

AN EEG INVESTIGATION OF MEMORY IN DEPRESSION:
THE EFFECT OF COGNITIVE PROCESSING

by

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Abstract

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Among clinical populations, depression patients tend to show impaired memory performance both in working memory and associative memory accompanied with disorders in neural activity in the DLPFC. However, it is unclear whether these deficits are related to selective deficits in different levels of processing, possibly due to a dysfunction of cognitive processing mediated by the prefrontal cortex. In order to investigate this possibility, the present study recruited individuals with high, moderate and low depression to examine the electrophysiological effects of cognitive processing in working memory and long-term memory with electroencephalography (EEG). As hypothesized, individuals with low depression showed a memorial benefit for deeper semantic processing whereas individuals with moderate and high depression did not. These findings provide supporting evidence of associative processing deficits among individuals with depression due to dysregulation of the frontal executive regions.

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Chapter 1

Introduction

1.1 Working vs Long-Term Memory

Memory is an important cognitive function that requires the encoding, storage, and retrieval of information in order to be successful. When recalling a memory, we often think of the specific aspects of a memory but, even more importantly, how those aspects relate to one another and oneself (i.e., episodic memory). Memory is a complex process that involves several different phases that can be influenced by attention, arousal, load of information, duration, and the level of processing (Braver et al., 1997; Engle et al., 1999). Traditionally, memory has been dichotomized into short-term or long-term memory with short-term memory referring to a limited-capacity system (7 +/- 2 items) for temporary storage of information and long-term memory referring to an unlimited capacity system for lasting storage which can be recalled by the individual. In an attempt to better understand the mechanism of short and long-term memory, Baddeley and Hitch (1974) proposed a model of working memory which involves a flow of information controlled by the central executive, a functional system responsible for selection and manipulation of information. Working memory is often used interchangeably with short term memory but they are distinct in that information is assumed to be manipulated in working memory (WM) whereas information is posited to be simply maintained in short-term memory (STM).

Despite differences between the STM and WM models, both models propose a limited amount of information that can be temporarily stored (Miller, 1956). However,

this temporary information can be transferred to long-term memory depending on the initial level of processing (LOP). To elaborate, when information is processed at a shallow level (i.e., only processing surface features of a stimulus), information is less likely to be successfully retrieved. In contrast, when information is processed at a deeper level (i.e., processing the details and relational features of a stimulus in conjunction with other stimuli), it is more likely to be remembered (Craik & Lockhart, 1972). The prefrontal cortex (PFC) plays an important role in the active manipulation of information and is essential for working memory processes (Barch et. al., 1997; Braver et. al., 1997; Courtney et. al., 1998; D'Esposito et al., 1995; D'Esposito et al., 1999; Goldman-Rakic, 1987). Researchers initially began to investigate the PFC's role in working memory after Jacobsen (1936) found that lesions in the lateral PFC within monkeys produced an inability to maintain information in mind over a short duration. Recent research has indicated that activity in the PFC may influence long-term memory through its control of information processing during working memory (Blumenfeld & Ranganath, 2006; Blumenfeld & Ranganath, 2007; Hunt & Einstein, 1981). Based on these findings, it appears that the neural correlates of the levels of processing effects may be related to differences in PFC activity. Examining electrophysiological changes at the whole brain level may further our understanding of how varying levels of processing affects memory performance at the neural level. A neuroscientific investigation of the levels of processing should help bridge the understanding of how information is transferred from WM to LTM. To better understand the levels of processing in memory, brain imaging

techniques can be used to detect the underlying electrophysiological changes involved with processing item-specific and associative information.

1.2 Item-Specific vs Associative Processing

Varying levels of processing (shallow versus deep processing) can influence working memory and long term memory. Level of processing (LOP) effects were first investigated by Craik and Lockhart (1972) in reference to the notion that the depth of mental processing at encoding ultimately influences memory retrieval, such that deeper processing tends to result in better long-term memory retention, whereas shallow processing tends to result in poorer retention of long-term memories. When one attempts to remember more than a single item of information, such as an item and its context, binding among those items is required to form a coherent memory representation. This kind of processing requires a greater level of cognitive demand (due to the relational binding of multiple items) than to shallow processing does. For instance, item-specific encoding, as an example of shallow processing, involves passively reciting information at a surface level such as rehearsing items in a given order. In contrast, associative encoding, as an example of deep processing, involves actively manipulating information with semantic association between items (Hunt & Einstein, 1981; Humphreys, 1978). Different regions of the PFC are involved in processing both item-specific (i.e. shallow processing) and associative (i.e. deep processing) information. Specifically, neuroimaging studies have found increased ventrolateral prefrontal cortex (VLPFC) activity during item-specific processing and increased dorsolateral prefrontal cortex (DLPFC) activity during associative processing (Badre & Wagner, 2007; D'Esposito et

al., 1999; Wagner et al., 2001). These findings, and many others, suggest that the VLPFC and DLPFC have functionally distinct roles when processing item-specific information versus associative information (Petrides, 1994; Owen, 1997; D'Esposito et al., 1999). These findings suggest that the benefit of deeper processing, or the lack thereof, may be related to functions of the PFC. The benefit of deeper (associative) processing resulting in better long-term memory may not be present in populations with neurological disorders that are accompanied by disorders in PFC activity, such as in depression.

