REPRESENTATION OF COGNITIVE STATES BY ELECTROPHYSIOLOGICAL INDICATORS

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Using EEG signals we did obtain the facial validation of the relationship between cognitive/affective states and characteristic periodic waveforms detected by Lee Method.

The system performs crosscorrelation between EEG records obtained during fantasy production and Dirac Delta waves periodically repeated. This procedure allows the extraction and identification of periodic waveforms with the same frequency as the frequency of repetition of Dirac Delta waves. Therefore with did not study immediately observable waveforms (Delta, Teta, Alfa; Beta) but rather non observable waveforms which were reconstructed through the use of Lee's Method.

Afterwards records were put in phase and their point to point averages were obtained.

Finally FFT was performed and the power spectrum components were calculated for all frequencies of the interval 1 to 20 Hz (some examples of periodic wave forms are shown in figures).

Stepwise Multivariate Discriminant Analysis allowed a reliable separation between pleasant and unpleasant emotional states, as well as cognitive states of thinking in numbers or else alphabet letters.

A second experiment of the same type was performed in 35 subjects, normal volunteers. The technic was similar, but in this second experiment subjects were asked to produce fantasies about joy, sadness, anger, anxiety and mistrust.

Results of Multivariate Discriminant Analysis between Power spectrum Components characteristic for each one of the five cognitive/affective situations we did study. These analysis were made on data obtained on Fronto-Temporal leads in the right and left hemisphere, respectively. The next tables summarize these results. The only comparisons which yelled non significant differences involved anger fantasies in the records obtained in right fronto-temporal leads.

Note that in the left hemisphere records in anger fantasies did significantly separate from the other four types of fantasies. The highest level of correct classifications was 96% versus 95% of classifications in comparisons between anxiety and anger, in the left hemisphere and in the right hemisphere , 100% and 90% of correct classification respectively in comparison between joyful and sad fantasies (tables 1-6).

Acknowledgments

This work was partially supported by a grant from BIAL Foundation, Oporto, Portugal and by JNICT PBCIC/2527/95.

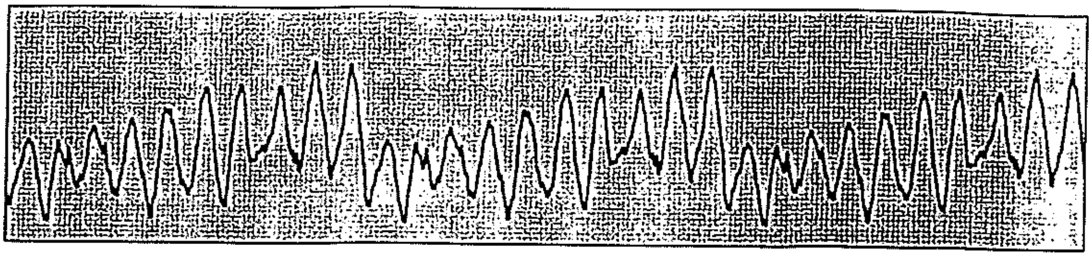
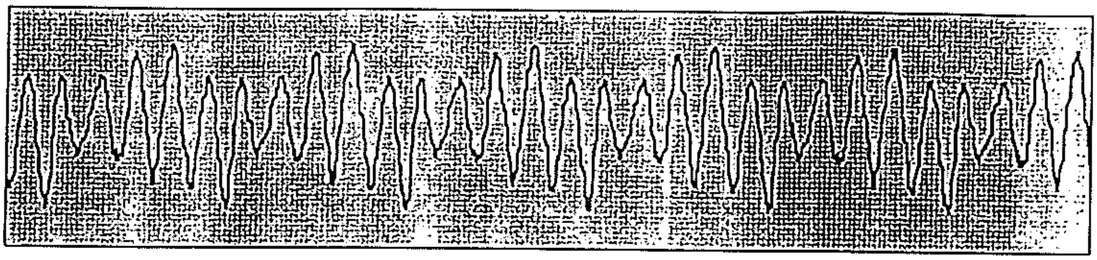
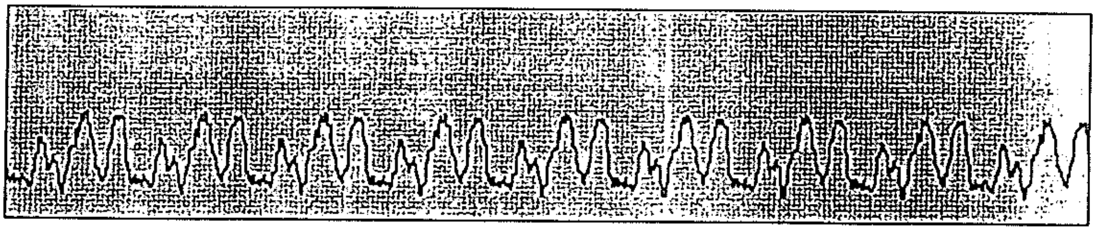


