Brain Electrical Oscillations Signature Profile of Experiential Knowledge

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ABSTRACT

In memory systems, ‘remembering’ is more attributed to ‘experiential knowledge’ (EK), while ‘knowing’ is related to mere recognition. Brain signature(s) specific to remembering as distinct from knowing will have enormous applied value including its forensic use. The present study aims to determine the validity of a newly developed technique, Brain Electrical Oscillations Signature (BEOS), in differentiating the individuals with specific EK from those without. Sample consisted of an experimental group with 56 normal volunteers who participated in specific activities and a control group of 54 matched individuals who had only the knowledge of these activities without actual participation. EEG was recorded while each participant had a series of auditory presentations of short verbal statements related to the previous ‘activity session’. Results showed that the experimental group had significantly more EK scores than the control group. Receiver Operating Characteristics (ROC) curve revealed high sensitivity and specificity for the BEOS profiling system.

Key Words: Forensic science, Brain Electrical Oscillations Signature (BEOS), Neuro Signature System (NSS), probe, Experiential Knowledge (EK), remembrance, knowing, Receiver Operating Characteristics (ROC) curve, sensitivity, specificity.

Introduction

Information is retrieved from memory during recognition as well as remembrance of past personal episodes. Recognition of familiarity requires retrieval of information acquired in the past, which form a major spectrum of neural activities related to perception. Retrieval of past personal events, often called remembrance of autobiographical episodes, may take place intentionally and when cued by stimuli. In perception, the retrieved information facilitates recognition of entities of the external world (1), whereas in remembrance, the individual becomes aware of the retrieved information. All learning contributes to the knowledge bank, and retrieval from this source facilitates not only recognition of entities but also understanding of different aspects of relationship among entities across temporal and spatial dimensions. Mandler (2) differentiated between ‘knowing’ and ‘remembrance’ as two memory systems; and Tulving (3,4) further substantiated multiple memory systems. Functional neuroimaging studies have shown that brain activation during remembrance of autobiographical episodes is distinctly different from that seen in ‘knowing’. Studies report extensive ventral brain activation, including that of anterior cingulate cortex, orbitofrontal cortex, and medial temporal cortex during remembrance; while ‘knowing’ correlated mainly with smaller activation patterns in dorsofrontal prefrontal cortex (5-15). These studies have shown that ‘knowing’, especially that leading to recognition may engage minimal brain resources in comparison with remembrance of personal past events, which may have temporal and spatial references, sensory and motor mental imageries, and emotional experiences, which require extensive neural participation. Source memory provides the contextual, temporal, and spatial references required to correctly identify or locate the autobiographical episode for retrieval. Source memory has a different neural localization compared to the main autobiographical episode, as shown in various neuroimaging studies (16-28). Remembrance of an experience is almost like reliving the same experience when all its original components are recalled (29). Remembrance may therefore include recreation of sensory mental imageries (30-36), and motor mental imageries (37-43). As seen in these studies transcoded verbal details of the episode may be used for the recreation of the original mental imageries.

Moscovitch (44-47) described two types of retrieval processes. One is associative and dependent on cues whereas the other is strategic. Cue dependent retrieval is automatic and mandatory. Mostly external stimuli may serve as cues; the cue could be provided by a specific characteristic or meaning of a stimulus, which makes the person remember the past episode. Moscovitch described the cued retrieval both automatic and mandatory. Physical characteristics or semantically interpreted meaning may be considered to serves as cue for triggering the recall of the related information. The cueing effect is considered present only in one who is able to link the stimulus characteristic with a specific past experience or knowledge. The association of the cueing stimulus with the stored information may be logical or purely incidental. When there is no logical association present, a stimulus may serve as a cue for the recall of the specific information only in one in whom that specific association exists. A verbal statement referring to the episode often serves as the most efficient cue for one to retrieve the past event and become aware of it. Remembrance of experience is possible only for one who has had it and one can remember only an experience that one has had or believed to a have had. A cue or reference does not lead to the remembrance of an experience or participation in it if one did not take part or have the said experience.

Experiencing emotions during remembrance of personal episodes is well known in the day-to-day life for everyone. Retrieved emotions may almost equal the same original experience. Its intensity and duration may vary based on the personal significance of the original experience. Significant differences in the intensity, vividness, and components may exist from one remembrance to another in the same individual. Quality of remembrance of a shared experience or event witnessed may differ from individual to individual. The triggering of the remembrance may not be uniformly time locked to the cueing stimulus across stimuli, occasions, and individuals. There are frequent instances when one remembers a name or details of a personal event much later after receiving a triggering cue. None of these factors can be differentially known or predicted presently from outside by a measuring system. Remembrance is indeed a complex neurocognitive process unlike other cognitive processes such as arousal of attention, attentional allocation, recognition, and anticipation. Neuroimaging can indicate the brain areas activated during remembrance but it cannot be considered to reflect the subjective quality of remembrance. Similarly, a surface EEG recording is only a reflection of widespread neural activity within the brain and the changes that accompany processing related to cognitive and motor events. Remembrance of autobiographical episodes may be considered one of the complex cognitive states, as complex as experiencing itself, requiring extensive neural participation.

