Brain-to-Brain (mind-to-mind) Interaction at distance: a pilot study

(v.1.2)

Patrizio Tressoldi*, Luciano Pederzoli°, Marco Bilucaglia°, Patrizio Caini°, Pasquale Fedele§, Alessandro Ferrini°, Simone Melloni° and Agostino Accardo#

*Dipartimento di Psicologia Generale, Università di Padova, Italy; °EVANLAB, Firenze, Italy; §LiquidWeb, Siena, Italy; # Dipartimento di Ingegneria e Architettura, Università di Trieste, Italy

For correspondence:

Patrizio E. Tressoldi
Dipartimento di Psicologia Generale
Università di Padova, ITALY
Email: patrizio.tressoldi@unipd.it

ABSTRACT

The hypothesis to detect a sequence of events by analyzing the EEG activity of two human partners spatially separated and connected only mentally, was explored sending to a member of the couple a sequence of silence-signal events and analyzing the EEG activity of the second member of the couple. By using a special classification algorithm and five couples of participants characterized by a long friendship and a capacity in maintaining a focused mental concentration, we observed an overall percentage of correct coincidences of 78%, ranging from one-hundred percent for the first two segments, to approximately forty-three percent of the last two. The percentages of coincidences of the first five segments of the protocol were above eighty percent.

Furthermore a robust statistically significant correlation was observed in the alpha band in twelve out fifteen pairs of recordings.

The observed results seem supporting the possibility to connect two brains at distance excluding conventional means, paving the way to devise a sort of mental telecommunication at distance.

INTRODUCTION

Brain-to-brain interaction (BBI) at distance, that is, out of the five senses detection range, has been demonstrated by Pais-Vieira et al. (2013), connecting the brain of rats by internet connection.

A similar effect has been demonstrated with humans in a pilot study by Rao and Stocco (2013), sending by internet the EEG activity generated imaging to move the right hand to the brain of a distant partner triggering his motor cortex causing the right hand to press a key.

Even though there is cultural resistance to accepting the possibility of observing similar effects in humans without an internet connection, some evidence of these effects nevertheless exists. A comprehensive search of studies related to this line of research has revealed at least eighteen studies from 1974 until the present time (see Supplementary Material).

In all these studies the principal aim was to observe whether the stimulus evoked brain activity (e.g. by presenting light flashes or images) in one member of the couple, could also be observed in the brain of the partner. Even if some of these studies, those using functional neuroimaging, can be criticized for potential methodological weaknesses that could account for the reported effects (Acunzo, Evrard and Rabeyron, 2013), the questions is still open regarding whether or not it is possible to connect two human brains at distance.

The possibility of connecting the brains of two humans at distance without using any classical means of transmission is theoretically expected if it is assumed that two brains, and consequently two minds, can be entangled in a quantum-like manner. In quantum physics, entanglement is a physical phenomenon that occurs when pairs (or groups) of particles are generated or interact in ways such that the quantum state of each member must subsequently be described relative to the others irrespective of their distance without apparent classical communication.

At present, generalizability from physics variables to biological and mental variables can be done only by analogy given the differences in their properties, but some theoretical models are already available, For example in the Generalized Quantum Theory (von Lucadou & Romer, 2007; Filk & Römer, 2011), entanglement can be expected to occur if descriptions of the system that pertain to the whole system are complementary to descriptions of parts of the system. In this case the individual elements within the system, that are described by variables complementary to the variable describing the whole system, are non-locally correlated.

Reasoning by analogy, we hypothesized the possibility of entangling two minds, and consequently two brains as complementary parts of a single system and studying their interactions at distance without any classical connections.

The possibility of a cognitive interaction at distance between two or more minds (brains) is allowed in another theoretical framework described by Tressoldi (2013) within the dual-process theory of information processing. In synthesis it is postulated that System 1, (the mental processing system mainly involved in the processing of unconscious information) in contrast to System 2, (mainly involved in the processing of conscious information), processes not only local information conveyed by sensory organs, but also nonlocal ones, that is, those beyond the detection range of sensory organs.

In the following, we report the results of a pilot experiment which main hypothesis was that the number of signals (coincidences) detected in the two partners during the stimulation were above chance, demonstrating for the first time that BBI at distance is feasible and can be used as a mental telecommunication device.

METHOD

Participants

Five healthy male adults were selected for this experiment. Their mean age was 35.5, SD = 8.3. The criteria for their inclusion were their friendship lasting more than five years and their experience in maintaining a focused mental concentration resulting from their experience in meditation and other practices to control mental activity.

