A CLOSED EEG FEEDBACK SYSTEM AND ITS CLINICAL APPLICATIONS IN TREATING NEUROLOGICAL DISORDERS

DHANJOO N. GHISTA
Biomedical Research Div., NASA, Ames Research Ctr., Moffett Field, Ca. 94035

T. M. SRINIVASAN, V. KAMATH and D. NANDAGOPAL
Biomedical Engineering Division, Indian Institute of Technology, Madras-36, India

and

B. RAMAMURTHI
Institute of Neurology, Government General Hospital, Madras-600 003, India

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In the conventional biofeedback technique, the subject is made aware of his own on-going physiological parameters like EEG, ECG, GSR, skin temperature, etc. The subject then achieves control over these parameters through volitional thought processes. Such a procedure requires cooperation and concentration on the part of the subject. Hence it cannot be conveniently and successfully employed for subjects who are non-cooperative as a result of being neurologically disordered.

This paper presents a novel, non-volitional EEG biofeedbacks set-up and technique. The procedure entails flashing a lamp (in front of the subject's closed eyes) or presenting an auditory signal in synchronism with the subject's filtered brain rhythms. Changes in EEG patterns are brought about by this technique. The associated subjective and physiological responses are recorded for normal and pathological subjects. For normal subjects, various frequency feedbacks elicit specific feelings ranging from depression (usually with delta feedback) to that of elation (usually with theta and alpha feedbacks). Among pathological subjects, epileptic subjects have also been rehabilitated; these subjects have had their abnormal brain discharges suppressed (with resulting disappearance of epileptic fits) with, generally, alpha and theta feedbacks.

I. INTRODUCTION

Biofeedback entails providing a person with information about his own on-going physiological processes through parameters such as EEG, ECG, GSR, etc. The subject is taught to consciously influence and hence control these parameters volitionally. This type of feedback may hence be classified as Volitional Biofeedback (VBF).

The available types of feedback signals include binary, analogue, percent time and integrated readouts. Binary signals are the simplest form of feedback, comprising a success-failure, good-bad, or yes-no signal which indicates success or failure in reaching a set threshold or criterion, but provides no absolute information. Binary displays frequently use either a light or tone signal. Analogue signals, however, provide information of actual signal levels of proportional changes in the signal, so the degree of success can be determined. Analogue display can use a calibrated meter or digital readout, or a proportional signal with light or with sound frequency.

Since EEG signals change so rapidly that analogue feedback can be confusing, an integrated, or averaged, level of electrical activity over a specified time period is often provided in addition to immediate binary or analogue cues. Here also, a percent time display can provide data by indicating the percentage of time the signal is above a specified threshold.
threshold in any period. The integrated and percent
time displays appear either digitally or on a panel
meter.

In the Autogenic feedback system of Green
et al. [1–3], the subjects were trained (over a
number of sessions) to control three physiological
variables, namely, to reduce muscular tension in
the forearm, to increase the percentage of alpha
rhythm in the occipital EEG wave pattern and to
increase the temperature of the fingers. In these
experiments, the subjects were made aware of the
finger temperature and muscle tension visually
(through meter deflection) and the percentage of
alpha and theta signals (present in EEG)
auditory (the presence of alpha was signaled by a tone of
900 Hz and that of theta by a tone of 400 Hz),
one at a time; sometimes, the increase in
percentage of alpha was also indicated by an increasing
column of light. The subjects learned to reduce the
meter deflection which was indicative of low muscle
tension and hence relaxation. Similarly, they
learned to produce increased percentage of alpha
and theta (in EEG) (associated with a stage of
well-being) by the same volitional feedback
training.

Several other similar systems, entailing awareness
and control of physiological variables on the part
of the subject, have also been devised [4]. The feed-
back system employed by Brown [5] entailed a
blue lamp activated by an RC circuit, which was
in turn triggered by EEG alpha activity. Here too,
the subjects were instructed to attempt to have
that ‘mental state’, which maintained and increased
the blue light intensity. It was reported that a
highly significant degree of enhanced alpha activity
was thus achieved. VBF procedures have also been
clinically utilised for the management of several
psychosomatic disorders [6–11].