Brain electrophysiology studies have firmly established the role of electrical oscillations of the brain in cognitive states. Electrical oscillations of the neurons in multiple frequencies contribute to extensive electrical changes in the brain and Electroencephalograph (EEG) recorded from the scalp is a reflection of such changes generated from within. Oscillating neuronal networks producing synchronous activity represent the dynamic functional bridge between consciousness, cognitive processes, behavior, and neurons (48). In diseases affecting the brain and its functions, the electrical oscillations show significant changes and recording these abnormalities are now integral part of disease diagnosis and monitoring. Wealth of studies have shown the relationship between electrical oscillations and cognitive states representing perception, memory, and thinking (49-62). These studies have shown that generation of gamma, beta, alpha, theta, and delta frequencies are closely associated with different cognitive processing states. These studies have reported patterns in EEG frequency, power, and event related potentials in various cognitive processing conditions. There have been relatively fewer electrophysiological studies, which differentiated 'remembrance' from 'knowing'. Freidman & Johnson (63) in their review of ERP and functional neuroimaging studies compared the results from the two modes of investigation in explicit memory and found good correspondence between the results of the two types of studies. Recognition memory tested using ERP occurring around 300 ms after the stimulus onset could differentiate between old and new stimuli (63,64). ERP study by Curran et al. (65) using recognition of familiarity in words presented earlier in the study along with new words demonstrated the adverse effect of Medozolam, a pharmacological agent with specific effect to produce amnesia on recall of remembered words as shown by P300 and FN400 potentials. Remembrance of words alone was affected adversely in the drug condition of amnesia, whereas the condition did not affect recognition of familiarity of the words. The FN400 peaking at 400 ms in the midfrontal area is found to have different functional significance compared to the same peaking at 600 ms in the parietal area (66-72). Duzel et al. (61) compared remembrance and knowing using event related potentials during recognition of a list of words in normal subjects. Some of the words in the list referred to narratives of events presented in a prior session. They considered the earlier narrative to elicit "autonoetic" awareness by presenting event related words as against "noetic" awareness produced by new event unrelated words in the list. The ERP showed a distinct positivity in the 600 - 1000 ms range when narrative related words were presented indicating remembrance of the narrative, seen bilaterally predominantly in the frontal areas and lesser in the parietal areas, which was absent in the other conditions tested. They could differentiate between false and true remembrance, whereas mere false and true recognitions did not show such differentiation in the ERPs. In their subsequent study Duzel et al. (73), using both the PET and the ERP, the neural profiles of information recall related to past episodic tasks was compared with the recalls in semantic tasks. Episodic retrieval was found to be associated with activation in the right prefrontal cortex and posterior cingulate cortex in the PET and sustained frontopolar positivity in the ERP recordings. Semantic recall was found to be associated with the typical left frontal and temporal activation seen in other studies. The late positivity seen (61) in the time domain analyses of remembrance data represented an increase in the slow oscillations in the EEG. Attending to or being aware of internal cognitive processing as in remembering needs one to look away from the external world/stimuli, thereby blocking its perception transiently so that attention can be directed inward to the internal processing. Such inward attention may also be required for the recreation of mental imageries and thoughts and for selectively attending to them for further processing. Harmony et al. (62) and Fernandez et al. (57) elicited evidence for such specific association of delta band frequencies with awareness of internal processing. Robinson (60) in his study indicated that 4 Hz activity is related to behavioral arousal, which is negatively related to 10 Hz activity. The importance of frequency bands in the theta and alpha ranges have been demonstrated in several studies. Klimesch et al. (58) suggested that synchronization of theta and alpha frequencies across distant neural areas is for specific processing of internal mental contexts during cognitive processing. Klimesch et al. (59) indicated that theta oscillations represent hippocampal engagement required for retrieving from long term cell assemblies in episodic memory recalls. The role of gamma activity in the 35 – 85 Hz range during retrieval of information, especially visual mental imageries has been demonstrated in several studies (49-51,53,55,56,74,75). The frontal participation is associated with the use and recall of the verbally transcoded information using which the visual the mental imagery can be reconstituted, which is accomplished in the posterior areas.

The purpose of the present study was to determine the sensitivity-specificity and other related characteristics of the technique called Brain Electrical Oscillations Signature (BEOS) profiling developed by Mukundan CR (Patent application pending) for identifying individuals with specific autobiographical episodes or experience. Specially designed verbal statements presented as probes in auditory mode referred to the participation of the individual in an activity specially designed for the test. The test recorded the electrical activity from the scalp of a subject using multiple electrodes and computed the changes in the activity while listening to the list of probes. The probes were expected to provoke or trigger the remembrance of the experience only in those who participated in the referred activities. If knowledge of the experience was present, the BEOS profiling extracted the accompanying remembrance specific changes in the electrical oscillations. “Signature” refers to a set of specific changes defined as markers of the process of remembrance. The changes are not expected to be time locked as in other ERP paradigms, as remembrance and the accompanying changes may occur at varying latencies.

The word ‘provoked’ or ‘triggered’ is preferred to ‘induced’ for referring to the neural activity and the electrical changes accompanying remembrance using the present probe presentation method, as the changes will not be induced in all subjects. The probe would serve as a cue only if it provides a contextual reference and triggers the retrieval of a linked past event. Further, this can happen only if the event itself has a personal significance to the subject and therefore has the chance to be retrieved. A cue may not work if the original experience does not have any personal significance and if one does not remember it. The triggering effect of a probe may be incidental and not logical as it makes meaning only to the person who has had the experience and finds an association between the cue and components of the experience. Probes are statements referring to the alleged involvement and direct participation in an activity by a subject. The system presented a recorded version of sequentially arranged probes at fixed intervals. Several probes arranged sequentially as ‘Scenarios’ directly refer to the different components/phases of the event. The sequentially presented probes form a ‘stream of thought’ (76-79) in the listener, in which the central idea moves from one to another in sequence, with reference to the context whenever possible. Words are selected carefully for maintaining the core theme and the contextual reference intact though out, in which verbal awareness of experiences (80,81) is used to trigger remembrance of the original experience. The subject is instructed to remain with eyes closed and without movement, and need only listen to the probes without giving any response. The subject is also given opportunity to either read through or listen to the list of the probes before they are presented during the BEOS recording. This eliminates novelty effects and other possible emotional responses related to listening to the probes for the first time. BEOS profiling records the electrical activity associated with the presentation of a probe from multiple channels and compares the changes in each channel with the preprobe baseline, and identifies specific predefined patterns in the changes. The probes are presented one after the other and continuous EEG with probe details is acquired. The study aimed at identifying individuals who had a specific experience by differentiating them from those who had only knowledge of the activities. The comparison of the responses of the two groups in the analyzed results of the BEOS profiles, using the same set of probes, signal processing, and analysis of the results helps in the computation of sensitivity, specificity, and related factors.

Methods

Participants

The study consisted of comparison of the brain electrical activities of subjects in an experimental group with that of a control group, recorded while each subject listened to a list of probes referring to activities, which the subjects in the experimental group had carried out whereas the control group subjects had only knowledge. The research staff identified volunteers from normal population who lived in the same city within a radius of about 5 kilometers. Those who volunteered for the study were invited for a selection process in the laboratory. Subjects were selected from ages 15 to 70 yrs and both male and female volunteers were included in the study. Informed consent was obtained from all participants, and ethical aspects of the project were monitored by the research monitoring committee. The experimental procedure of this study was in accordance with the recent version of the Ethical guidelines for Biomedical Research on Human Participants as mandated by the Indian Council for Medical Research (ICMR) (82).

Materials and Design

To begin with, each was administered the General Health Questionnaire (83) for a quick screening for the absence of psychiatric morbidity. This was done by the Indian standardized version of GHQ-12 (84). The selected subject was randomly assigned to the experimental or control group. Immediately after obtaining a written informed consent for the study, each subject was tested by s small battery of psychological tests. Intelligence was assessed using J.C. Raven's Standard Progressive Matrices and learning, and memory functions using the Learning & Memory Functions subscale from the NIMHANS Neuropsychological Tests battery (85). The percentile scores on the progressive matrices test was taken to indicate fluid intelligence based on complex abstract reasoning. The Learning & Memory Functions test has a verbal and visual form. In the verbal form, a passage is read out to the subject, which the subject must recall immediately. The same passage is read again in a second and third trial, with immediate recalls in both the trials for assessing the learning function. In a fourth trial, which followed the third trial, the subject is instructed to recall the same passage from memory after an interval of 10 minutes. The visual form consisted of a complex figure, which was administered in the same manner as the verbal test. The number of units of information recalled formed the sores for each trial in the verbal and visual forms. Of the 120 subjects who were initially identified and selected for the study, 110 completed the BEOS profiling. The experimental group consisted of 56 volunteers and the control group had 54 subjects. Table 1 gives the means and SDs of the age and scores of various tests administered.