1.3 Memory Impairments in Depression

Dysfunctions of memory are often found in symptoms of neurological and psychiatric disorders such as dementia, schizophrenia, Alzheimer's disease, amnesia and depression (Nester, 2006; Ragland, 2012; Cohen, 2006). A recent meta-analysis suggests that individuals with depression show impairments in long-term memory, but it is unclear whether these impairments are caused by a broad deficit in memory overall or are instead the result of a selective memory deficit (Austin et al., 1992; Austin et al., 2001; Burt et al., 1995; Iisley, Moffoot, & O'Carroll, 1995). Studies have consistently reported impairments in attentional and executive control among clinically depressed individuals, suggesting impairments in their working memory (WM) (Beats et al., 1996; Friedman, 1964; Raskin et al., 1982; Silberman et al., 1983). In addition, rodent models and clinical studies of depression patients have found impairments in associative memory. These impairments may reflect a deficit in the ability to allocate cognitive resources to more demanding tasks (Darcet et al., 2014; Weingartner et al., 1981; Hasher & Zacks, 1979; Cohen et al, 1982; Roy-Byrne et al. 1986). However, other studies have suggested that

memory impairments in depression may be independent of the inability of depressed individuals to allocate cognitive resources during difficult tasks (Golinkoff & Sweeney, 1989).

If memory impairments in depression are based on information processing deficits mediated by differences in the prefrontal cortex, then item-specific processing effects (which only requires shallow processing) would still emerge in a similar behavioral pattern in individuals with varying degrees of depression, whereas associative processing effects would differ among these individuals. However, if the memory impairments in depression are based on broad memory processing deficits, then highly depressed individuals would perform poorly on both item-specific and associative memory tasks whereas individuals with low depression would display a memorial benefit of associative processing. To elaborate, if memory impairments in depression are related to a dysfunction of broad memory processing, then individuals with high depression would not show the memorial advantage of associative memory, with overall low memory accuracy. On the other hand, individuals with low depression would display better long-term memory as result of associative processing. To assess the effect of memory processing in individuals who vary in their levels of depression, an electroencephalography (EEG) was employed in the present study to detect the electrophysiological changes associated with item-specific and associative processing. The EEG is an electrophysiological measure that is sensitive enough to detect the temporal changes occurring in the brain, albeit with rather limited spatial resolution. Because a distinction between encoding (study) and retrieval (test) lies in the time that

information is processed and that the PFC region is critical for working memory and long-term memory, I propose an EEG investigation for this study.

For this study, the working memory paradigm was used for encoding items with varying degrees of processing as a study task, whereas the long-term memory paradigm was used for testing the participants' memory of the studied items. Further, for the long-term memory paradigm, objective measurements of memory accuracy and subjective measurements of confidence ratings were collected and analyzed to determine the relationship between memory accuracy and memory strength. Memory strengths were assessed based on the individual's subjective confidence ratings of their recognition decision about whether or not a particular item was "old" (meaning it was previously studied during the working memory task) or "new" (meaning it was a new image that was not studied during the working memory task).

1.4 Research Aims

The primary aim of this study was to determine if there were any differences in brain activity (event-related potential, ERP), which corresponded to item-specific and associative processing, among individuals with high, moderate and low depression during both working and long-term memory. This study provided a novel approach to analyzing the effects of levels of processing on working memory and long-term memory formation. Understanding how levels of processing can influence memory will further our understanding of how information is transferred from short-term to long-term memory. Many studies have successfully used an EEG to detect electrophysiological changes

when investigating attention and memory in depression (Armitage, 2001; Brenner, 1986; Grimshaw, 2014).

As compared to an MRI, an EEG has greater sensitivity to temporal changes occurring in the brain which can allow researchers to examine early and late ERP (averaged EEG signals) effects. Examining early ERP effects allows researchers to analyze the ‘familiarity’ of a stimulus whereas examining late ERP effects allows researchers to analyze the ‘recognition’ of a stimulus. To address this study’s predictions, a memory paradigm of working memory and long-term memory tasks developed by Blumenfeld and Ranganath (2006) was implemented. This paradigm was used for the behavioral memory tasks while electrophysiological responses in the brain were measured by an EEG. Averaged EEG signals, event-related potentials (ERP) were examined as electrophysiological responses which correspond to specific cognitive processes. For this experiment, ERPs refer to evoked potentials in response to a visual stimulus of item-specific and associative information.