II. CLOSED-LOOP NONVOLITIONAL EEG
BIOFEEDBACK SYSTEM (NVEF)

The biofeedback system developed and clinically
employed by us differs from the above described
information (volitional) feedback systems (VBF).
The VBF systems require conscious effort to
attain a desired physiological state. They hence
cannot be used in the case of subjects who are
either uncooperative or retarded. Therefore, a
closed-loop system has been developed, which
does not need the subject’s volitional or conscious
effort (and is hence termed as nonvolitional).

In our NVEF system, the parameters monitored
and selected for feedback are the various bands of
the subject’s EEG. The (visuo or audio) feedback
of certain spectra of EEG waves (after modulation
and transduction) to the brain results in inhibition
or facilitation (or enhancement) of certain
components of the signal, with consequent changes
in mental state. This technique is a form of externally
engineered auto stimulation (by modulation and
transduction of the EEG) of the signal generation
centers. Continuous stimulation over a long period
of time results in alteration of the characteristics of
these centers, so that even when the feedback
therapy is stopped, these brain centers continue
(having gone through a ‘learning’ process) to
perform in a fashion similar to when feedback
was applied.

As opposed to open-loop visuo or audio stimula-
tion, one of the principal EEG frequency bands
(such as, say, alpha or theta), biofeedback of a
component frequency band of the subject’s own
EEG signal has been found to be considerably
more effective. Apparently, feedback of a (trans-
duced) frequency component of a subject’s
EEG preferentially resonates the multi-oscillator
(4 in number for the 4 major frequency bands:
alpha, beta, theta, delta) EEG generation sys-
tem of the brain at the instantaneous natural frequency
of one of the oscillators (such as alpha or theta). Hence,
the EEG frequency response, at the follow-
ing instant, is appropriately modulated (with
associated subjective response), resulting in a
higher response of the resonating oscillator (or
in a higher output of the associated tone) in the
total EEG signal. In the case of our NVEF system,
it is the feedback of the identical EEG signal of
that particular oscillator which causes it to
resonate. This cannot be achieved by a mere
stimulation (in an open loop system) at a particular
frequency band (such as, say, the alpha or beta
frequency band).

Figure 1 presents the schematic of our CL/VBF
system. The EEG signal picked up by the scalp
electrodes of the subject is amplified and displayed
on four channels of an eight channel (Grass
Model 6) EEG machine; alternately, one or more of
these four channels are utilised for EMG and/or
ECG. The output of one of the EEG channels
from which feedback is to be achieved is taken
through a set of bandpass filters with 3 dB band-
widths corresponding to delta, theta, alpha and
beta bands (with frequencies 1–3 Hz, 4–7 Hz,
8–13 Hz and 14–25 Hz respectively). The outputs
of these filters are again displayed on the remaining four channels of the EEG machine. Any of the filtered components is selected, either in-phase or out of phase through a phase selector and again amplified. This amplified component is fed to a filament lamp or after suitable frequency translation to a pair of headphones.

For visual feedback, the filtered output is power amplified to drive a six watt filament lamp, whose intensity follows the amplitude of the selected component of the EEG. The lamp is placed in the visual field of the subject. Since the visual cortex is in the occipital area, the left and right occipital EEG is usually employed for monitoring, except in the case of epileptic subjects. The nomenclature of the feedback applied to a subject depends on EEG frequency band used; for example, alpha feedback denotes that the alpha filter output is connected to the lamp.

For auditory biofeedback, the system is similar to visual feedback, except that a frequency translation is necessary to drive the headphones. A carrier tone at 800 Hz is modulated by the amplitude of one of the filter outputs. Thus, the auditory output varies in amplitude and frequency around 800 Hz, depending on the feedback channel.