Procedure

After the completion of the psychological tests, each subject in the experimental group was assigned a specially designed task consisting of activities to be carried out in a designated room, as per an instruction booklet. A video recording of the activities of the experimental subjects in the 'activity room' was not carried out as several subjects refused video recording of their movements in the room while obtaining the informed consent. According to the instructions, 'the subject retrieved a key for the test room, opened the 'activity room', switched on the lights in the dark room, and inspected the contents in the room'. As per the instructions, the subject 'searched and retrieved an iron rod from a locked cupboard, used it to break a large clay piggy back, which needed to be hit hard for breaking, and then collected large number of coins and some chocolates that dropped out of the pot. The coins were collected in a plastic bag and the broken parts of the piggy bank in another plastic bag. The room was cleaned by using a broom kept in the room, and the plastic bag containing the broken pieces of the piggy bank was disposed off in a wastepaper basket in the corner of the room. The subject switched off the lights, locked the room, and left the room with the coins and the chocolates.' A research staff later examined the 'activity room' looking for evidence of breakage of the piggy bank and for ascertaining that the coins were removed. The subjects in the control group were given the instruction booklet and requested to study the contents. Subjects in both the groups were administered BEOS profiling using list of probes referring to the activities carried out by the experimental group subject in the ‘activity room’. The BEOS profiling was done 2-3 weeks after the subject took part in the above activity.

Probes

The probes referred to the different components of the activity carried out by the subjects, in the sequence in which the activities were deemed to have taken place. The probes that directly refer to the test room activities are called the Target probes. Additionally there were two sets of probes called the neutral probes as they measured the baseline changes due to semantic interpretation and also the effects of impersonal mental imageries. Two more sets of probes may be used when the test is used for forensic purposes. One set called the control probes are probes referring to significant events in the personal life of the subject. The positive findings on the control probes serve for self-validation of the technique as they refer to events that indeed took place. The fourth set called the Target-B probes may refer to an alternate version(s) of events, which are opposed to subject’s involvement as stipulated in the Target A set of probes. In the present investigation, there were no control probes, as they required in-depth interview and independent verification of the information provided by each subject about the personal past. There was no scope for the Target-B probes in the present study. The activities carried out in the ‘activity room’ by a subject form the basis for the Target-A probes. A ‘scenario’ consisted of a set robes referring to one set or phase of activity, as envisaged by the examiner. Each probe was assigned a code according to the guidelines provided in the NSS manual. A code is assigned based on what the examiner expects the probe to provoke in a subject who listens to it. For example, a set of codes would direct the program to look for pattern indicating presence of sensory mental imagery, whereas another set of codes directs the program to look for patterns indicating presence of motor mental imagery. A third set of codes directed the program not to look for changes defined related to either type of mental imageries. Use of the codes increases the specificity of changes looked for in the analysis, as the program decides on the presence of ‘experiential knowledge’ only when it identifies the pattern associated with the respective code.

The length of each probe varies in terms of the number of words, the language used, and the speed of articulation used for its oral presentation. The purpose of a probe is to serve as cue for the retrieval of an associated memory, if present, and not for its mere semantic interpretation. The probes are presented in the language most comfortable to a subject. An audio presentation in different languages may last for different durations. The duration of a probe is kept within a maximum duration of 3.5 sec and the shortest statement may have two words. Though the speed of recording of words can be varied minimally depending on subject’s preferences, a constant speed was used for al subjects who were presented with probes in one language. Each probe is presented in first person as “I read the instructions”, “I walked to the test room”, “I opened the lock,” etc. The probe is read out for recording without any emotional effects. Male or female voices are used for recording depending on the gender of the subject to be tested. Probes were presented in Gujarati, Hindi, or English, as the subjects of the study preferred one of these languages.

The probes were typed into the computer in English. If the probes were presented in any other language to a subject, the articulated speech sounds were converted into English and entered. The Visual and Auditory Stimulus Program (VASP) of the Neuro Signature System (NSS) used for BEOS profiling recorded them into the computer for audio presentation. The VASP marks each probe with the necessary event markers and allows adjustment of the interval between consecutive probes. The probes were arranged in nine scenarios. The first two scenarios consisted of list of neutral probes (4 and 6 probes). The next six scenarios contained list of probes related to sequence of activities in the ‘activity room’. They were Scenario 3 (12 probes) related to visiting the laboratory and being given the instruction booklet, Scenario 4 (7 probes) related to entering the locked room, Scenario 5 (13 probes) of observing the objects in the ‘activity room’, Scenario 6 (12 probes) related to deciding the action strategy, Scenario 7 (8 probes) related to breaking the piggy bank and collecting the coins, and Scenario 8 (16 probes) related to cleaning up and leaving the room. A ninth scenario had probes (13 probes) related to the visit to the laboratory, undertaking psychological tests, and some irrelevant probes related to watching cricket on video. Each subject read the list of probes before the test.

The examiner informed each before starting the BEOS profiling that they have to recall the probes after completing the recording. After recording the EEG with the eyes open and closed conditions for 3 minutes each, and before starting the presentation of the probes, a frame by frame video display of the objects in the ‘activity room’ was made to the subject on a computer screen. They were informed that the video display was of the objects in the ‘activity room’ and they were merely to watch the display without making any response. This gave the subjects of the experimental group opportunity to recognize the objects and remember what they did in the ‘activity room’, whereas there was no question of such recognition for the subjects in the control group, though they readily recognized them as otherwise familiar objects. They also knew that the display was of objects in the ‘activity room’ about which they had read about in the instruction booklet. The video display can prime the memory of the objects and activities in the 'activity room' in the experimental subjects. It may even prime such memories in the control subjects if they had any prior significant experience relating them. In the absence of any such event, the display could only lead to new perceptions of familiar objects about which some information was already provided in the instruction booklet. The probes were presented to the subject at 80 dB level, through a sound system placed a meter away from the subject. The subjects sat through with the eyes closed and listened to them while continuous acquiring of the EEG. All subjects went through a post-test interview. Last 22 subjects of the control group completed a post-test rating of the familiarity of the probes in terms of their reference to the objects and events in their personal life. They rated each probe on total strangeness, minimal, moderate, and maximum levels of personal reference.