H1: It was hypothesized that individuals with high depression would perform poorly on both WM and LTM tasks, as compared to individuals with moderate and low depression, possibly due to memory impairments associated with depression

H2: There should be no group differences in memory judgments on new items because this study examines the influence of levels of processing on previously studied items, I did not expect memorial differences for newly presented items.

H3: It was expected that associative processing would result in better long-term memory for individuals with low depression scores but not for individuals with moderate or high depression scores, possibly due to a dysfunction of associative processing during working memory.

H4: Differential effects of processing between groups should correspond to different brain activity in the frontal cortex while the participants performed a long-term memory task.

Chapter 2

Experimental Methods

2.1 Participants

The participants were recruited from the University of Texas at Arlington. Each participant completed a prescreen questionnaire which included the Center of Epidemiological Studies Depression Scale (CES-D) which will be used to separate groups of high and low depression. The clinical cut-off score for Major Depression Disorder using the CES-D Scale is 15. For this study, individuals whose CES-D scores ranged between 17 to 24 were eligible for “Moderate Depression” whereas individuals who scored 25 or above qualified to be part of the “High Depression” group, which served as the experimental group. Individuals whose CES-D scores were below 15 were eligible to be part of the “Low Depression” group, which served as the control group. A total of 60 individuals (20 low depression individuals, 20 moderate depression individuals, and 20 high depression individuals) were recruited for the purposes of this experiment. Informed consent was given by the subject before participating in the study. Participants were excluded if they were 18 or younger, non-native English speakers, had a serious mental/physical health problems, or were pregnant, had any implanted device, had taken medications/drugs within the past 6 months that affect the central nervous system, alcohol abuse, and/or had a major medical or psychiatric illness. After completion of the experiment, the participants were debriefed about the purpose of the experiment and were granted research credit for their participation.

2.2 Procedures

Item-Specific vs Associative Processing

For item-specific processing, participants were instructed to remember the sequence of three pictorial items based on their serial order from top to bottom, with 1 representing the top item, 2 representing the middle item, and 3 representing the bottom item ('rehearsal'). During the presentation of the WM probe screen, participants were instructed to indicate whether the number on the probe screen correctly matched the serial order of the rehearsal images using a two-button response on a keyboard. This task represented a shallow and less elaborative form of mental processing.

For associative processing, participants were instructed to mentally reorder the sequence of three pictorial items based on their physical weight in an arrangement from lightest to heaviest, with 1 representing the lightest item, 2 representing the mid-weight item, and 3 representing the heaviest item ('reorder'). During the WM probe, participants were instructed to indicate whether the number on the probe screen correctly matched the position of the image after the images have been mentally reordered according to physical weight using a two-button response on a keyboard. This task required a greater cognitive demand and represented a deeper and more elaborate form of mental processing. Experimental schematics are shown in Figure A.3, A.4, and A.5.

The item-specific ('rehearsal') and associative ('reorder') processing trials differed primarily in terms of the cognitive demand and the level-of-processing required to manipulate the sequence of study items but they were matched in all other respects such as timing parameters, key responses, and stimulus type. To ensure adequate

understanding of task instructions, participants completed practice tasks of the working memory paradigm before being permitted to continue. After successful completion of the practice task, participants were instructed to begin the working memory task while an electroencephalography (EEG) based on the 10-20 system recorded corresponding brain activity (Figure A.2).

Working vs Long-Term Memory Tasks

A total of 504 neutral Google clip-art images were used for this experiment. Of these images, 336 of them were assigned to the working memory condition whereas all 504 (336 old items + 168 new items) were assigned to the long term memory condition. Images in the working memory condition were randomly assigned to two separate conditions (168 images per condition); item-specific processing (i.e. ‘rehearsal’ or shallow processing) and associative processing (i.e. ‘reorder’ or deep processing). For the ‘rehearsal’ and ‘reorder’ condition, images were further subdivided into random groups of three, or triplets, which were displayed during the working memory task (56 triplets per condition). Each triplet consisted of 3 vertically arranged pictorial stimuli that were either cued with task instructions to ‘rehearse’ or ‘reorder’ the items. Only those images that were assigned to the ‘rehearsal’ and ‘reorder’ condition were used during encoding (i.e. working memory task). For the long term memory test, studied images from the rehearsal and reorder conditions were presented, intermixed with non-studied images (new) which served as foils.