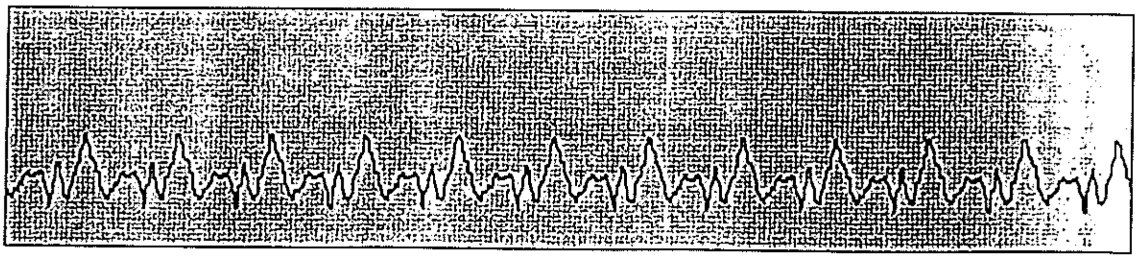
Figure 1 Periodic waveform of 1 Hz detected in EEG records (3 seconds), by crosscorrelation with Delta Dirac function of the same period, followed by averaging after phase sincronyzation. Condition of joy fantasies.



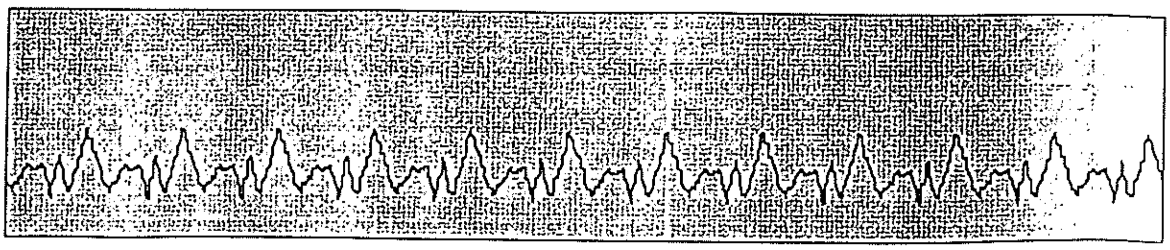
Periodic waveform of 2 Hz .



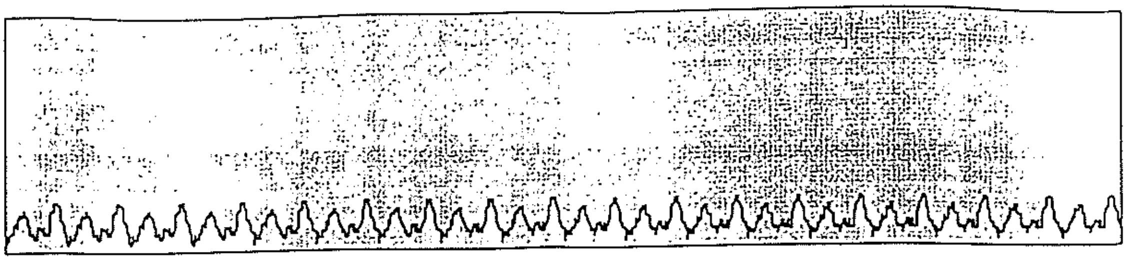
Periodic waveform of 3 Hz.



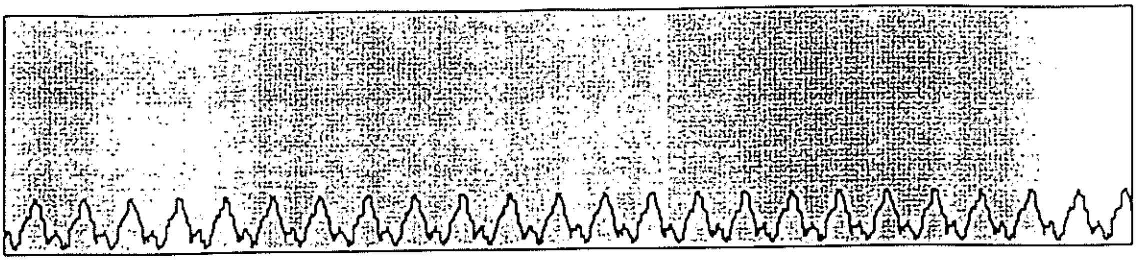
Periodic waveform of 4 HZ.



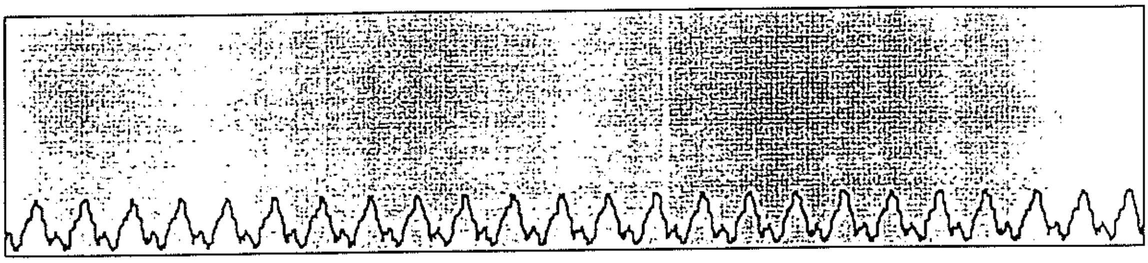
Periodic waveform of 5 Hz.