EEG recording

The command for presentation of a probe is sent by the NSS while monitoring the online EEG of the suspect. Thirty channels of NSS acquire the EEG using a custom-made Electrocap with linked earlobe electrodes as reference. The EEG was recorded from Fp1, AF3, F7, F3, FT7, FC3, T3, C3, TP7, T5, CP3, P3, O1, Fp2, AF4, F8, F4, FT8, FC4, T4, C4, TP8, T6, CP4, P4, O2, Fz, FCz, Cz, CPz electrode sites. Additional two channels were used for recording vertical and horizontal eye movements. The bandwidth used for EEG acquisition was 0.16 - 100 Hz without any other hardware filtering. The online EEG was analyzed for energy spectrum and the values were used for online control of probe presentation. These values were displayed as brain maps. The NSS uses a program by which a probe is presented only if the power values in different frequency ranges are within preset ranges as derived from the EEG of the eyes closed condition of the subject. If the value in any frequency range is outside the preset percentage range, the probe presentation is delayed until the value returns to the optimum range. Continuous delay warns the examiner of the event and the consequent stoppage of probe presentation. The continuous video of the subject recorded from the front of the subject, and the audio presentation of the probes as heard by the subject and the orthographic form of the probe were recorded in the NSS along with the EEG, all of which were time locked to each other and encrypted to form a single file. The output data file cannot be opened for any alteration of its components and the raw data file alone is always automatically selected for analysis. At the end of the recording after presentation of all the probes, the acquired data is saved into a file and automatically converted into an epoch file of 10 sec each, with 3 sec of data prior to the probe, and 7 sec data from the onset of the probe. The beginning and end of each probe are marked in the epoch.

Signal Processing and Data Analysis

Before starting the auto-analysis, visual analysis of the entire EEG record of each subject revealed adequacy of recording in all channels and absence of continuous artifacts and fluctuations, which may render the recording not suitable for analysis. Occasional movement artifacts would have been already detected and reported on the screen against each probe in each epoch. To start the auto-analysis, the user must enter the scenario numbers of the neutral probes. The analyses consist of systematic and complex procedures involving computation of power-coherence measures and detection of positive and negative responses in the frequency-time data of each probe.

The moving window analysis program first compute the baseline parameters and then determines the changes in the response segments and extracts predefined patterns if they are present. The program automatically carries out the entire sequence of signal processing, detection of predefines responses, their statistical analyses, interpretations, and report generation. Based on the significant findings from the statistical analyses, the program interprets the pattern of response detected with each probe and generates a comprehensive report. The user has no role in the entire analysis except initiating it. It is important to reject the data before analysis if it is visually unsuitable for the same.

A pattern of electrical oscillations accompanied by time domain changes identified by the program during the presentation or immediately after the presentation of a probe indicates presence of Experiential Knowledge. The authors have willfully suppressed the technical details of the analyses as required and directed by the pending patent application for this technology. A result screen displays the summary of all the analyses. The results of all the statistical analyses are available for the user in text format in different files. The program also produces several thousands of brain maps and histograms of power spectrum and amplitude values for visual inspection and comparisons. The program makes interpretations as per the inbuilt algorithm for significant specific changes detected. When the pattern required for the identification of Experiential Knowledge (EK) response is absent, the program interprets the identified pattern as one of the cognitive processing stages viz. (1) Inattention (2) Primary Processing, (3) Encoding, (4) Emotional Response, (5) Activity Suppression, and (6) Familiarity. Primary processing and encoding are sequential cognitive processes required for understanding the meaning of the probe, which may lead to retrieval of experiential knowledge. Inattention represents absence of changes related to the presence of sensory processing in the EEG or absence of primary processing and subsequent further processing. Similarly encoding represents absence of changes beyond the process of predefined changes indicating semantic interpretation. Activity suppression is defined to denote significant decrease in the power in different frequencies in the sequence of data segments. Emotional response is defined to represent similar changes as in activation suppression though significant changes representing primary processing and encoding is present. Familiarity denotes presence of topographically significant negative-positive components seen during or after the presentation of a probe. However, none of these can be directly compared to the presence or absence of regular ERP components obtained after data averaging and recorded with stimuli of equal duration. Further developmental research for their validation is in progress, and these results are not directly relevant for the purpose of the present study related to sensitivity and specificity measures and hence attempt is not made for a discussion of these results. The program comes out of the analysis loop if conditions for the presence of any of these stages are absent, in which case it reports the last satisfactorily resolved processing stage. “Experiential Knowledge” (EK) is reported if all the assigned stages are satisfactorily identified by the program. After the automatic analysis, the program prints out a report giving details of the scenarios, probes, their codes, and the results of individual analysis of the probe, as well as list of all preset conditions used for analyses. Additional report can be printed out which arranges the probes in terms of relative strength of the activity related to EK, which gives a comprehensive profile of the individual’s experiences related to the actions and events referred by each probe. However, scores on these measures are not used for the current analysis.

Table 1

Mean and SD scores of sample variables in Experimental and Control Groups.

Variable	Experimental Group		Control Group		Sig
	Mean	SD	Mean	SD	
Age (in yrs)	36.8	16.0	36.9	14.8	NS
Sex	*Male = 30* *Female = 26*		*Male = 28* *Female =26*		NS
Education (in yrs)	13.94	2.49	14.81	2.39	NS
Verbal Memory Trial 1	8.2	3.5	9.5	3.9	NS
Verbal Memory Trial 2	12.1	3.5	12.9	3.6	NS
Verbal Memory Trial 3	13.8	3.6	15.4	3.0	NS
Verbal Memory Delayed	13.7	3.0	14.4	3.3	NS
Visual Memory Trial 1	7.7	3.3	7.4	3.3	NS
Visual Memory Trial 2	11.9	4.0	11.5	4.4	NS
Visual Memory Trial 3	16.0	4.6	15.0	4.9	NS
Visual Memory Delayed	15.8	4.7	14.9	5.1	NS
SPM Percentile Score	73.8	12.9	74.4	13.1	NS

Results

The score considered for the comparison of the two groups is the number of EK responses produced by each subject in the BEOS profiling. The results of statistical analysis of the scores on age, education and the results of the psychological tests in the two groups are presented in Table 1. These results show that the two groups were comparable on these measures and any significant difference seen in the mean EK scores of the two groups cannot be attributed to differences in the basic sample characteristics considered here. After an initial scenario wise comparison of the EK scores in the two groups, Receiver Operating Characteristics Curve is computed using the total EK scores in the two groups.

