES

- [1] U. Noppeney, “The effects of visual deprivation on functional and structural organization of the human brain,” *Neurosci. Biobehav. Rev.*, vol. 31, no. 8, pp. 1169–1180, 2007, doi: [10.1016/j.neubiorev.2007.04.012](https://doi.org/10.1016/j.neubiorev.2007.04.012).
- [2] Z. Cattaneo, T. Vecchi, C. Cornoldi, I. Mammarella, D. Bonino, E. Ricciardi, and P. Pietrini, “Imagery and spatial processes in blindness and visual impairment,” *Neurosci. Biobehav. Rev.*, vol. 32, no. 8, pp. 1346–1360, Oct. 2008, doi: [10.1016/j.neubiorev.2008.05.002](https://doi.org/10.1016/j.neubiorev.2008.05.002).
- [3] P. Pietrini, M. Pfito, and R. Kupers, “Blindness and consciousness: New light from the dark,” in *The Neurology of Consciousness: Cognitive Neuroscience and Neuropathology*. San Diego, CA, USA: Academic, 2009, pp. 360–374, doi: [10.1016/B978-0-12-800948-2.00024-8](https://doi.org/10.1016/B978-0-12-800948-2.00024-8).
- [4] L. B. Merabet and A. Pascual-Leone, “Neural reorganization following sensory loss: The opportunity of change,” *Nature Rev. Neurosci.*, vol. 11, no. 1, pp. 44–52, Jan. 2010, doi: [10.1038/nrn2758](https://doi.org/10.1038/nrn2758).
- [5] R. Kupers, P. Pietrini, E. Ricciardi, and M. Pfito, “The nature of consciousness in the visually deprived brain,” *Frontiers Psychol.*, vol. 2, p. 19, Jan. 2011, doi: [10.3389/fpsyg.2011.00019](https://doi.org/10.3389/fpsyg.2011.00019).
- [6] S. L. Fairhall, K. B. Porter, C. Bellucci, M. Mazzetti, C. Cipolli, and M. I. Gobbi, “Plastic reorganization of neural systems for perception of others in the congenitally blind,” *NeuroImage*, vol. 158, pp. 126–135, Sep. 2017, doi: [10.1016/j.neuroimage.2017.06.057](https://doi.org/10.1016/j.neuroimage.2017.06.057).
- [7] J. Decety and J. M. Cowell, “The complex relation between morality and empathy,” *Trends Cognit. Sci.*, vol. 18, no. 7, pp. 337–339, Jul. 2014, doi: [10.1016/j.tics.2014.04.008](https://doi.org/10.1016/j.tics.2014.04.008).
- [8] A. F. Hamilton, K. Kessler, and S. H. Creem-Regehr, “Perspective taking: Building a neurocognitive framework for integrating the ‘social’ and the ‘spatial,’” *Frontiers Hum. Neurosci.*, vol. 8, p. 403, Jun. 2014, doi: [10.3389/fnhum.2014.00403](https://doi.org/10.3389/fnhum.2014.00403).
- [9] M. de Guzman, G. Bird, M. J. Banissy, and C. Catmur, “Self-other control processes in social cognition: From imitation to empathy,” *Philos. Trans. Roy. Soc. B, Biol. Sci.*, vol. 371, no. 1686, Jan. 2016, Art. no. 20150079, doi: [10.1098/rstb.2015.0079](https://doi.org/10.1098/rstb.2015.0079).
- [10] P. Luo, D. Xu, F. Huang, and F. Wei, “Emotion intensity modulates perspective taking in men and women: An event-related potential study,” *NeuroReport*, vol. 29, no. 9, pp. 773–778, Jun. 2018, doi: [10.1097/WNR.0000000000001030](https://doi.org/10.1097/WNR.0000000000001030).
- [11] M. D. Lieberman, “Social cognitive neuroscience: A review of core processes,” *Annu. Rev. Psychol.*, vol. 58, no. 1, pp. 259–289, Jan. 2007, doi: [10.1146/annurev.psych.58.110405.085654](https://doi.org/10.1146/annurev.psych.58.110405.085654).
- [12] J. Pelletier and R. Beatty, “Children’s understanding of Aesop’s fables: Relations to reading comprehension and theory of mind,” *Frontiers Psychol.*, vol. 6, p. 1448, Oct. 2015, doi: [10.3389/fpsyg.2015.01448](https://doi.org/10.3389/fpsyg.2015.01448).