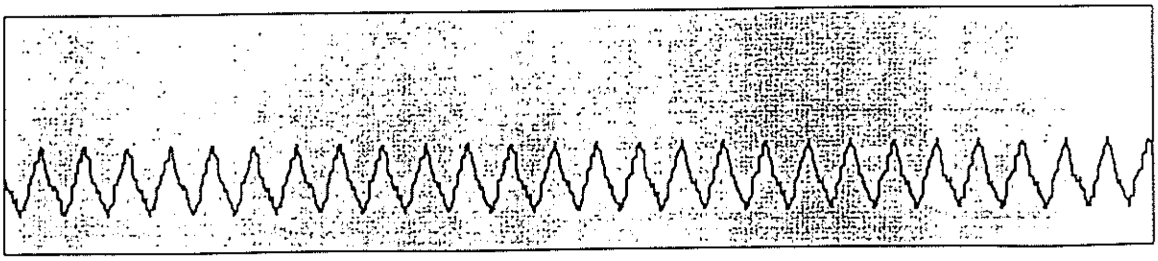
Periodic waveform of 6 Hz.



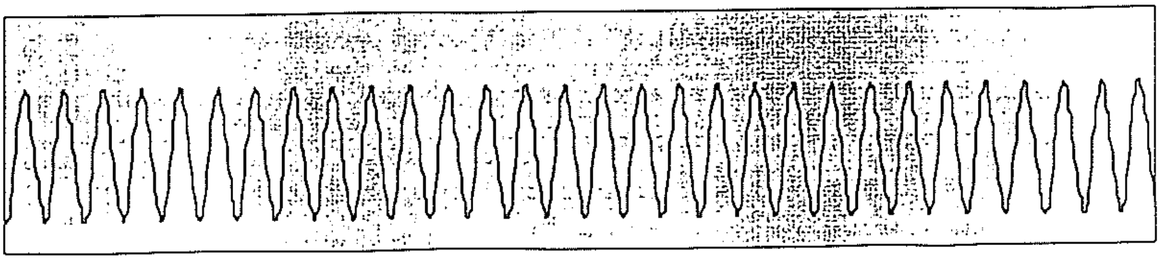
Periodic waveform of 7 Hz



Periodic waveform of 8 Hz

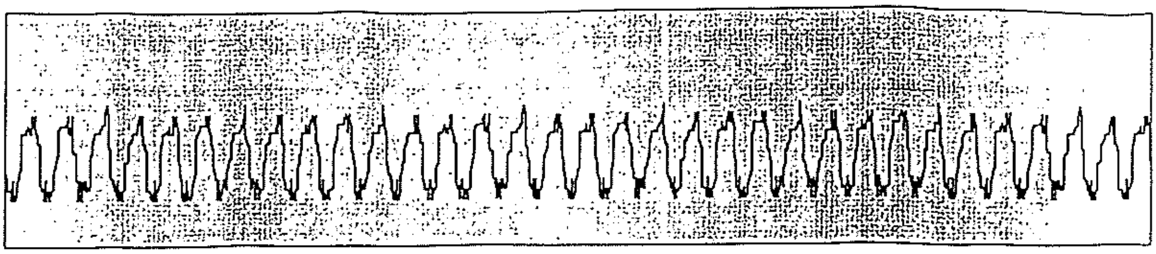


Periodic waveform of 9Hz

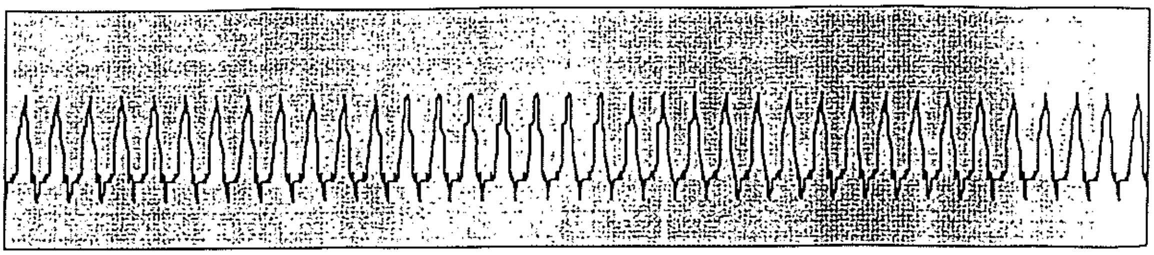


10 Periodic waveform of 10 Hz

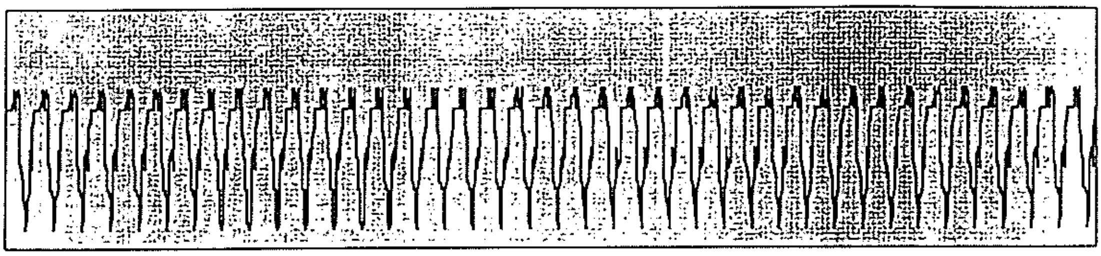
3