Ethics Statement

Participation inclusion followed the ethics guidelines in accordance with the Helsinki Declaration and the study was approved by the Ethics Committee of Dipartimento di Psicologia Generale, the institution of the main author. Before taking part to the experiment, each participant provided a written consent after reading a brief description of the experiment.

Apparatus

An ad-hoc software designed by one of the co-author, SM, managed the sequence of stimulations and the timing of the EEG activity recordings of the two partners. EEG activity was measured using two Emotiv® EEG Neuroheadset connected wirelessly to PCs running Windows OS. Their technical characteristics are 14 EEG channel based on the International 10-20 locations (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, plus 2 references), one mastoid (M1) sensor acted as a ground reference point to which the voltage of all other sensors was compared. The other mastoid (M2) was a feed-forward reference that reduced external electrical interference. Sampling rate is 128 Hz, bandwidth 0.2-45 Hz,. Filtering is made by a build in digital 5th order sinc and connectivity is obtained by a proprietary wireless network.

Stimuli

One auditory clip was delivered binaurally at a high volume (80 dBs) to one of the partners through Parrot ZIK® headphones connected with the PC controlling stimulus delivery and EEG recordings. This clip, reproducing a baby crying, was selected among the list of the most arousing sounds (Cox, 2008) in order to enhance the EEG activity of the stimulated person.

Stimulation protocol

The protocol consist of three periods of listening the auditory clip lasting 1 minute each interspersed by silent periods lasting 2.5 minutes for a total of seven segments (i.e. silence-signal-silence-signal-silence-signal-silence).

Procedure

We devised a procedure aimed at recreating a real situation when there is an important event to share, in this case a communication related to a baby crying. In order to isolate the two partners, we

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placed them in two separated rooms at approximately 5 meters of distance. Each rooms was acoustically and visually isolated. Between these two rooms a third room served as control room were the research assistant controlled all procedure, the start of the experiment and the registration of the EEG activity of the two partners (see Figure S2). Any sensory information from the central PC and from the rooms of the pairs were completely absent.

The partner designated as "sender" received the following instructions: "*when ready, you will hear music for 1 minute to relax and prepare you to receive the stimulation to send to your partner. To facilitate your mental connection with him/her, you will see a photo of his/her face by the special glasses (*virtual glasses model Kingshop OV2, see Figure S3). *Your only task is to aim to send him mentally what you will hear, reducing your body and head movements in order to reduce artifacts. You will receive three stimulations lasting 1 minute each, separated by 2 and half minutes intervals. The experiment will last approximately 15 minutes.*

The instructions to the second partner designated as "receiver" were: "*when ready, you will hear music for 1 minute to relax and prepare you to receive the stimulation sent by your partner. To facilitate your mental connection with him, you will see the photo of his/her face by the special glasses. Your task is to connect with him mentally trying to receive the stimulation he is hearing, reducing your body and head movements in order to reduce artifacts. The experiment will last approximately 15 minutes.*

When both partners gave their approval for the start of the experiment, the research assistant started the experiment running automatically. At the end of the experiment both partners were informed of its end. After a break, they reversed their roles if agreed.

A total of 15 pairs of data were collected.

Data analysis

The EEG activity of each couple was analyzed off-line using the classification algorithm (see description below), detecting the number of coincidences and the number of errors and missing signals. Given our interest in detecting the correct sequence of events (silence-signal) and not their absolute overlapping, a signal detected in the EEG activity of the receiver was considered a coincidence if at least one of its boundaries (initial or final) overlapped with that of the stimulation protocol. All other signals were classified as errors or missing (see examples in Figure S1). To check the reliability of the scoring system, the data were analyzed independently by two co-authors, PE and SM. Their overall agreement was 69.5 %, weighted Kappa statistic 0.81. Discrepancies were solved re-checking the original data. All data are available for independent analyses in Figshare (Tressoldi, 2014).

Classification Algorithm
The BrainScanner™ classification software was originally developed and is available by one of the co-author P.F.[1] The analysis was carried out offline taking as input the two files of each pair of participant obtained by the Emotiv® EEG Neuroheadset. The first analysis is a classical principal component analysis (PCA) to reduce the data obtained by the fourteen channels to their latent

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[1] Pasquale Fedele p.fedele@liquidweb.it

variables. Fifty percent of these data, randomly sampled, are then feed forwarded with the corresponding labels related to signal and silence to a support vector machine (SVM) using a standard C- support vector classification (C-SCV; Steinwart and Christmann, 2008; Chang and Lin, 2011), for the training phase.