After the analysis of the EEG by the BEOS profiling program, the number of probes eliciting Experiential Knowledge was counted in each scenario for each subject in the two groups. Three sets of EK scores were derived for each subject, viz., 1) total EK scores for scenarios 3 to 8 related to the activity in the 'activity room', 2) total EK scores in sequence in scenarios 3 to 8, and 3) total EK scores for the scenario 9. A sequence is defined to be present when a scenario has two or more probes showing EK responses. Table 2 shows the mean and SD of the total EK scores for Scenarios 3-8, total, and total within sequences, as well as the results of One Way ANOVA between the two groups.

Table 2

Mean and SD scores of EK responses in Scenarios and F values in one-way ANOVA between the EXP and CTL groups.

	EXP Group		CTL Group		F	Sig[§]
	Mean	S.D.	Mean	S.D.		
EK in Scenario 3	1.77	1.22	0.50	0.69	44.40	0.0000
EK in Scenario 4	0.68	0.81	0.17	0.38	17.80	0.0001
EK in Scenario 5	2.00	1.25	0.50	0.69	59.91	0.0000
EK in Scenario 6	1.70	1.25	0.41	0.53	48.90	0.0000
EK in Scenario 7	1.27	1.00	0.39	0.53	32.86	0.0000
EK in Scenario 8	1.98	1.34	0.59	0.79	43.42	0.0000
EK in Scenario 9	1.84	1.39	0.43	0.63	46.79	0.0000
EK in Scenarios 3-8	9.29	2.87	2.56	1.81	214.57	0.0000
EK in Sequence in Scenarios 3 - 8	7.64	3.64	0.78	1.21	173.57	0.0000

[§] Significance level was adjusted after Bonferroni correction for multiple comparisons.

Significant differences exist between the mean scores of the experimental and control groups in various scenarios and their combinations as shown in the Table 2. The experimental group has significantly higher EK scores independently in all the scenarios, totally, and totally within the sequence as defined earlier. Scenarios 2 to 8 have probes related to the activities carried out only by the subjects in the experimental group. Scenario 9 presented at the end of 68 ‘activity’ related probes, elicited significantly greater number of EK responses in the experimental group compared to the control group despite the fact that at least 7 probes in the scenario 9 referred to some of the activities that were common to the subjects in both the groups. The difference in the mean scores between the two groups in each scenario is remarkably significant in all comparisons.

Receiver Operating Characteristic (ROC) Curve analysis was carried out using the SPSS version 10, on the EK scores of the two groups for computing the sensitivity and specificity related values of the test for identifying and differentiating the subjects in the two groups. Figures 1 and 2 show the ROC Curves computed with total EK scores and EK scores within each scenario, and total EK scores in sequences. The table provides the sensitivity and specificity values of the test for the different cut off scores of EK. With a cut off score of EK at ≥ 5.5 the test could discriminate the two groups with a sensitivity at 0.91 and specificity at 0.94 (Table 3). The False Positivity and Negativity scores were 0.07 and 0.91 respectively. The test has Positive and Negative Predictive Values of 0.93 and 0.93 respectively at this level of sensitivity/specificity. Mean values of total EK scores less than this cut off value reduce the sensitivity and specificity values of the test. Mean values greater than 5.5 increases the specificity but markedly reduces the sensitivity of the test, as could be seen in the Table 3. The mean value of the total number of EKs in sequences within the scenarios 3 to 8 is a superior measure that discriminated the two groups (Table 4). With a smaller (≥ 2.5) mean cutoff score of total EK scores in sequences within the scenarios, the test has a higher sensitivity and specificity of 0.95 and 0.94 respectively. Using sequence scores, the False Positivity and Negativity scores were 0.04 and 0.07 respectively and the test has Positive and Negative Predictive Values 0.96 and 0.93 respectively. Higher total EK scores (at ≥ 10) in sequence increased the specificity to 1.00 though the sensitivity fell to 0.82. Interestingly the Experimental group had significantly more number of EKs in the ninth scenario compared to the control group though this was not in the expected direction. In

Scenario 9, the experimental group had a mean EK score of 1.8 (SD = 1.4) and the control group had a mean EK score of 0.43 (SD = 0.62).

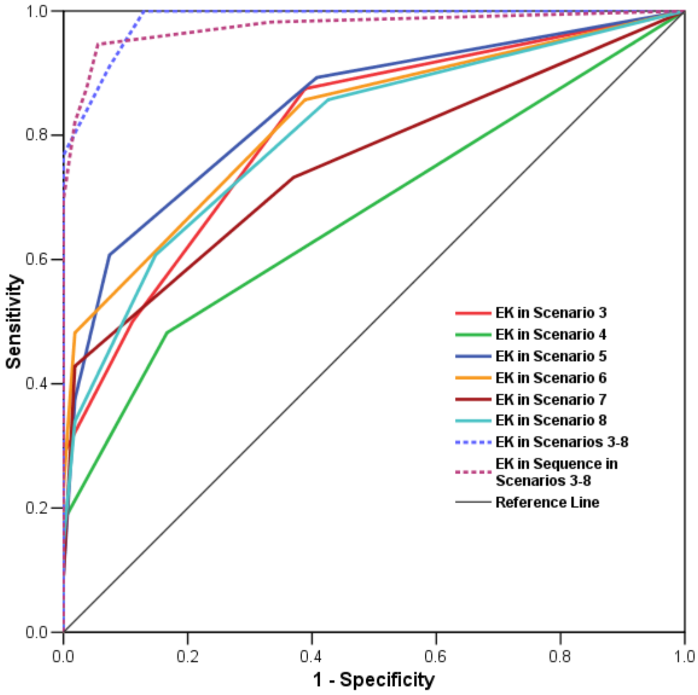

Fig. 1. ROC Curves of total EK scores within Sequence and for Scenarios 3 - 8 separately between the Experimental and Control groups.

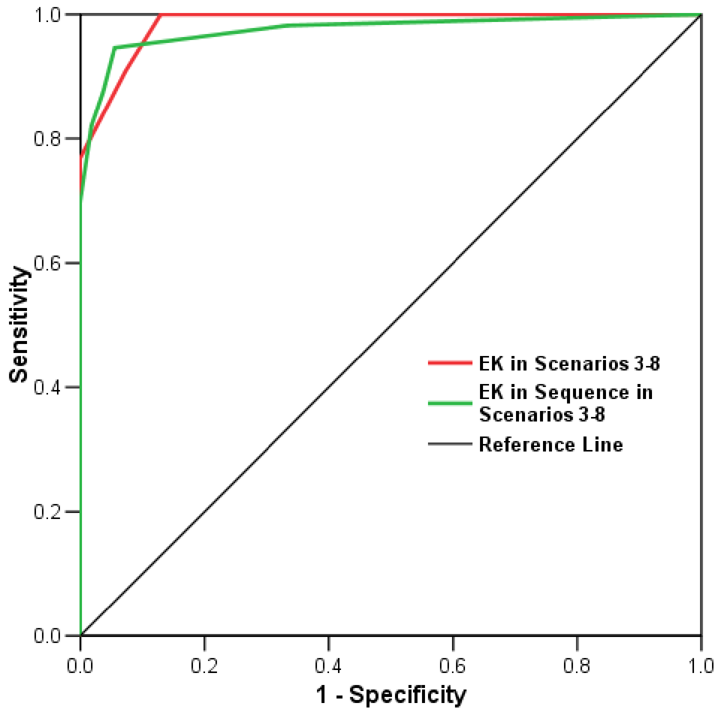

Fig. 2. ROC Curves of total EK scores in Scenarios 3-8 within Sequences between the Experimental and Control groups.