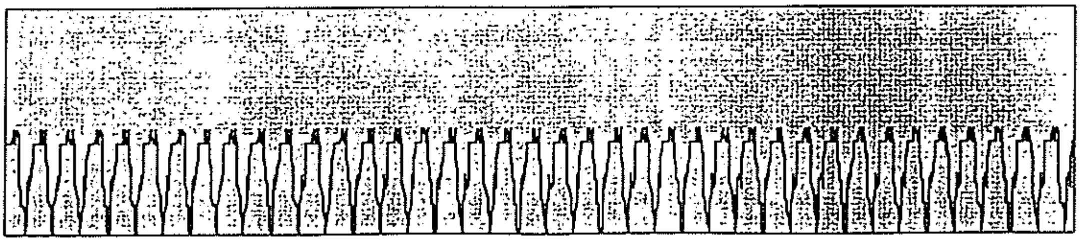
Periodic waveform of 11 Hz



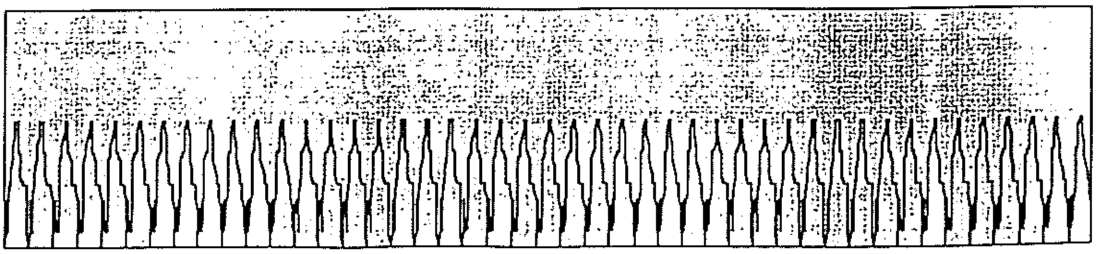
Periodic waveform of 12 Hz



Periodic waveform of 13 Hz



Periodic waveform of 14 Hz



Periodic waveform of 15 Hz

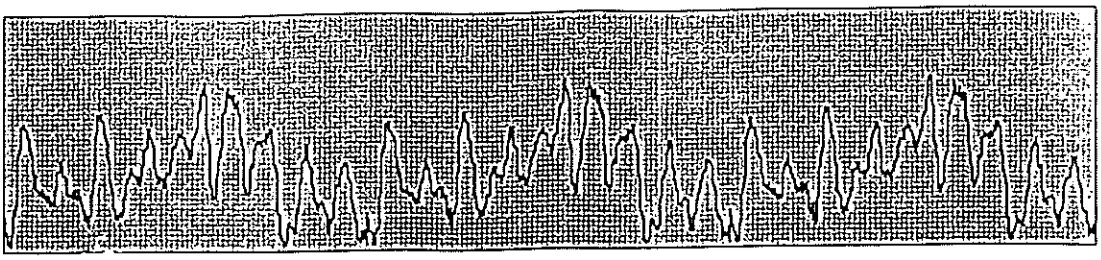
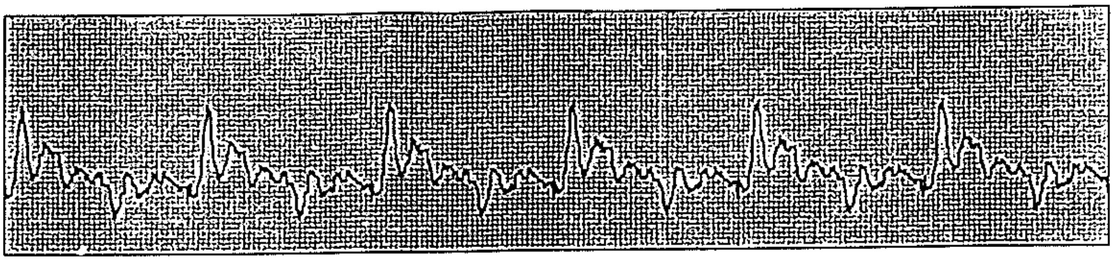
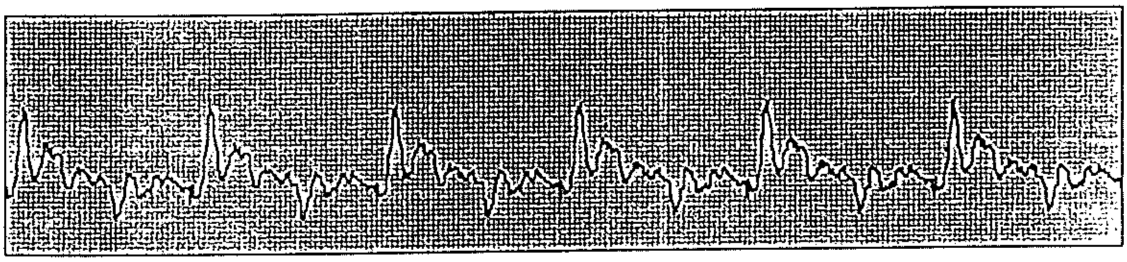