The SVM belongs to the family of generalized linear classifiers and are also known as maximum margin classifiers, because at the same time minimize the empirical error classification and maximize the geometric margin. SVM can be thought of as an alternative technique for the learning of polynomial classifiers, as opposed to the classical techniques of neural networks training. Neural networks with a single layer have an efficient learning algorithm, but they are useful only in the case of linearly separable data. Conversely, the multilayer neural networks can represent non-linear functions, but they are difficult to train because of the number of dimensions of the space of weights, and because the most common techniques, such as back-propagation, allow to obtain the network weights by solving an optimization problem not convex and not bound, consequently it presents an indeterminate number of local minimum.

The SVM training technique solves both problems: it is an efficient algorithm and is able to represent complex non-linear functions. The characteristic parameters of the network are obtained by solving a convex quadratic programming problem with equality constraints or box type (in which the value of the parameter must be maintained within a range), which provides a single global minimum. Regarding the kernel choice, the one that gave the best performance during the tests was the RBF (radial basis function).

After the training phase, the algorithm is ready to generalize the obtained classification model to the remaining data, matching the sequence of events of the stimulation protocol with the EEG activity of the person connected at distance. The result is a contingency table (see results and examples in Figure S1) were it is possible to observe whether and how many events are coincident.

For all pairs of data, we used the same parameters to be used for the training phase: fifty percent of data randomly selected for each of the three signal periods.

Correlational analyses

To have a convergent evidence of the relationship between the EEG activity of the two partners, we correlated their EEG activity related to the signal and silence periods observed in the fourteen channels, with respect to the five frequency bands, delta, theta, alpha, beta and gamma normalized with respect to the total power and the fractal dimension (FD), which measures the fractal-like behavior of a time series, using the Higuchi algorithm (Accardo, Affinito, Carrozzi & Bouquet, 1997; Esteller, Vachtsevanos, Echauz, & Litt, 2001). Each period of silence and stimulation was divided in tracts of 4 seconds computing the Power Spectral Density (PSD) by the periodogram method. The five spectral bands were distinguished as follows: delta (0.5-4Hz), theta (4-8Hz), alpha (8-15Hz), beta (15-30Hz) and gamma (30-60Hz). The PSD of the different bands was then expressed in normalized units dividing the power in each band by the sum of the powers in all the bands.

RESULTS

Coincidences classification

The matrix of the total of coincidences out of 15 sessions and errors or missing for each of seven segments of the stimulation protocol between the partners is reported in Table 1, for a total of 105 segments (15∗7).

Table 1: Matrix of the total of coincidences out of 15 and errors, for each segment of the stimulation protocol.

		sequence of events							
		silence	**signal**	silence	**signal**	silence	**signal**	silence	Coincidences (%)
detected events	silence	**15**							100
	signal		**15**						100
	silence			**14**	1				93.3
	signal				**13**	2			86.7
	silence					**12**	3		80.0
	signal						**6**	17	40.0
	silence							**7**	46.7

The overall percentage of coincidences is 78%; 95% CI= 72-87, far exceed the percentage of errors and omissions, of 22%; 95% CI= 14-31. The corresponding Bayes Factor calculated with the online applet available on http://pcl.missouri.edu/bf-binomial, using the uniformed prior, equals 4347826 in favor of the alternative hypothesis.

COMMENT

From the data presented in Table 1, it can be observed that the coincidences are concentrated in the diagonal with a percentage of coincidences decreasing almost linearly moving from the first two segments to the last ones (*rho*= -0.95; 95%CI: -0.66,1.0[2]). However the percentages of coincidences of the first 5 segments are above 80%.

Correlational analyses

The graphs[3] of the FD and the frequency bands relationship between each of the fifteen pairs of participants as well as their Pearson's *r* correlation values with corresponding 95% CIs are reported in the Supplementary Materials. To test the significance of the correlation coefficient we adopted a distribution-free approach, the Bivariate non-parametric Bootstrap (Bishara & Hittner, 2012) with 5000 iterations. From the sampling distribution, we computed the 95% confidence interval

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[2] Obtained with 5000 bootstrap resampling
[3] Original graphs can be downloaded from http://figshare.com/articles/BrainToBrainPilot/100479

following the percentile method. The Bivariate Test reject the null hypothesis if *r*=0 do not belongs to the confidence interval.

In Table 1, we report the averaged correlations among the fifteen pairs.