III. EXPERIMENTAL PROCEDURE FOR FEEDBACK EXPERIMENTS

A. The Experimental Set-up

The subject is made to rest in a comfortable position in the EEG laboratory. Left and right occipitals are monitored with respect to left and right ear and displayed on two channels of the EEG machine; (ECG or EMG) and respiration are generally monitored with the other two channels. The remaining four channels are utilised to record the four filters’ outputs corresponding to delta, theta, alpha and beta bands. The calibration and recordings of the EEG are carried out in the usual manner.

B. Biofeedback Procedure for Normal Subjects

The normal EEG of the subject (undergoing feedback) is recorded for 10 minutes. The amplitude distribution of the frequencies of the occipital EEG can be seen from the filter output channels. Then the output of each of the four filters is selected (both in phase and out of phase), in turn, for feedback application. In each case, feedback is given for three minutes, with the subject being unaware of the type of feedback. Then the feedback is stopped for two minutes and the subject is asked to report his feelings and experience during the feedback. Also, the effect of feedback on the EEG can be seen from the chart record. The increase or decrease in alpha, theta, delta and beta rhythms can be clearly seen from the record.

At the end of this period the frequency band and its phase for which the subject’s EEG response (increased alpha/theta) as well as subjective response are optimal are determined. Normally, the optimal subjective responses are ‘well-being’ characterised by mental tranquility and elation, etc. This particular feedback is again continued for 30 minutes, during which the subject’s physical behaviour is also observed. The changes in heart rate and respiration rate are also monitored continuously.

C. Biofeedback Procedure for Pathological Cases

The procedure is identical except that a psychological approach is used to obtain cooperation in allowing the electrodes to be fixed and in conducting the experiment. Also, repeated questioning of the subject’s experiences during biofeedback is avoided. Instead, in the case of a mentally depressed subject, the particular feedback which produces amplified alpha is given for 15 to 20 minutes, and thereafter regularly (on a long-term basis) until the subject is rehabilitated.

In the case of epilepsy, initially all 8 channels of the EEG machine are employed for recording EEG in the conventional manner. If a focus for epileptiform discharges is found, then that channel is also recorded during feedback. Theta, alpha, and beta feedbacks are then given, each for three minutes, and the changes in the EEG waveforms are noted. Usually, alpha feedback enhances the alpha content of the output waveform and suppresses low frequency, high voltage discharges. The optimum feedback is then selected which reverts the occipital EEG from epileptiform to normal waveform. Once this feedback type is determined for a patient, it is administered, in a 30 minute session, as a long-term therapy. The feedback is given daily at the beginning. If improvement is observed after one week, it is given on alternate days. The duration of feedback is usually 30 minutes. The subject is instructed to keep his eyes closed throughout the session.
BIO FEEDBACK SET UP

FIGURE 1 Schematic of our Biofeedback system.

EEG OF SUBJECT LH: BEFORE AND AFTER ALPHA FEEDBACK

FIGURE 2 Sample of EEG record of subject LH before and after feedback was switched on.

THIS SUBJECT LH HAS VIRTUALLY NO ALPHA IN HIS NORMAL EEG. HE ALSO REPORTED A FEELING OF ALOOFNESS. DURING ALPHA FEEDBACK (AND LONG AFTER THE FEEDBACK WAS STOPPED) HE GENERATED SUBSTANTIAL BURSTS OF HIGH AMPLITUDE ALPHA. QUOTING HIM, "I LOST MYSELF IN A VERY PLEASANT STATE AND FELT A SENSE OF ONENESS".
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FIGURE 3a  Sample record of subject PB before feedback.

FIGURE 3b  Sample EEG record of subject PB during feedback.
NORMAL EEG OF SUBJECT SNP

FILTERED OUTPUTS OF CHANNEL $O_2A_1$

THIS IS THE EEG OF A NORMAL SUBJECT SNP BEFORE FEEDBACK.

FIGURE 4a  Sample record of subject SNP before bio-feedback.

EEG OF SUBJECT SNP DURING ALPHA FEEDBACK

CHANNEL $O_2A_1$ IS FILTERED

THIS IS THE EEG OF THE NORMAL SUBJECT SNP.
NOTE THE CONSIDERABLY HIGHTENED "ALPHA".