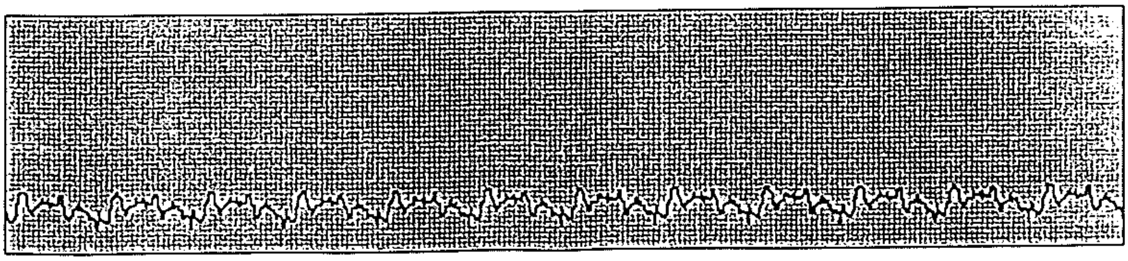
Figure 2 Periodic waveform of 1Hz detected in EEG records, sadness condition, same subject and same leads of the preceding figures



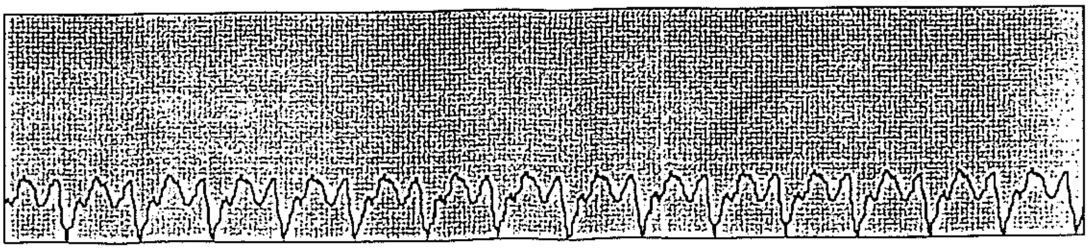
Periodic waveform of 2Hz, condition sadness.



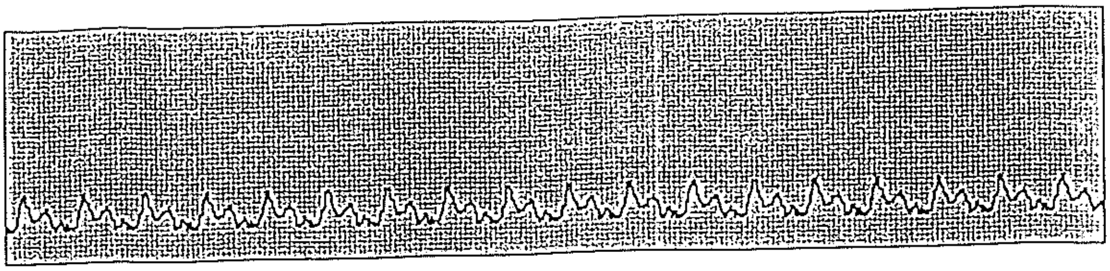
Periodic waveform of 3 Hz, condition sadness.



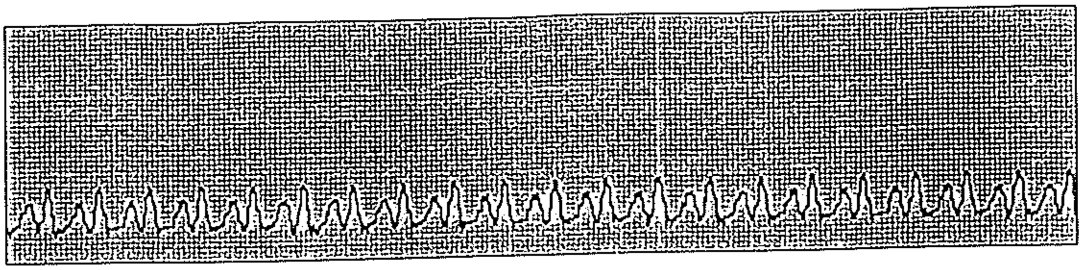
Periodic waveform of 4 Hz, condition sadness.



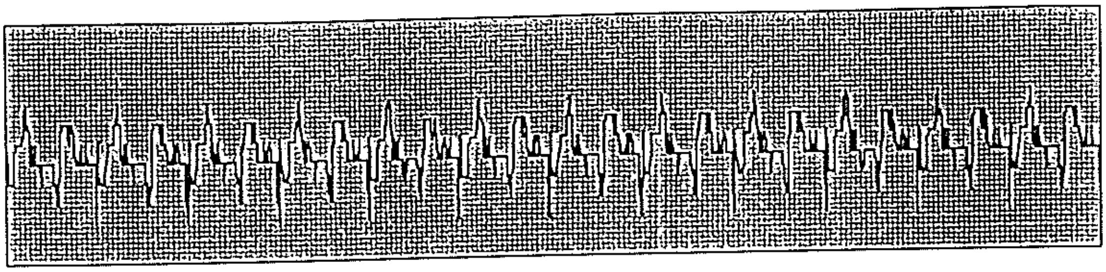
Periodic waveform of 5 Hz, condition sadness