Table1: Averaged correlations with the corresponding confidence intervals for each EEG frequency band, separately for the silence and signal events.

	DELTA		THETA		ALPHA		BETA		GAMMA	
	Silence	Signal	Silence	Signal	Silence	Signal	Silence	Signal	Silence	Signal
Correl	0.25	0.26	0.45	0.31	0.58	0.55	0.04	0.07	0.36	0.32
95%CI	0.11,0.39	0.12,0.38	0.33,0.56	0.17,0.43	0.46,0.69	0.43,0.65	-0.09,0.18	-0.07,0.21	0.24,0.49	0.19,0.46

The correlations are all statistically significant out those related to the beta band. The strongest one are those related to the alpha band.

To give an example of a strong correlation, in Figure 1 we present the graph related to alpha band of pair 8.
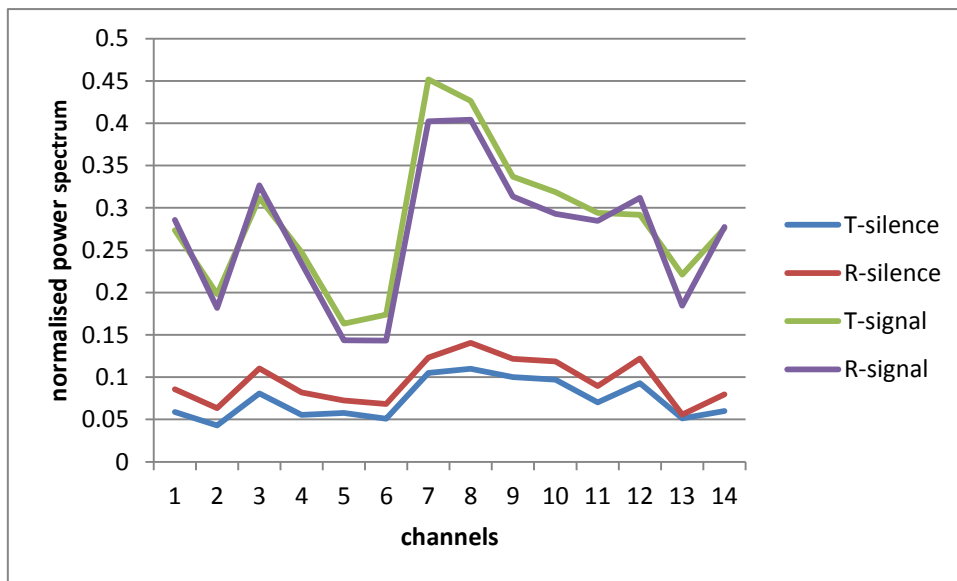

Figure 1: alpha band normalized power spectrum values recorded in the fourteen channels of the EEG activity of pair 8 (T=transmitter, R=receiver) .

Comment

In eleven out fifteen pairs, it emerges a strong correlation in the alpha band between the silence and signal events. In all other frequency bands, few significant correlation are present, ranging from two to a maximum of six. The average correlation in the alpha band among all participants, was 0.58 and 0.55 for the silence and the signal, respectively, followed by a correlation 0.45 and 0.31

respectively for the silence and signal events in the theta band, 0.36 and 0.32 in the gamma band and 0.25 and 0.26 in the delta band. Only in the beta band there were no statistical significant correlations.

DISCUSSION

The hypothesis to detect a number of coincidences in the brains activity of two humans at distance, that are not connected using classical means, seems supported by our pilot study. Using a protocol of three periods of stimulation lasting one minute each, interspersed within periods of non-stimulation (silence) lasting two and half minutes, for a total of seven segments, we recorded a percentage of correct coincidences of the sequence of events from 100% for the first two, to approximately 43% of the last two. Furthermore, the percentages of coincidences of the first five segments were above 80%.

We think that these results are mainly due to the innovative classification algorithm devised for this line of investigation and the enrolment of participants selected for their long friendship and experience in maintaining a mental concentration on the task. The drop of coincidences after the five segments, corresponding to approximately ten minutes, could be a limit of our classification algorithm to detect the differences between silence and signal, due to an increase of exogenous and endogenous EEG noise correlated to fatigue and loose of concentration (mental connection) between the two partners.

The relationship between the EEG activities of the pairs of participants is further supported by the positive and statistical significant correlations both for the silence and signal events in all but the beta band, but particularly elevated in the alpha band in eleven out fifteen pairs. The alpha band is a marker of attention (Klimesch et al.1998; Klimesh, 2012) and in this case it could represent an EEG correlate of the synchronized attention between the pairs of participants.