- [13] S. Regel, L. Meyer, and T. C. Gunter, “Distinguishing neurocognitive processes reflected by P600 effects: Evidence from ERPs and neural oscillations,” *PLoS ONE*, vol. 9, no. 5, May 2014, Art. no. e96840, doi: [10.1371/journal.pone.0096840](https://doi.org/10.1371/journal.pone.0096840).
- [14] Z. Oralhan, “A new paradigm for region-based P300 speller in brain computer interface,” *IEEE Access*, vol. 7, pp. 106618–106627, 2019.
- [15] Z. Oralhan, “3D input convolutional neural networks for P300 signal detection,” *IEEE Access*, vol. 8, pp. 19521–19529, 2020.
- [16] A. C. Gouvea, C. Phillips, N. Kazanina, and D. Poeppel, “The linguistic processes underlying the P600,” *Lang. Cognit. Process.*, vol. 25, no. 2, pp. 149–188, Feb. 2010.
- [17] A. D. Friederici, “The brain basis of language processing: From structure to function,” *Physiol. Rev.*, vol. 91, no. 4, pp. 1357–1392, Oct. 2011.
- [18] H. Brouwer, H. Fitz, and J. Hoeks, “Getting real about semantic illusions: Rethinking the functional role of the P600 in language comprehension,” *Brain Res.*, vol. 1446, pp. 127–143, Mar. 2012, doi: [10.1016/j.brainres.2012.01.055](https://doi.org/10.1016/j.brainres.2012.01.055).
- [19] H. Brouwer, J. C. J. Hoeks, “A time and place for language comprehension: Mapping the N400 and the P600 to a minimal cortical network,” *Frontiers Hum. Neurosci.*, vol. 7, p. 758, Nov. 2013, doi: [10.3389/fnhum.2013.00758](https://doi.org/10.3389/fnhum.2013.00758).
- [20] S. Moratti, C. Saugar, and B. A. Strange, “Prefrontal-occipitoparietal coupling underlies late latency human neuronal responses to emotion,” *J. Neurosci.*, vol. 31, no. 47, pp. 17278–17286, Nov. 2011, doi: [10.1523/JNEUROSCI.2917-11.2011](https://doi.org/10.1523/JNEUROSCI.2917-11.2011).
- [21] H. T. Schupp, T. Flaisch, J. Stockburger, and M. Junghöfer, “Emotion and attention: Event-related brain potential studies,” *Prog Brain Res.*, vol. 156, pp. 31–51, Jan. 2006, doi: [10.1016/S0079-6123\(06\)56002-9](https://doi.org/10.1016/S0079-6123(06)56002-9).
- [22] G. Hajcak, A. MacNamara, and D. M. Olvet, “Event-related potentials, emotion, and emotion regulation: An integrative review,” *Develop. Neuropsychol.*, vol. 35, no. 2, pp. 129–155, Feb. 2010, doi: [10.1080/87565640903526504](https://doi.org/10.1080/87565640903526504).
- [23] H. Fu, W. Qiu, H. Ma, and Q. Ma, “Neurocognitive mechanisms underlying deceptive hazard evaluation: An event-related potentials investigation,” *PLoS ONE*, vol. 12, no. 8, Aug. 2017, Art. no. e0182892, doi: [10.1371/journal.pone.0182892](https://doi.org/10.1371/journal.pone.0182892).
- [24] A. D. Friederici, D. Y. Von Cramon, and S. A. Kotz, “Language related brain potentials in patients with cortical and subcortical left hemisphere lesions,” *Brain*, vol. 122, no. 6, pp. 1033–1047, Jun. 1999.
- [25] C. Sfagos, C. C. Papageorgiou, K. K. Kosma, E. Kodopadelis, N. K. Uzunoglu, D. Vassilopoulos, and A. D. Rabavilas, “Working memory deficits in multiple sclerosis: A controlled study with auditory P600 correlates,” *J. Neurol., Neurosurg. Psychiatry*, vol. 74, no. 9, pp. 1231–1235, Sep. 2003.
- [26] G. Hajcak and S. Nieuwenhuis, “Reappraisal modulates the electrocortical response to unpleasant pictures,” *Cognit., Affect., Behav. Neurosci.*, vol. 6, no. 4, pp. 291–297, Dec. 2006.