FIGURE 4b  Sample record of subject SNP during feedback.
FIGURE 5  EEG Tracings of patient MS (on 9–26–74), (a) before, and (b) during visual alpha Biofeedback.
FIGURE 6  EEG Tracings of patient MS (on 10–21–74). (a) before and (b) during visual alpha Biofeedback.
FIGURE 7 EEG Tracings of patient S (on 3–19–75), (a) before, and (b) during visual alpha Biofeedback.
FIGURE 8  EEG Tracings of patient PN (on 2–20–75). (a) before, and (b) during visual alpha Biofeedback.
FIGURE 9 EEG Tracings of patient BJ (on 9–14–74). (a) before and (b) during visual alpha Biofeedback.
FIGURE 10  EEG Tracings of patient BJ (on 10–6–74), (a) before and (b) during visual alpha Biofeedback.
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THIS IS THE EEG OF AN EPILEPTIC SUBJECT AY (A TEN-YEAR OLD GIRL). NOTE THE HIGH VOLTAGE DELTA AND NEGLIGIBLE ALPHA. AFTER 2 WEEKS OF DAILY FEEDBACK, HER FITS REDUCED TO 1 OR 2 PER DAY. AFTER A MONTH OF FEEDBACK, SHE GOT A FIT EVERY ALTERNATE DAY. AFTER 6 WEEKS OF TREATMENT HER FITS DISAPPEARED.

FIGURE 11a Pretreatment sample EEG record of subject AY.

THIS IS THE EEG OF THE SUBJECT AY, DURING ALPHA FEEDBACK, AFTER 6 WEEKS OF FEEDBACK THERAPY; A NORMAL EEG, WITH EVEN CONSIDERABLE "THETA"!

FIGURE 11b Sample EEG record of subject AY after 40 days of feedback treatment.
IV. RESULTS

A. Normal Subjects

The majority of normal subjects reported feelings of elation, floating sensation, relaxation during feedback sessions. The alpha content of the EEG was increased substantially and persisted for several minutes after the feedback was discontinued.

Figures 2–4 (a and b) depict the effects of our visual biofeedback (NVEF) on a sample of three normal subjects. Their responses are depicted on the figures themselves as well as summarised in Table 1. The following observations are made regarding the response of these subjects:

1) Delta feedback reduces the alpha and increases the delta component. All subjects reported being irritated by this feedback, some even complaining of nausea and headache. On account of these observed negative effects, clinical trials of delta feedback were not undertaken.

2) Beta feedback increased the beta content of the EEG. Some subjects reported feeling ‘comfortable’ and a few subjects started sleeping during feedback.

3) Alpha feedback increased the alpha amplitude from 50% to 200%. ‘Well-being’ and ‘relaxed’ feelings were reported by most subjects.

4) Theta feedback produced vivid imagery. All subjects reported to be in an ‘elevated’ state and reported being ‘happy’ and ‘relaxed’ during the experiment.

B. Pathological Cases

Table II summarises the results-applications of our nonvolitional visual and audio biofeedback therapy to clinical cases (insomnia, depression and generalised epilepsy).

| TABLE I |
| Summary of the effect of alpha feedback on normal subjects |
| Subject | Resting EEG | During biofeedback | Subjective feeling during biofeedback |
| 1, LH | Very little alpha | 200% increase in alpha amplitude | Very comfortable, spiritual, floating |
| 2, SNP | Well formed alpha | Considerable increase in alpha | Comfortable |
| 3, PB | Normal alpha | | Feels like dancing. Responds to call stimuli. Likes to continue in the same state |