Even if we are planning to improve the stimulation protocol, in its present form it is sufficient to support a simple mental telecommunication code at distance. For example it is sufficient to associate any piece of the first five segments with a message, i.e. silence-signal = "CALL ME"; silence-signal-silence= "DANGER", etc.

The next steps of this line of research are the completion of a pre-registered confirmatory study increasing the physical distance between the pairs of participants, followed by an optimization of the classification algorithm to detect segment of EEG activity related to signal lasting 30 seconds or less, longer sequences of events and with the possibility to analyze the data online.

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SUPPLEMENTARY MATERIAL

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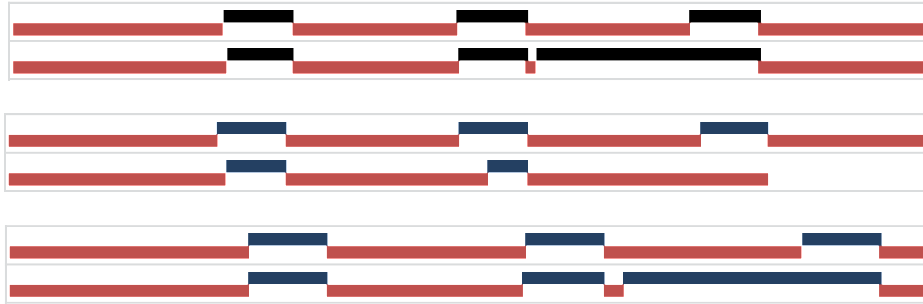
Figure S1: three examples of the matrices of coincidence between the protocol of stimulation and the EEG activity recorded in the "receiver" brain. The first row shows the timing and the sequence of the seven periods of silence and stimulation as delivered to the "sender" brain. The second row shows the timing and the sequence of the seven periods of silence and stimulation as observed in the "receiver" brain.

Using the criteria to consider a coincidence a segment of the protocol with at least one timing boundary (initial or final) overlapped between the two rows, we count 7 coincidences in the first example, 5 in the second and 7 in the third one.
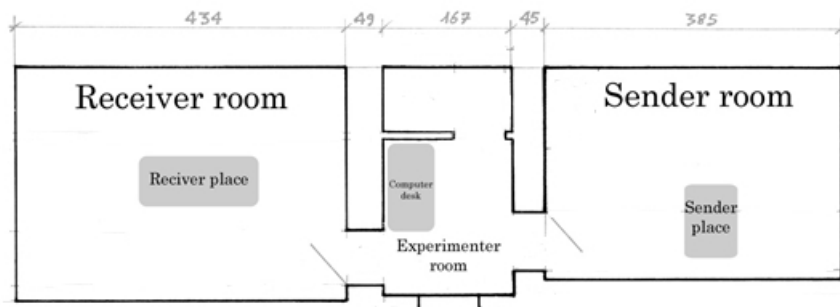

Figure S2: schematic outline of the lab rooms

Figure S3: Image of a participant with the complete apparatus: Emotiv™ EEG, digital glasses and headphones.

Table S1: Pearson correlation and 95%CIs between the values of the different frequency bands observed in the fourteen channels, for each of the fifteen pairs for both the silence (sil) and signal (sign) events. Values in bold are statistically significant.