- [27] Aesop, *The Complete Fables*. London, U.K.: Penguin Books, 1998.
- [28] A. B. Moore, B. A. Clark, and M. J. Kane, “Who shalt not kill? Individual differences in working memory capacity, executive control, and moral judgment,” *Psychol. Sci.*, vol. 19, no. 6, pp. 549–557, Jun. 2008, doi: [10.1111/j.1467-9280.2008.02122.x](https://doi.org/10.1111/j.1467-9280.2008.02122.x).
- [29] R. Plutchik, “The measurement of emotions,” *Acta Neuropsychiatrica*, vol. 9, no. 2, pp. 58–60, Jun. 1997, doi: [10.1017/S0924270800036802](https://doi.org/10.1017/S0924270800036802).
- [30] G. H. Klen, H. O. Luders, H. H. Jasper, and C. Elger, “The ten twenty electrode system of the international federation,” *Electroencephalogr. Clin. Neurophysiol.*, vol. 52, no. 2, pp. 3–6, 1999.
- [31] A. Delorme and S. Makeig, “EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis,” *J. Neurosci. Methods*, vol. 134, no. 1, pp. 9–21, Mar. 2004, doi: [10.1016/j.jneumeth.2003.10.009](https://doi.org/10.1016/j.jneumeth.2003.10.009).
- [32] V. J. Samar, A. Bopardikar, R. Rao, and K. Swartz, “Wavelet analysis of neuroelectric waveforms: A conceptual tutorial,” *Brain Lang.*, vol. 66, no. 1, pp. 7–60, Jan. 1999, doi: [10.1006/brln.1998.2024](https://doi.org/10.1006/brln.1998.2024).
- [33] V. Bostanov, “BCI competition 2003-data sets Ib and IIb: Feature extraction from event-related brain potentials with the continuous wavelet transform and the t-value scalogram,” *IEEE Trans. Biomed. Eng.*, vol. 51, no. 6, pp. 1057–1061, 2004, doi: [10.1109/TBME.2004.826702](https://doi.org/10.1109/TBME.2004.826702).
- [34] P. Herman, G. Prasad, T. M. McGinnity, and D. Coyle, “Comparative analysis of spectral approaches to feature extraction for EEG-based motor imagery classification,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 16, no. 4, pp. 317–326, Aug. 2008, doi: [10.1109/TNSRE.2008.926694](https://doi.org/10.1109/TNSRE.2008.926694).
- [35] S. Guo, S. Lin, and Z. Huang, “Feature extraction of P300s in EEG signal with discrete wavelet transform and Fisher criterion,” in *Proc. 8th Int. Conf. Biomed. Eng. Informat. (BMEI)*, Oct. 2015, pp. 200–204, doi: [10.1109/BMEI.2015.7401500](https://doi.org/10.1109/BMEI.2015.7401500).

- [36] C. D'Avanzo, V. Tarantinob, P. Bisiacchib, and G. Sparacinoa, "A wavelet methodology for EEG time-frequency analysis in a time discrimination task," *Int. J. Bioelectromagnetism*, vol. 11, no. 4, pp. 185–188, 2009.
- [37] T. Rondik and J. Ciniurk, "Detection of ERP components—Comparison of basic methods and their modifications," in *Proc. 4th INCF Congr. Neuroinform.*, 2011, doi: [10.3389/conf.fninf.2011.08.00022](https://doi.org/10.3389/conf.fninf.2011.08.00022).
- [38] C. Papageorgiou, X. Stachtea, P. Papageorgiou, A. T. Alexandridis, E. Tsaltas, and E. Angelopoulos, "Aristotle meets zen: Psychophysiological evidence," *PLoS ONE*, vol. 11, no. 12, Dec. 2016, Art. no. e0168067, doi: [10.1371/journal.pone.0168067](https://doi.org/10.1371/journal.pone.0168067).
- [39] A. C. Neubauer and A. Fink, "Intelligence and neural efficiency," *Neurosci. Biobehav. Rev.*, vol. 33, no. 7, pp. 1004–1023, Jul. 2009, doi: [10.1016/j.neubiorev.2009.04.001](https://doi.org/10.1016/j.neubiorev.2009.04.001).