Table 3

ROC Curve values using total EK scores for Scenarios 3-8 area under the curve.

Area Under the Curve Test Result Variable(s): EK 3-8				
Area	**Std. Error**[a]	**Asymptotic Significance**[b]	**Asymptotic 95% Confidence Interval**	
			Lower Bound	**Upper Bound**
.989	.007	.000	.976	1.002
The test result variable(s): EK 3-8 has at least one tie between the positive actual state group and the negative actual state group.				
[a]Under the nonparametric assumption				
[b]Null hypothesis: true area = 0.5				

Coordinates of the Curve Test Result Variable(s): EK 3-8		
EK score in Exp Group if Equal to or Greater than[a]	**Sensitivity**	**Specificity**
-1.00[a]	1.000	0.000
.50	1.000	0.185
1.50	1.000	0.315
2.50	1.000	0.463
3.50	1.000	0.685
4.50	1.000	0.889
5.50	.911	0.944
6.50	.768	1.000
7.50	.750	1.000
8.50	.607	1.000
9.50	.429	1.000

Table 4

ROC Curve values using total EK scores in Sequence in Scenarios 3-8.

Area Under the Curve Test Result Variable(s): EK in Sequence in Scenarios 3-8				
Area	**Std. Error[a]**	**Asymptotic Significance[b]**	**Asymptotic 95% Confidence Interval**	
			Lower Bound	**Upper Bound**
.977	.014	.000	.949	1.004
The test result variable(s): EK in Sequence has at least one tie between the positive actual state group and the negative actual state group.				
[a]Under the nonparametric assumption				
[b]Null hypothesis: true area = 0.5				

Coordinates of the Curve Test Result Variable(s): EK in Sequence in Scenarios 3-8		
EK score in Exp Group if Equal to or Greater Than[a]	**Sensitivity**	**Specificity**
-1.00[a]	1.000	0.000
1.00	.982	.667
2.50	.946	.944
3.50	.875	.963
4.50	.821	1.000
5.50	.696	1.000
6.50	.589	1.000
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15.00	.036	1.000
16.50	.018	1.000

Figure 3 shows percentage of subjects showing different EK scores. Thirty-four percentages of the experimental subjects has shown maximum EK scores in the range of 9 – 10. The distribution of experimental subjects with different EK scores appears to have a normal distribution. Correlations of EK scores with different sample characteristics, shown in Table 4 do not also reveal any significant values to indicate that presence of EK been influenced by any sample characteristic. No significant correlation scores are obtained between total EK scores and psychological test scores except in the third trial immediate verbal recall scores, at the 0.05 level of significance.

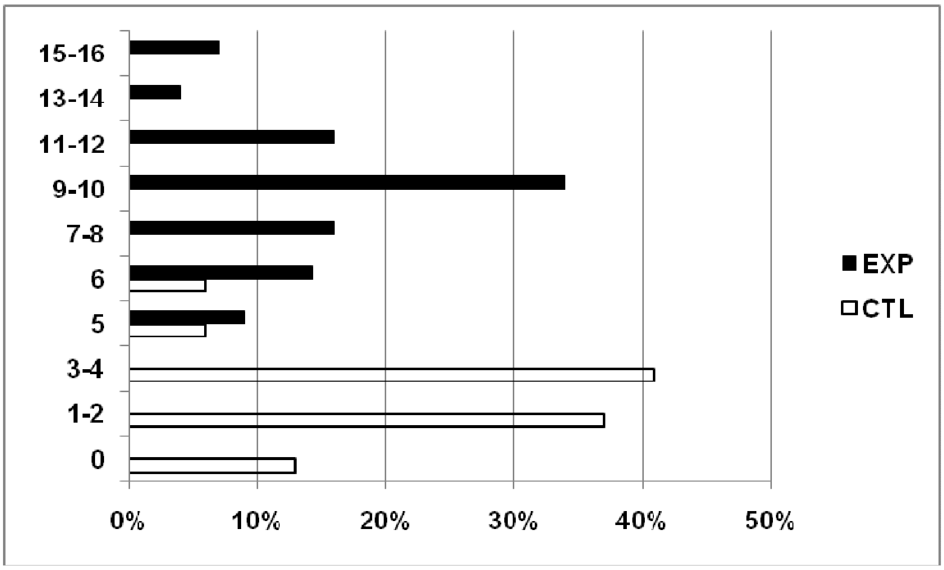

Fig. 3. Percentage of subjects with different range of total EK scores in the experimental (EXP, N = 56) and control (CTL, N = 54) groups.

Table 5

Correlation coefficients (Pearson r) between total Experiential Knowledge Scores, and Sample characteristics and psychological test scores in the Exp group.

Subject and other Test Variables	**Correlation**
Age	- 0.05
Education	-1.40
Income	0.02
General Health Questionnaire Scores	- 0.10
Verbal Learning-Memory Test - Immediate recall Trial 1	- 0.10
Verbal Learning-Memory Test - Immediate recall Trial 2	- 0.10
Verbal Learning-Memory Test - Immediate recall Trial 3	- 0.22*
Verbal Learning-Memory Test - Delayed recall	- 0.10
Visual Learning-Memory Test – Immediate recall Trial 1	0.05
Visual Learning-Memory Test – Immediate recall Trial 2	0.005
Visual Learning-Memory Test – Immediate recall Trial 3	0.11
Visual Learning-Memory Test – Delayed recall Trial	0.06
Raven's Standard Progressive Matrices Score	0.02

* Significant at 0.05 level

A very low but significant negative correlation (at 0.05 level), is seen between the verbal memory trial 3 scores and EK scores in the experimental group.