| TABLE II |
| Clinical use of NBF |
| Patient, age, sex | Observed disorder | Duration of feedback | Before feedback | Remarks |
| a) Visual biofeedback |
| 1. MS(28/f), mental depression, 6 months. | Patient non-cooperative in day to day activity of life. | Non-cooperative. | Significant improvement in behaviour and motivation. |
| 3. PN(35/m), obsessional neurosis, 3 months. | Average of 60 tremors per day. | | Cooperative. |
| 4. BJ(7/m), myoclonic epilepsy, 45 days. | One attack every 10 days. | | All pains are gone, according to the patient. |
| 5. K(35/m), generalized epilepsy, 5 months. | One attack every 2 days. | | Number of tremors reduced to 18. |
| 6. AM(26/m), generalized epilepsy, 6 months. | | | Drug dosage reduced by 20%. |
| b) Auditory biofeedback |
| 7. LAK(12/m), generalized epilepsy, 3 months. | One attack per day. | | One attack every three weeks. Gait and behaviour improved. |
| 8. E(25/m), generalized epilepsy. | No attacks. Mentally sub-normal, non-cooperative, slightly violent. | | One attack in 10 days. Drug dosage reduced by 25%. |
| | | | Improvement in behaviour. |
| | | | | cooperative. |
Patient M.S. Figures 5 (a and b), 6 (a and b). This patient was mentally depressed, functionally non-cooperative and restless at the beginning of therapy. Initially, there was little change in alpha during feedback. After about a month, the alpha output had grown steadily in amplitude. At the end of six months of therapy, she had improved in behaviour and motivation considerably.

Patient S. Figures 7 (a and b). This patient was mentally depressed and non-cooperative at the start of therapy. Her tenseness was characterised by her maintaining her right hand clenched when she first came in for biofeedback therapy. Hence, EMG from both the biceps were monitored. The subject was asked to relax for 15 minutes without feedback, with no change in EMG amplitude, as can be noted in Figure 7a. After 30 minutes of alpha visual feedback, muscular relaxation was achieved, as shown in Figure 7b. Further, with therapy the subject improved in behaviour and became cooperative in about a week’s time.

Patient P.N. Figures 8 (a and b). This patient complained of pains in the neck with symptoms of obsessional neurosis. His feedback EEG demonstrates (in Figure 8b) increased alpha band. Over a 3-month period, the patient had stopped complaining of pains and started attending his work with increased cooperation.

Patient B.J. Figures 9 (a and b) and 10 (a and b). This patient was suffering from myoclonic epilepsy, with an average of 60 tremors a day. His EEG showed considerable spike activity. As seen from Figures 9 (a and b), and 10 (a and b), the spike activity was considerably reduced with therapy. Correspondingly, his tremors decreased from 60 to 18 per day, and drugs (depressants) were reduced by 25%. Note also that (by comparing Figures 9 and 10) with prolonged treatment, the EEG of the patient, even without feedback, is almost normal, with little spike activity. This long term observed change is very significant for the efficacy of our NVEF treatment of epilepsy.

Patient A.Y. Figures 11 (a and b). This patient had generalised epilepsy and had an average of 10 fits per day prior to therapy. Note the high voltage (200 µ volts) delta and minimal alpha activity in her EEG record in Figure 11a. Her progress during the course of therapy is delineated on the figure itself. After two months of therapy, her EEG became normal and her fits disappeared altogether.

V. DISCUSSION

In our clinical experiments with the NVEF system, every effort was made to reduce the effects due to environmental and extraneous parameters. Thus, extraneous acoustical and visual stimuli were minimised. Initially, electro-oculogram have been monitored to ensure no large eye movements are present. The anxiety and uneasiness of the subject were minimised and an initial period of acclimatisation (usually three sittings, during which no feedback is given) was allowed. With all these precautions, a marked improvement in psychosomatic response of normal and pathological subjects have been observed along with changes in EEG waveform. It has thus been well established by us that our Nonvolitional EEG Biofeedback (NVEF) brings about changes in psychosomatic responses of an individual, and is also an effective therapy for patients with neurological disorders. In our experiments, the NVEF system was employed by us as well as by clinicians and technicians. The changes are independent of the operator and the environment. No volitional effort was required on the part of the subjects.

The advantages of this nonvolitional feedback system over conventional volitional types are many:

1) Since subject’s cooperation is not required, this therapy is useful for uncooperative patients.

2) Patients who are very young and/or uneducated can be treated in this method.

3) Changes in the EEG and behavioural responses of a patient can be brought about almost immediately through our NVEF.

REFERENCES


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