- [40] B. Dunst, M. Benedek, E. Jauk, S. Bergner, K. Koschutnig, M. Sommer, A. Ischebeck, B. Spinath, M. Arendasy, M. Bühner, H. Freudenthaler, and A. C. Neubauer, "Neural efficiency as a function of task demands," *Intelligence*, vol. 42, pp. 22–30, Jan. 2014, doi: [10.1016/j.intell.2013.09.005](https://doi.org/10.1016/j.intell.2013.09.005).
- [41] S. H. Creem-Regehr, K. T. Gagnon, M. N. Geuss, and J. K. Stefanucci, "Relating spatial perspective taking to the perception of other's affordances: Providing a foundation for predicting the future behavior of others," *Frontiers Hum. Neurosci.*, vol. 7, p. 596, Sep. 2013, doi: [10.3389/fnhum.2013.00596](https://doi.org/10.3389/fnhum.2013.00596).
- [42] R. Kupers and M. Ptito, "Compensatory plasticity and cross-modal reorganization following early visual deprivation," *Neurosci. Biobehav. Rev.*, vol. 41, pp. 36–52, Apr. 2014, doi: [10.1016/j.neubiorev.2013.08.001](https://doi.org/10.1016/j.neubiorev.2013.08.001).
- [43] E. Ricciardi, D. Bonino, L. Sani, T. Vecchi, M. Guazzelli, J. V. Haxby, L. Fadiga, and P. Pietrini, "Do we really need vision? How blind people 'see' the actions of others," *J. Neurosci.*, vol. 29, no. 31, pp. 9719–9724, Aug. 2009, doi: [10.1523/JNEUROSCI.0274-09.2009](https://doi.org/10.1523/JNEUROSCI.0274-09.2009).
- [44] E. Ricciardi, D. Bonino, S. Pellegrini, and P. Pietrini, "Mind the blind brain to understand the sighted one! Is there a supramodal cortical functional architecture?" *Neurosci. Biobehav. Rev.*, vol. 41, pp. 64–77, Apr. 2014, doi: [10.1016/j.neubiorev.2013.10.006](https://doi.org/10.1016/j.neubiorev.2013.10.006).
- [45] L. Lazzouni and F. Lepore, "Compensatory plasticity: Time matters," *Frontiers Hum. Neurosci.*, vol. 8, p. 340, Jun. 2014, doi: [10.3389/fnhum.2014.00340](https://doi.org/10.3389/fnhum.2014.00340).
- [46] J. P. Rauschecker, "Compensatory plasticity and sensory substitution in the cerebral cortex," *Trends Neurosci.*, vol. 18, pp. 36–43, Jan. 1995, doi: [10.1016/0166-2236\(95\)93948-W](https://doi.org/10.1016/0166-2236(95)93948-W).
- [47] J. P. Rauschecker, "Developmental plasticity and memory," *Behav. Brain Res.*, vol. 66, nos. 1–2, pp. 7–12, 1995, doi: [10.1016/0166-4328\(94\)00117-X](https://doi.org/10.1016/0166-4328(94)00117-X).
- [48] R. Weeks, B. Horwitz, A. Aziz-Sultan, B. Tian, C. M. Wessinger, L. G. Cohen, M. Hallett, and J. P. Rauschecker, "A positron emission tomographic study of auditory localization in the congenitally blind," *J. Neurosci.*, vol. 20, no. 7, pp. 2664–2672, Apr. 2000, doi: [10.1523/JNEUROSCI.20-07-02664.2000](https://doi.org/10.1523/JNEUROSCI.20-07-02664.2000).
- [49] P. Voss, M. Lassonde, F. Gougoux, M. Fortin, J.-P. Guillemot, and F. Lepore, "Early- and late-onset blind individuals show supra-normal auditory abilities in far-space," *Current Biol.*, vol. 14, no. 19, pp. 1734–1738, Oct. 2004, doi: [10.1016/j.cub.2004.09.051](https://doi.org/10.1016/j.cub.2004.09.051).
- [50] L. Cecchetti, R. Kupers, M. Ptito, P. Pietrini, and E. Ricciardi, "Are supramodality and cross-modal plasticity the yin and yang of brain development? From blindness to rehabilitation," *Frontiers Syst. Neurosci.*, vol. 10, p. 89, Nov. 2016.