Discussion

Discussion of the results is based on the interpreted results of the BEOS profiling generated by the NSS. The most important result is the presence of 'Experiential Knowledge', reported by the NSS based on the analysis of the changes in the EEG activity time locked to the probe and in comparison with the pattern detected in the preprobe segments in each electrode channel and in each trial related to a probe. The distributions of EK scores in the two samples are markedly diverse as seen in the Figure 3. The results of the BEOS profiling show that EK responses were indeed present in the experimental as well as control groups, though there is significant difference between the mean scores of the two groups. A striking finding is that of the 68 probes used in the scenarios 3 to 8, only mean 9.3 (SD=2.9, 13.68%) probes elicited EK responses in the experimental group. Comparatively, the presence of EK response in the control group is insignificant indeed (mean 2.6, SD=1.87, 3.82%) contributing to a very significant difference between the two mean scores. It does not warrant that each probe shall elicit a specific remembrance. Subjective reports of individual on the content of remembrance show that once a probe triggers remembrance, chunks of related information may flow in. Additional probes presented during this period do not show significant difference in the probe related changes in comparison with the preprobe baseline. The present analysis does not attempt to determine the total duration of such changes once a probe initiates the changes. Additional cueing can enrich remembrance only if one has missed important pieces of information during the recall and the preprobe baseline activity has subsided.

That only one out of fourteen probes elicited EK response may also suggest different possibilities for the outcome. One is that the preset conditions used in the signal detection and analysis of EK responses are very stringent affecting the sensitivity of measurement of EK responses. The three probe that elicited maximum EK responses are “There was a bottle of water on the table” (29%) and “I closed the wooden box” (25%), and “I collected the broken pieces of the piggy-bank” (23%). Another possibility is that the experimental subjects participated in a set of routine activities, which did not have any significant personal value to them influencing the recall processes and the EK responses. A third explanation may be found in the possibility that many of the remembrances of experiences may be in the form of recall of transcoded information assembled at a later stage, rather than the remembrance of the original activity, as in the case of recall of many other logically assembled units of information. There may be obviously no need to access source memory details and recreate the components of the original experience, every time one recalls the details of the event, as they do not have any emotional value to the individual. Even experientially acquired information may get transcoded, interlinked with other existing pieces of conceptual information already present in memory, and thereby becomes consolidated (86-93). These studies indicate that accessing the hippocampus is an important requirement for the retrieval of autobiographical episodes. However, once consolidated, one can directly recall semantic and episodic information without accessing the source memory, for which accessing the hippocampus may be necessary (94).

The control group showed a few EK responses in scenarios 3 – 8 despite the fact the subjects in the group did not carry out the task. The fact that the control groups had not only known about the activities, but they had also seen the associated objects in the 'activity room' just before the BEOS profiling were not good enough for producing the neural changes responsible for the EK responses. Despite this, the results of the One Way ANOVA given in the Table 2 clearly support the ability of the test to differentiate the two groups using the response of "experiential knowledge" of actions carried out by subjects in the experimental group. The total EK scores, EK scores in sequence, and EK scores in each scenario can significantly differentiate the experimental group from the control group.

ROC Curve analysis of the three sets of EK scores supports the strength of the procedure for identifying persons with specific experiences, provided there is no reason to believe that the probes could have elicited any other associated remembrance. The association between a probe and the content of remembrance if provoked by it is presently inferential as we presume that a specific probe must have provoked an associated remembrance. There is no clue to the possibility if a probe has provoked a remembrance different from one what one was expecting. However, the strength for such inference arises from the fact that sequence of probes has triggered EK responses in different scenarios in the experimental subject. Further, there is no reason to consider that the subjects in the study could have indulged in an unrelated mental processing that produced EK responses while listening to the probes.

Sensitivity and specificity scores obtained from the ROC analysis using scenario wise EK scores have much lesser capability for discrimination of the two groups. ROC Curves of the total EK scores and the EK scores in sequence shows excellent probability (higher than 90%) for the procedure to differentiate the two groups and identify an individual who took part in an activity referred in the probes. An important aspect of the test is that EK response on single probe alone is not good enough for the classification or identification of a subject. Multiples of probes showing EK responses in sequence are required for deciding on the participation of an individual in an activity with adequately high specificity. It is characteristic feature of the test that it allows testing such multiple points of references. Greater the number of probes with EK, more certain one can be about the diagnostic interpretation derived from it. Greater the number of EK scores, especially of probes linked with one another, the confidence level of diagnosis may become close to unity as seen in Table 4. EK scores equal to greater than 4.5 in sequence yields a specificity of 1.0 though sensitivity falls to 0.82 and lower. Deciding on participation in an activity using a few EK scores increases the possibility of false positivity and false negativity increases and hence it is prudent to avoid such interpretation based on low EK scores. There does not appear to be a case emerging from the present results to pre-decide what must be a cut off score. Sensitivity is very high with low scores and it falls as specificity rises. Keeping the computational parameters of BEOS profiling constant, the cut off score and the total EK scores may be considered a function of the complexity of the experiential nature of the episode and the presence and accuracy of the probes referring to them. This is bound to change from event to event and from individual to individual. It is apparent that the cut off scores seen to differentiate the two groups in this study cannot be used if another task or experiential situation is used with different number of probes. This is a strong point for consideration during interpretation of the results if an individual is tested without an appropriate control condition. The control probes that are to be used in such situation are expected to overcome this difficulty in the sense of the appropriateness of its usage, as they can help in the self-validation of the results. A self-validation using control probes may be considered a superior alternative to using another person as control and using contextually irrelevant probes on that subject. However, it would also depend on the vividness of the experiences to be used for control probes, which in turn may depend on independent confirmation of the experiences used for designing them. A significant aspect that emerged in the study is that the probes producing EK scores support recall of sequence of the related activities, a finding significantly absent in the control subjects.

The results indicate that the presence of EK responses on interrelated probes in sequence is a sure way of identifying participation of a subject in an activity investigated. Temporal sequencing has been reported an important factor in all encoding. True sequencing is the basis of logical connectivity of events. Sequences encoded in experiences are as understood or interpreted by the participating or witnessing individual, which may differ from the true sequences of events. However, these sequences are important links for retrieving information logically. The brain does not have a temporal clock by which it could use to go to a specific point in time and retrieve whatever information stored at that point in time. Time estimation is made as before and after a particular episode that can be remembered. Therefore, remembering the episode and the sequence of events are important requirements for arriving at a period. Searching the past appears to be a function of the retrieval of content of an event in reference to a personal context or event, which serve as the personal clock. Personal significance is the most important factor that facilitates recall of experiences, whereas logical associations (95) may be the factor that need to be used for the recall of impersonal information. The mechanism of storage appears to consider the events as they are perceived to have happened as well as known to have been executed by the self. Links across events occurred at different points in time may be encoded at any time during their remembrance. Therefore, remembrance of personal significance is an important requirement for the brain to retrieve the core episode and whatever happened prior to or after it. The sequences interpreted or detected serve the rule for storing the order of events in a time locked brain. Studies have shown the presence of temporal gradient in the brain involving the entorhinal cortex (96) and other several cortical areas (97,98) centered on the perception of familiarity of famous faces over long time intervals in life. Maguire & Frith (99) found evidence for the role of the bilateral hippocampus for the recall of autobiographical episodes, in which they inferred that the left hippocampus might be related to all such personal recalls whereas the right may have a temporal gradient based on the remoteness of the memory recalled. In BEOS profiling, great care must be taken to maintain the sequence of components of events that are investigated, whether they are verified or hypothetical. This seems to have an effect on the presence of EK scores to sequentially presented probes. The study does not consider the effects of random presentation of probes. The examiner arranges the probes strictly in a sequential manner, best known or considered possible by the examiner.