pair	Delta		Theta		Alpha		Beta		Gamma	
	sil	sign	sil	sign	sil	sign	sil	sign	sil	sign
1	-0.17	-0.19	0.50	0.32	0.50	0.49	**-0.32**	**-0.37**	0.02	-0.05
	-0.61,0.45	-0.66,0.36	-0.04,0.90	-0.11,0.74	-0.03,0.85	-0.01,0.79	**-0.86,-0.03**	**-0.83,-0.16**	-0.79,0.64	-0.83,0.36
2	-0.22	-0.18	0.12	0.09	0.30	0.32	-0.39	-0.30	0.08	0.17
	-0.64,0.24	-0.65,0.31	-0.47,0.70	-0.46,0.71	-0.34,0.69	-0.20,0.69	-0.79,0.13	-0.84,0.24	-0.58,0.68	-0.47,0.84
3	**0.64**	**0.50**	0.21	0.04	**0.79**	**0.69**	0.05	-0.010	0.18	0.09
	0.35,0.84	**0.26,0.81**	-0.26,0.58	-0.44,0.38	**0.56,0.93**	**0.47,0.88**	-0.57,0.61	-0.45,0.56	-0.40,0.71	-0.46,0.59
4	0.27	0.24	0.20	0.27	**0.68**	**0.44**	-0.02	0.05	0.41	0.41
	-0.27,0.72	-0.20,0.63	-0.31,0.56	-0.23,0.74	**0.33,0.88**	**0.04,0.74**	-0.47,0.23	-0.23,0.43	-0.80,0.88	-0.36,0.80
5	0.17	0.32	**0.52**	-0.30	**0.53**	**0.75**	-0.14	0.01	0.32	**0.34**
	-0.55,0.82	-0.50,0.89	**0.13,0.89**	-0.73,0.32	**0.24,0.80**	**0.54,0.92**	-0.83,0.64	-0.66,0.86	-0.04,0.66	**0.06,0.75**
6	0.51	0.36	**0.55**	0.46	**0.69**	**0.58**	-0.14	-0.16	0.10	0.01
	-0.02,0.82	-0.40,0.76	**0.27,0.81**	-0.008,0.79	**0.30,0.92**	**0.20,0.83**	-0.54,0.28	-0.66,0.25	-0.23,0.75	-0.28,0.65
7	-0.12	-0.32	**0.68**	**0.57**	0.67	0.54	-0.33	-0.34	0.05	-0.06
	-0.53,0.43	-0.70,0.20	**0.37,0.90**	**0.22,0.82**	0.45,0.85	0.24,0.78	-0.66,0.14	-0.70,0.13	-0.22,0.75	-0.39,0.53
8	0.32	0.27	**0.50**	**0.54**	**0.88**	**0.88**	0.00	0.08	0.50	**0.53**
	-0.31,0.86	-0.41,0.79	**0.15,0.88**	**0.16,0.89**	**0.76,0.95**	**0.77,0.95**	-0.48,0.48	-0.58,0.60	-0.11,0.85	**0.30,0.90**
9	0.34	0.45	**0.77**	**0.58**	**0.90**	**0.82**	**0.50**	**0.50**	**0.93**	**0.94**
	-0.23,0.83	-0.13,0.85	**0.49,0.95**	**0.12,0.89**	**0.79,0.98**	**0.64,0.95**	**0.10,0.78**	**0.06,0.84**	**0.62,0.98**	**0.69,0.98**
10	**0.54**	**0.58**	-0.01	-0.04	**0.65**	**0.63**	0.49	0.39	0.49	0.42
	0.31,0.85	**0.23,0.85**	-0.31,0.91	-0.29,0.74	**0.40,0.91**	**0.18,0.92**	-0.14,0.87	-0.28,0.76	-0.20,0.81	-0.67,0.80
11	0.10	0.31	**0.56**	**0.46**	0.16	0.04	-0.025	0.36	0.36	0.12
	-0.56,0.88	-0.48,0.86	**0.28,0.79**	**0.14,0.77**	-0.54,0.84	-0.67,0.58	-0.53,0.68	-0.13,0.74	-0.14,0.69	-0.23,0.63
12	0.02	0.23	**0.80**	**0.57**	0.11	0.30	0.35	0.38	**0.72**	**0.57**

	-0.54,0.57	-0.32,0.78	**0.58,0.94**	**0.20,0.83**	-0.49,0.62	-0.30,0.76	-0.11,0.80	-0.08,0.75	**0.24,0.95**	**0.003,0.87**
13	**0.60**	0.43	0.52	0.30	**0.67**	**0.48**	0.18	0.22	0.32	**0.52**
	0.09,0.95	-0.11,0.84	-0.07,0.86	-0.29,0.79	**0.33,0.92**	**0.15,0.74**	-0.46,0.80	-0.33,0.72	-0.30,0.76	**0.004,0.89**
14	0.39	0.39	0.47	0.45	**0.65**	**0.69**	0.11	-0.12	0.56	0.48
	-0.16,0.86	-0.31,0.85	-0.16,0.86	-0.10,0.85	**0.20,0.91**	**0.30,0.93**	-0.48,0.68	-0.69,0.49	-0.13,0.90	-0.20,0.88
15	**0.45**	**0.52**	0.37	0.34	**0.64**	**0.64**	0.32	0.40	0.39	0.41
	0.15,0.78	**0.11,0.84**	-0.11,0.70	-0.19,0.75	**0.21,0.88**	**0.31,0.85**	-0.22,0.72	-0.13,0.80	-0.40,0.79	-0.26,0.79

Graphs of the values related to the FD and the five frequency bands related to the silence and signals observed in each of the fourteen channels on the fifteen pairs of participants. Legend: t=transmitter; r=receiver.