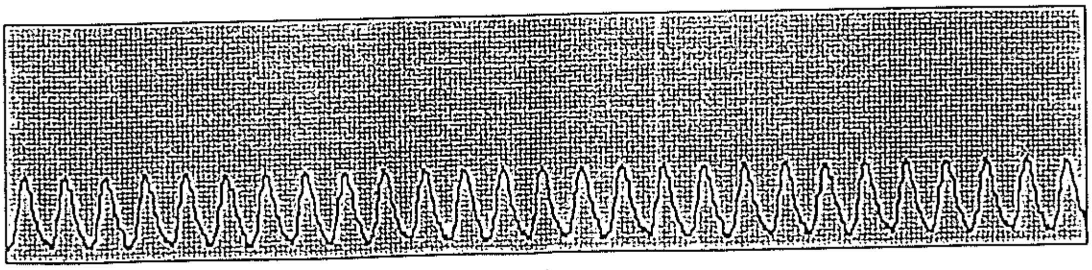
Periodic waveform of 6 Hz, condition sadness



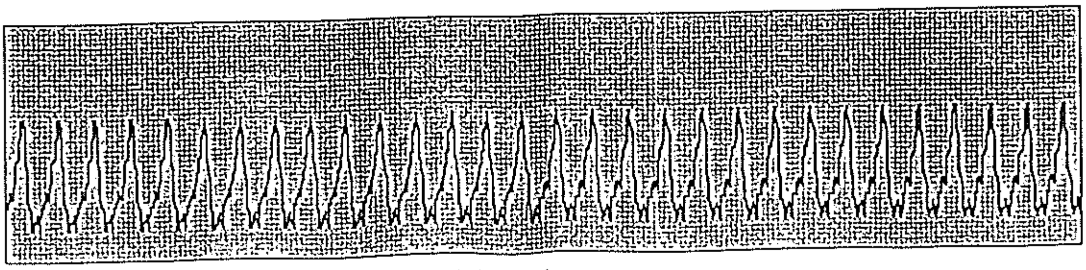
Periodic waveform of 7 Hz, condition sadness.



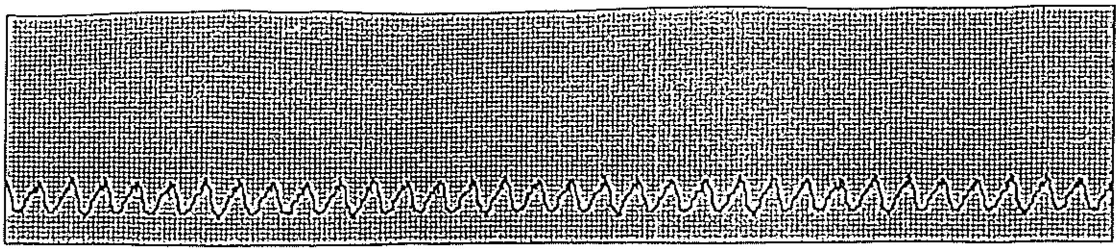
Periodic waveform of Hz, condition sadness



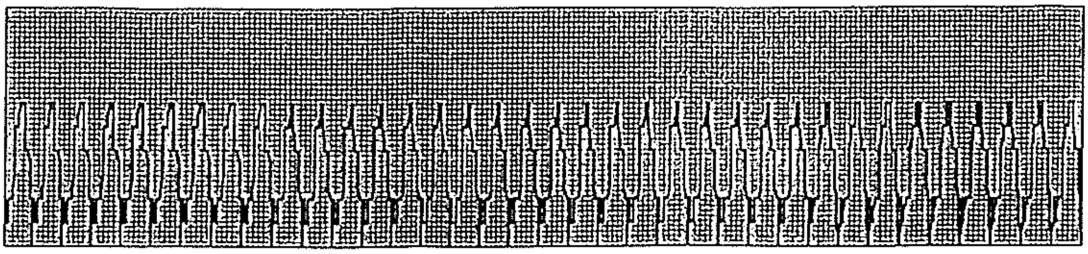
Periodic waveform of Hz, condition sadness.



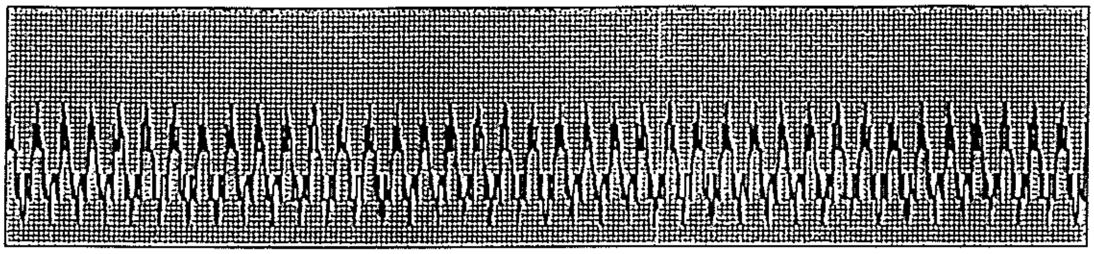
Periodic waveform of 10Hz, condition sadness



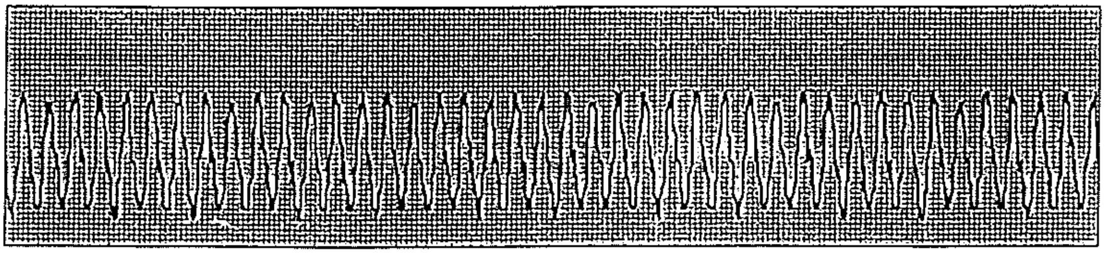
Periodic waveform of 11 Hz, condition sadness.