The task used in the 'activity room' comprised of normal activities in life except breaking the clay piggy bank with an iron rod and collecting the coins from it. The most significant aspect of the study reported by the subjects was the strangeness experienced by the subjects that the said tasks were carried out in the laboratory of a scientific institution. This is the central theme, which made the test memorable for many as revealed in the post-test interview of some of the experimental subjects. It may be presumed that the different insignificant components of the activities were linked to this core theme and the subjects could retrieve them too. That the subjects were informed the purpose of the study in the beginning itself could also have contributed to their intention to remember the activities they carried out so that they could recall them during the BEOS profiling. Such intention was obviously not present in the control subjects as they did not to carry out the activities. The post-test interview further revealed that the subjects in the experimental group indulged in anticipating the probes as they referred to the sequence of actions they had carried out during the test, which was totally absent in the control group despite the fact they had known the probes beforehand.. The post-test interview of the control subjects revealed mere knowledge of the contents of some of the probes they heard. They also remembered and reported their first visit to the laboratory. There is no error in assuming that there could have been changes more subtle and short lived than measured by the program. A serious difficulty with the measurement procedure is the absence of an objective criterion for calibration of the neurocognitive process of remembrance, which can affect the sensitivity of the measurement system. The preset conditions used in the signal detection and analysis of EK responses may have been very stringent affecting the sensitivity of measurement of EK responses, because of which only less than one third of the probes elicited EK responses.

The two sample groups used in the study have not shown any significant differences with regard to psychological test scores. The two groups had subjects in a wide age range of 15 years to 70 years, with comparable mean ages. The two groups were also comparable in their mean number of years of education. With regard to memory, the immediate recall and the delayed recall scores were comparable in the two groups. The findings indicate that age related or any of the psychological factors of the sample tested have not contributed to the differences in the EK scores of the two groups. Significant personal experiences may alter or influence earlier related experiences and their interpretations. However, the present study does not enquire this aspect.

An important aspect of the study is that the subjects who carried out the activities as per the instructions given could sit through the BEOS profiling, with a frame of mind, which did not necessitate them to offer any resistance to a process of normal remembrance of the activities they had carried out. There was no need for them to think either that they had carried out an unacceptable act by breaking the piggy bank and removing the coins, or they were to pretend that they had not done the same. The probes were familiar to them, as they had heard them before and knew they were not to respond to them. The post-test interview showed some degree of eagerness on their part by anticipating the probes. Even the control subjects were primed with information, which could facilitate retrieval of visual images presented a few minutes back, which could also cue remembrance of any other event in their personal life. There is no reason to consider that the neural changes indicated by the EK response may be representing a contextually different remembrance in the subjects. However, this is an issue, which needs serious consideration, as the neural process measured only represents a cognitive process and not the content. The temporal proximity the neural activation and the associated cognitive process, and the contextual relevance of the cognitive task as inferred from the test instructions make us the inference about its content. A neural activation measured during a cognitive process only indicates the presence of the said cognitive process and may not represent its content. The coding used with the probes has directed the program to look for specific changes that indicate the presence and type of mental imageries, but does not go beyond it to give information about the content itself of the remembrance. This is an important issue for consideration if the test is to be used for forensic purpose. There are also possibilities of intentional efforts by a subject to alter the content of remembrance or the subject retrieving a contextually different theme. For example, trauma experienced during an elaborate interrogation may become associated with a probe, and the probe may help to remember the trauma producing an EK response, though there may not be any other experience itself associated with it. It is equally important that the mental state of the subject must be conducive for remembrance of past events. This is unlikely to happen if the subject is emotionally tense and disturbed, while listening to the probes.

The results of the study further indicate the need for systematic understanding of the mechanisms and factors that influence the process and the quality of remembrance of personal experiences, especially with reference to the procedure used in the study. Absence of Experiential Knowledge in BEOS profile may not necessarily indicate that the individual did not have the experience, as the ability to remember an autobiographical episode depends on its personal significance to the individual over time. A few random EK scores on the BEOS profiling elicited by probes may also not be enough to infer that the subject has had those experiences contextually specific to the probes, as a probe may trigger recall of contextually unrelated episode, when the entire scenario has no personal significance. However, the presence of Experiential Knowledge to sequence of events referred by probes is indeed a strong indication of the presence of occurrence or participation in the episode. Results strongly suggest that awareness or presence of EK responses occurring in such sequence do not indicate remembrance of unrelated personal episode. Remembrance in sequence represents the logical connectivity of the components of the experience, which unrelated probes cannot elicit in a random manner. On the other hand, absence of significant EK responses is equally strong indication of the absence of experiential knowledge because the individual has not participated in the said actions.

It is unlikely that one may fail to recall personally significant autobiographical episodes unless there is interference in terms of a disease process or any other traumatic condition in the individual. The duration between the original experience and the time of its remembrance and presence of emotional states in which one intends to remember or encounters a cue may also have important influences on the vividness, quality, and content of remembrance. Intense emotional experiences may render the vividness and quality of remembrance of earlier personally significant experiences. Personal episodes frequently remembered do have chance of easy recall as they would have already been transcoded and linked to several other units of information in the knowledge bank. Retrospective transcoding of experiences based on new experiences and interpretation may influence their subsequent remembrances. It is presently a mere guess if subjects who took part in the above activities will remember them as an experience or an idea, a few months or years later. The volunteers took part and carried out the activities willingly, though the activities did not have any personal significance to the participant, except the possible excitement and the reward. Irrespective of this, the test could show presence of experiential knowledge in those subjects who had participated in them. There is indeed significant differences between the profiling of the experiences of a subject in a laboratory based experimental study and testing a subject for the presence of experiential knowledge acquired in real life situations. In the second case, the formulation may always have hypothetical possibilities. Several ecological factors, which escape quantification, may influence the results. It is indeed very important to establish the ecological validity of the test before using it as a diagnostic tool. This is all the more important when the test is to be used as a forensic tool for investigation of suspects and accused persons.

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