- [51] R. Johnson, J. Barnhardt, and J. Zhu, "The deceptive response: Effects of response conflict and strategic monitoring on the late positive component and episodic memory-related brain activity," *Biol. Psychol.*, vol. 64, no. 3, pp. 217–253, Nov. 2003, doi: [10.1016/j.biopsycho.2003.07.006](https://doi.org/10.1016/j.biopsycho.2003.07.006).
- [52] G. Dong, H. Wu, and Q. Lu, "Attempting to hide our real thoughts: Electrophysiological evidence from truthful and deceptive responses during evaluation," *Neurosci. Lett.*, vol. 479, no. 1, pp. 1–5, Jul. 2010, doi: [10.1016/j.neulet.2010.05.014](https://doi.org/10.1016/j.neulet.2010.05.014).
- [53] K. D. Iversen, M. Ptito, P. Møller, and R. Kupers, "Enhanced chemosensory detection of negative emotions in congenital blindness," *Neural Plasticity*, vol. 2015, Mar. 2015, Art. no. 469750, doi: [10.1155/2015/469750](https://doi.org/10.1155/2015/469750).
- [54] C. Klinge, B. Röder, and C. Büchel, "Increased amygdala activation to emotional auditory stimuli in the blind," *Brain*, vol. 133, no. 6, pp. 1729–1736, Jun. 2010, doi: [10.1093/brain/awq102](https://doi.org/10.1093/brain/awq102).
- [55] D. G. Amaral, "The primate amygdala and the neurobiology of social behavior: Implications for understanding social anxiety," *Biol Psychiatry*, vol. 51, no. 1, pp. 11–17, 2002, doi: [10.1016/S0006-3223\(01\)01307-5](https://doi.org/10.1016/S0006-3223(01)01307-5).
- [56] D. Sander, J. Grafman, and T. Zalla, "The human amygdala: An evolved system for relevance detection," *Rev. Neurosci.*, vol. 14, no. 4, pp. 303–316, Jan. 2003, doi: [10.1515/REVNEURO.2003.14.4.303](https://doi.org/10.1515/REVNEURO.2003.14.4.303).
- [57] J. D. Greene, R. B. Sommerville, L. E. Nystrom, J. M. Darley, and J. D. Cohen, "An fMRI investigation of emotional engagement in moral judgment," *Science*, vol. 293, no. 5537, pp. 2105–2108, 2001, doi: [10.1126/science.1062872](https://doi.org/10.1126/science.1062872).
- [58] D. Marazziti, S. Baroni, P. Landi, D. Ceresoli, and L. Dell'Osso, "The neurobiology of moral sense: Facts or hypotheses?" *Ann. Gen. Psychiatry*, vol. 12, no. 1, p. 6, 2013, doi: [10.1186/1744-859X-12-6](https://doi.org/10.1186/1744-859X-12-6).
- [59] H. Kwon, S. Kuriki, J. M. Kim, Y. H. Lee, K. Kim, and K. Nam, "Meg study on neural activities associated with syntactic and semantic violations in spoken Korean sentences," *Neurosci. Res.*, vol. 51, pp. 349–357, Apr. 2005, doi: [10.1016/j.neures.2004.12.017](https://doi.org/10.1016/j.neures.2004.12.017).
- [60] E. Service, P. Helenius, S. Maury, and R. Salmelin, "Localization of syntactic and semantic brain responses using magnetoencephalography," *J. Cognit. Neurosci.*, vol. 19, no. 7, pp. 1193–1205, Jul. 2007, doi: [10.1162/jocn.2007.19.7.1193](https://doi.org/10.1162/jocn.2007.19.7.1193).
- [61] C. J. Ortiz-Echeverri, S. Salazar-Colores, J. Rodríguez-Reséndiz, and R. A. Gómez-Loenzo, "A new approach for motor imagery classification based on sorted blind source separation, continuous wavelet transform, and convolutional neural network," *Sensors*, vol. 19, no. 20, p. 4541, 2019.
- [62] R. L. Buckner and D. C. Carroll, "Self-projection and the brain," *Trends Cognit. Sci.*, vol. 11, no. 2, pp. 49–57, Feb. 2007, doi: [10.1016/j.tics.2006.11.004](https://doi.org/10.1016/j.tics.2006.11.004).