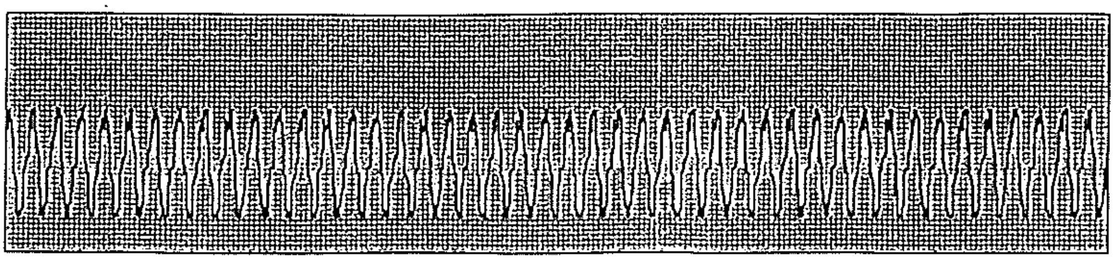
Periodic waveform of 12 Hz, condition sadness.



Periodic waveform of 13 Hz, condition sadness.



Periodic waveform of 14 Hz, condition sadness.



Periodic waveform of 15 Hz, condition sadness.

TABLES 1

MULTIVARIATE DISCRIMINANT ANALYSIS - LEFT FRONTO-TEMPORAL ANTERIOR LEADS
ANXIETY VERSUS RAGE

Symbols used in Plots

Symbol	Group	Label
1	13	ANXIETY
G	29	RAGE

All-groups stacked Histogram

Canonical Discriminant Function 1

```
      16 é                                          é
         °                                          °
         °                                          °
         °                                          °
      12 é                                          é
         °                                          °
         °                                          °
         °                          1               °
       8 é                          1               é
         °             GG           1               °
         °             GG           1               °
         °             GG           1               °
       4 é             GG           11              é
         °             GG       G   11              °
         °            GGGGG   G 11 1111             °
         °           GGGGGG  1G111111111            °
          XááááéááááéááááéááááéááááéááááéááááéááááX
        Out -6.0 -4.0 -2.0   .0  2.0  4.0  6.0    Out
  Class   GGGGGGGGGGGGGGGGGGGGG11111111111111111111
Centroids                G          1
```

Classification Results -

Actual Group	No. of Cases	Predicted Group Membership 13	29
Group 13 ANXIETY	25	24 96.0%	1 4.0%
Group 29	24	1 4.2%	23 95.8%

Percent of "grouped" cases correctly classified: 95.92%

Classification Processing Summary
- 49 Cases were processed.
- 0 Cases were excluded for missing or out-of-range group codes.
- 0 Cases had at least one missing discriminating variable.
- 49 Cases were used for printed output.

MULTIVARIATE DISCRIMINANT ANALYSIS - LEFT FRONTO TEMPORAL ANTERIOR LEADS
SADNESS VERSUS MISTRUST

Symbols used in Plots

Symbol	Group	Label
1	17	SADNESS
G	33	MISTRUST

```
                    All-groups stacked Histogram

                 Canonical Discriminant Function 1
      8 é                                              é
        °                                              °
        °                                              °
        °                                              °
      6 é                      G                       é
        °                      G                       °
        °                1     G  G                    °
        °                1     G  G                    °
      4 é                11   G1  G G                  é
        °                11   G1  G G                  °
        °                11  G11 GG GG                 °
        °                11  G11 GG GG                 °
      2 é               1111 111GGGGGGG                é
        °               1111 111GGGGGGG                °
        °               11111111GGGGGGG                °
        °               11111111GGGGGGG                °
         XáááááéáááááéáááááéáááááéáááááéáááááéáááááéáááááX
       Out -6.0 -4.0 -2.0    .0  2.0  4.0  6.0    Out
  Class    11111111111111111111GGGGGGGGGGGGGGGGGGGG
Centroids                   1      G
Page 119                           SPSS/PC+
```

Actual Group		No. of Cases	Predicted Group Membership 17	33
Group	1 SADNESS	23	22 95.7%	1 4.3%
Group	33 MISTRUST	25	2 8.0%	23 92.0%

Percent of "grouped" cases correctly classified: 93.75%

Classification Processing Summary
48 Cases were processed.
0 Cases were excluded for missing or out-of-range group codes.
0 Cases had at least one missing discriminating variable.
48 Cases were used for printed output.