- [63] C. E. V. Mahy, L. J. Moses, and J. H. Pfeifer, "How and where: Theory-of-mind in the brain," *Develop. Cognit. Neurosci.*, vol. 9, pp. 68–81, Jul. 2014, doi: [10.1016/j.dcn.2014.01.002](https://doi.org/10.1016/j.dcn.2014.01.002).
- [64] D. Valente, A. Theurel, and E. Gentaz, "The role of visual experience in the production of emotional facial expressions by blind people: A review," *Psychonomic Bull. Rev.*, vol. 25, no. 2, pp. 483–497, Apr. 2018.
- [65] C. E. Wakefield, J. Homewood, and A. J. Taylor, "Cognitive compensations for blindness in children: An investigation using odour naming," *Perception*, vol. 33, no. 4, pp. 429–442, Apr. 2004, doi: [10.1068/p5001](https://doi.org/10.1068/p5001).
- [66] B. A. Converse, S. Lin, B. Keysar, and N. Epley, "In the mood to get over yourself: Mood affects theory-of-mind use," *Emotion*, vol. 8, no. 5, pp. 725–730, 2008.
- [67] S. Gu, F. Wang, C. Cao, E. Wu, Y.-Y. Tang, and J. H. Huang, "An integrative way for studying neural basis of basic emotions with fMRI," *Frontiers Neurosci.*, vol. 13, p. 628, Jun. 2019.
- [68] G. Hajcak, A. Weinberg, A. MacNamara, and D. Foti, "ERPs and the study of emotion," in *The Oxford Handbook of Event-Related Potential Components*, S. J. Luck and E. S. Kappenman, Eds. New York, NY, USA: Oxford Univ. Press, 2011.
- [69] S. B. Brown, H. van Steenbergen, G. P. Band, M. de Rover, and S. Nieuwenhuis, "Functional significance of the emotion-related late positive potential," *Frontiers Hum. Neurosci.*, vol. 6, p. 33, Feb. 2012.
- [70] Y. Lei, Y. Wang, C. Wang, J. Wang, Y. Lou, and H. Li, "Taking familiar others' perspectives to regulate our own emotion: An event-related potential study," *Frontiers Psychol.*, vol. 10, p. 1419, Jun. 2019, doi: [10.3389/fpsyg.2019.01419](https://doi.org/10.3389/fpsyg.2019.01419).
- [71] A. T. Martins, L. Faísca, H. Vieira, and G. Gonçalves, "Emotional recognition and empathy both in deaf and blind adults," *J. Deaf Stud. Deaf Educ.*, vol. 24, no. 2, pp. 119–127, Apr. 2019.
- [72] A. Harris, J. A. Clithero, and C. A. Hutcherson, "Accounting for taste: A multi-attribute neurocomputational model explains the neural dynamics of choices for self and others," *J. Neurosci.*, vol. 38, no. 37, pp. 7952–7968, Sep. 2018.
- [73] C. Regenbogen, D. A. Schneider, A. Finkelmeyer, N. Kohn, B. Derntl, T. Kellermann, R. E. Gur, F. Schneider, and U. Habel, "The differential contribution of facial expressions, prosody, and speech content to empathy," *Cognition Emotion*, vol. 26, no. 6, pp. 995–1014, Sep. 2012.
- [74] H.-J. Park, J.-W. Chun, B. Park, H. Park, J. I. Kim, J. D. Lee, and J.-J. Kim, "Activation of the occipital cortex and deactivation of the default mode network during working memory in the early blind," *J. Int. Neuropsychol. Soc.*, vol. 17, no. 3, pp. 407–422, May 2011.
- [75] S. Pinker, *The Better Angels of Our Nature: Why Violence Has Declined*. London, U.K.: Penguin Group, 2011.
- [76] D. C. Kidd and E. Castano, "Reading literary fiction improves theory of mind," *Science*, vol. 342, no. 6156, pp. 377–380, Oct. 2013.



Charalabos C. Papageorgiou received the Medical (M.D.) degree from the Medical School, National and Kapodistrian University of Athens, Greece, in 1980, and the Ph.D. degree from the University of Ulm Medical School, Ulm, Germany, in 1983. He received his Certificate of the Specialty of Neurology and Psychiatry in 1987 following board examinations. He is currently a Professor and a Chairman of the First Department of Psychiatry, National and Kapodistrian University of Athens, Medical School, Eginition Hospital.



Georgios Th. Kouropetroglou (Member, IEEE) received the B.S. degree in physics and the Ph.D. degree in communications and signal processing from the National and Kapodistrian University of Athens, Greece, in 1978 and 1983, respectively. He is currently an Associate Professor and the Director of the Speech and Accessibility Laboratory, and also the Director of postgraduate studies with the Department of Informatics and Telecommunications, and the Head of the Accessibility Unit for Students with Disabilities, National and Kapodistrian University of Athens, Greece. His current research interests focus on the area of computer accessibility and voice user interfaces, as a part of the major domain of human-computer interaction. He is a member of the Editorial Board of the journals *Universal Access in the Information Society* and *Technology and Disability*.



Xanthi P. Stachteia is currently pursuing the Ph.D. degree. She is currently a Psychiatrist and an Academic Scholar with the 1st Department of Psychiatry, Eginition Hospital, National and Kapodistrian University of Athens, and also a Fellow Researcher with the Psychophysiology Research Laboratory, University Mental Health Research Institute (U.M.H.R.I). Her research interests include developmental psychophysiology and learning procedures.



Panos C. Papageorgiou (Member, IEEE) received the B.S. and M.S. degrees in electrical and computer engineering from the Department of Electrical and Computer Engineering, University of Patras, Greece, in 2014 and 2015, respectively, where he is currently pursuing the Ph.D. degree. His current research interests include modeling, control, and stability analysis for a large class of nonlinear dynamic systems, along with signal processing in biomedical applications. He is a member of the IEEE Industrial Electronics Society and of the National Technical Chamber of Greece.



Antonios K. Mavromatos was born in Athens, Greece, in 1990. He graduated from the Medical School, University of Crete, Greece, in 2013, and received the M.Sc. degree in consultation-liaison psychiatry from the National and Kapodistrian University of Athens, Greece, in 2017. He is currently pursuing the Ph.D. degree in psychophysiology. He is currently a Resident Doctor in psychiatry with the 2nd Department of Psychiatry, University General Hospital "Attikon", Medical School, National and Kapodistrian University of Athens, Greece.



George P. Chrousos was the first General Director of the Foundation of Biomedical Research of the Academy of Athens from 2001 to 2002. He was a Senior Investigator and the Director of the Pediatric Endocrinology Section and Training Program, and a Chief of the Pediatric and Reproductive Endocrinology Branch, National Institute of Child Health and Human Development (NICHD), National Institutes of Health (NIH). He is currently a Professor of pediatrics and endocrinology emeritus and a Former Chairman of the Department of Pediatrics, Athens University Medical School, Greece. He is also a Clinical Professor of pediatrics, physiology, and biophysics with the Georgetown University Medical School and also a Distinguished Visiting Scientist, NICHD, NIH. He holds the UNESCO Chair on Adolescent Health Care, while he held the 2011 John Kluge Chair in Technology and Society, Library of Congress, Washington, DC, USA.

He is among the 250 most prominent clinical investigators in the world. He has authored more than 1100 scientific publications, has edited 29 books and his work has been cited more than 138 000 times. According to the ISI, he is the highest cited clinical pediatrician and endocrinologist in the world. According to Google Scholar Citations, he is in the list of 100 most cited scientists in the world, and his h factor is > 183.



Nikos K. Logothetis received the degree in mathematics from the University of Athens and the Ph.D. degree in biology in Munich with Ernst Pöppel. He is currently the Director of the Department of Physiology of Cognitive Processes, Max Planck Institute for Biological Cybernetics, Tübingen. His research interest includes in exploring the neural mechanisms of visual perception. He has made significant discoveries, such as finding out that the blood-oxygen-level dependent (BOLD) response is connected to brain activity at a neuronal level. He is a member of the Editorial Board for *Current Biology*. He is one of the 2003 winners of the Louis-Jeantet Prize for Medicine.



Eleftheria Tsaltas received the B.S. degree in psychology from Mc Gill University, Montreal, Canada, in 1976, and the Ph.D. degree from Université de Montreal, Montreal, in 1978, and also from the University of Oxford, in 1982. She is currently a Professor of psychology, the Director of the Psychology Sector, the Head of the Experimental Psychology Laboratory, and the Head of the Neuropsychology Laboratory, 1st Department of Psychiatry, Eginition Hospital, Medical School, National and Kapodistrian University of Athens, Greece.

...