MULTIVARIATE DISCRIMINANT ANALYSIS - RIGHT FRONTO TEMPORAL LEADS
ANXIETY VERSUS SADNESS

Symbols used in Plots

Symbol	Group	Label
1	9	ANXIETY
9	17	SADNESS

All-groups stacked Histogram

```
                 Canonical Discriminant Function 1
    16 é                                                      é
       °                                                      °
       °                                                      °
       °                                                      °
    12 é                                                      é
       °                                                      °
       °                                                      °
       °                                          9           °
     8 é          1                               9           é
       °          11                              9           °
       °          11                              9           °
       °          11                             99           °
     4 é          11                             99           é
       °          11                            999           °
       °         111 1                         9999           °
       °       1111111 1      1    9           99999   99     °
        XáááéáááéáááéáááéáááéáááéáááéáááéáááéáááéáááéáááéáááX
      Out -6.0 -4.0 -2.0   .0  2.0  4.0  6.0    Out
 Class   1111111111111111111111199999999999999999999
Centroids            1                   9
```

Classification Results -

Actual Group		No. of Cases	Predicted Group Membership 9	17
Group	9	24	23	1
			95.8%	4.2%
Group	17	23	0	23
			.0%	100.0%

Percent of "grouped" cases correctly classified: 97.87%

Classification Processing Summary
47 Cases were processed.
0 Cases were excluded for missing or out-of-range group codes.
0 Cases had at least one missing discriminating variable.
47 Cases were used for printed output.

TABLE 4

MULTIVARIATE DISCRIMINANT ANALYSIS - LEFT FRONTO-TEMPORAL ANTERIOR LEADS
JOY VERSUS ANXIETY

All-groups stacked Histogram

Canonical Discriminant Function 1

```
      16  é                                        é
          °                                        °
          °                                        °
          °                                        °
      12  é                                        é
          °                                        °
          °                                        °
          °                  9                     °
       8  é                  9                     é
          °                  9                     °
          °                  9                     °
          °                9 9 1                   °
       4  é              9999191   1               é
          °              9999191 9 1               °
          °              999911111111              °
          °           9  9919111111111 1           °
          XááááéááááéááááéááááéááááéááááéááááéááááX
        Out -6.0 -4.0 -2.0    .0  2.0  4.0  6.0    Out
  Class   9999999999999999999911111111111111111111
Centroids                   9    1
```

Classification Results -

Actual Group	No. of Cases	Predicted Group Membership 5	13
Group 5 JOY	26	19 73.1%	7 26.9%
Group 13 ANXIETY	25	1 4.0%	24 96.0%

Percent of "grouped" cases correctly classified: 84.31%

Classification Processing Summary
51 Cases were processed.
0 Cases were excluded for missing or out-of-range group codes.
0 Cases had at least one missing discriminating variable.
51 Cases were used for printed output.

TABLE 5

MULTIVARIATE DISCRIMINANT ANALYSIS - LEFT FRONTO TEMPORAL ANTERIOR LEA
ANXIETY VERSUS SADNESS

Symbols used in Plots

Symbol	Group	Label
1	13	ANXIETY
9	21	SADNESS

All-groups stacked Histogram

Canonical Discriminant Function 1

```
                                                                          é
      8 é                                                                 °
        °                                                                 °
        °                           9                                     °
        °                           9                                     °
      6 é                           9                                     é
        °                           9                                     °
        °                 19        99                                    °
        °                 19        99                                    °
      4 é                1111      999                                    é
        °                1111      999                                    °
        °               11111    9 999                                    °
        °               11111    9 999                                    °
      2 é              111111    9 9999                                   é
        °              111111    9 9999                                   °
        °             11111111999 1999       9                            °
        °             11111111999 1999       9                            °
         XááááéááááéááááéááááéááááéááááéááááéááááéááX
       Out -6.0 -4.0 -2.0     .0  2.0  4.0  6.0    Out
 Class    1111111111111111111199999999999999999999
Centroids                  1       9
```

Classification Results -

Actual Group	No. of Cases	Predicted Group Membership 13	21
Group 13 ANXIETY	25	24 96.0%	1 4.0%
Group 21 SADNESS	24	1 4.2%	23 95.8%

Percent of "grouped" cases correctly classified: 95.92%

Classification Processing Summary
- 49 Cases were processed.
- 0 Cases were excluded for missing or out-of-range group codes
- 0 Cases had at least one missing discriminating variable.
- 49 Cases were used for printed output.

TABLE 6

MULTIVARIATE DISCRIMINANT ANALYSIS - LEFT FRONTO - TEMPORAL ANTERIOR LEADS
ANXIETY VERSUS MISTRUST

Symbols used in Plots

Symbol	Group	Label
1	13	ANXIETY
0	37	MISTRUST

All-groups stacked Histogram

Canonical Discriminant Function 1

```
    20 é                     0                   é
       °                     0                   °
       °                     0                   °
       °                     0                   °
    15 é                     0                   é
       °                     0                   °
       °                     1                   °
       °                     1                   °
    10 é                     1                   é
       °                     1                   °
       °                     10                  °
       °                     10                  °
     5 é                    010                  é
       °                    011                  °
       °     0            11111                  °
       °    00      000 0111110 0    1          1 °
        XááááéááááéááááéááááéááááéááááéááááéááááX
     Out -3.0 -2.0 -1.0    .0  1.0  2.0  3.0   Out
 Class  0000000000000000000011111111111111111111
Centroids                  0  1
```

Classification Results -

Actual Group		No. of Cases	Predicted Group Membership 13	37
Group	13 ANXIETY	25	21 84.0%	4 16.0%
Group	37 MISTRUST	24	15 62.5%	9 37.5%

Percent of "grouped" cases correctly classified: 61.22%

Classification Processing Summary

49 Cases were processed.
0 Cases were excluded for missing or out-of-range group codes.
0 Cases had at least one missing discriminating variable.
49 Cases were used for printed output.