For each trial of the working memory task, a vertical series of three pictorial items (triplets) was presented for 2 seconds, followed by a delay screen of a fixation cross

for 4 seconds, and then a probe screen which displayed one of the pictorial triplets that was just presented and a number ranging from 1 to 3 for 2 seconds. The purpose of the task was to determine whether or not the image and number on the probe screen match correctly in accordance with instructions based on either the ‘rehearsal’ or ‘reorder’ group conditions. All working memory trials were randomized in presentation, counterbalanced across participants, and distinguished based on whether or not the task involved item-specific or associative processing.

After completing the working memory task, the participants performed a subsequent long-term memory recognition task consisting of the 336 images (168 per ‘rehearsal’ and ‘reorder’ condition) that were previously studied during the working memory task and 168 new non-studied items which served as foils while an EEG recorded the corresponding brain activity. During the long-term memory condition, participants were asked to indicate whether each image was either “old” or “new” using their right hand, followed by a confidence rating of that decision which ranged from 1 to 3, with 1 representing low confidence, 2 representing medium confidence, and 3 representing high confidence using their left hand. To ensure their adequate understanding of task instructions, the participants completed practice tasks of the long-term memory paradigm before being permitted to continue. After successful completion of the practice task, participants were instructed to begin the long-term memory task while an EEG response was recorded.

Group Comparisons

Brain activity measured by ERP and behavioral performance (memory accuracy, reaction times, and confidence ratings) was recorded for the high, moderate, and low depression groups while they completed a working memory task that varied in the cognitive demand required by the item-specific and associative processing conditions. A subsequent long-term memory recognition task was administered to both groups to examine the influence of item-specific and associative processing during working memory on long-term memory performance.

2.3 EEG acquisition

An EEG was used to record the brain's electrical activity (i.e. ERPs) occurring along the scalp. The data were acquired at the University of Texas at Arlington using the Brain Vision EEG system. The EEG data were recorded from 32 electrodes mounted and gelled onto the participant's scalp according to the international 10-20 system. In reference to the 10-20 system, I focused on the region of interest, the PFC, which is located around the FP1, F7, F3, FC1, and FC5 electrodes. Cortical regions, such as the PFC, display electrophysiological changes when actively manipulating information. An EEG is sensitive enough to detect the electrophysiological changes during this active manipulation of item-specific and associative information.

2.4 Behavioral data analysis

For the long-term memory task, objective measurements of memory recognition and subjective measurements of confidence ratings were collected and analyzed to determine recognition accuracy and memory strength. Long-term memory recognition

accuracy (d') was calculated based on a z-score transformations of false alarm rates and hit rates for each individual. More specifically, it was determined by subtracting standardized false alarm rates (i.e. the participant mistakenly claims to “remember” a picture that was not presented during the study session) from standardized hit rates (i.e., the participant correctly claims to “remember” a picture that was actually presented during the study session), and then analyzed using a mixed ANOVA (Analysis of Variance). d' is a commonly used discriminability measure of accuracy proportions (Macmillan & Creelman, 1991). Post-hoc analyses were ran to assess any potential differences or interactions involving the high, moderate and low depression groups, levels of processing, and/or differences in working and long-term memory performance.

2.5 EEG data analysis

The data were acquired by the Brain Vision Inc. EEG system. All data were preprocessed using MATLAB software equipped with EEGLab and analyzed for group comparisons using ERPLab. The EEG data were cleaned and corrected for artifacts, movement, and eye blinks with the aid of EEGLab. All EEG data were filtered using both a high-pass (30 Hz) and a low-pass (0.10 Hz) Butterworth filter. Based on the standardized 10-20 system, the electrodes t9 and t10 (mastoids) served as common reference points during analysis. In accordance with the 10-20 system, I examined all cortical changes, and specifically focused on the cortical changes located around the left prefrontal cortex (FP1, F7, F3, FC1, and FC5 electrodes). The EEG data were analyzed 200 ms before the presentation of each visual stimuli and continued until 1,000 ms after

each event, with the greatest timing effects occurring between 700 to 1000 ms. Averaged ERP contrasts of item-specific and associative processing were compared to assess any electrophysiological differences occurring during varying levels of processing among individuals with low, moderate and high depression.

Chapter 3

Experimental Results

3.1 Behavioral Results

Sixty native English speaking participants (22 male) with ages ranging from 18 to 40 were recruited at the University of Texas at Arlington and offered research credit for their participation. Eighteen individuals met the criteria for a high level of depression with an average CESD-score of 29.83 (5.06). Eighteen individuals met the criteria for moderate depression with an average CESD-score of 20.28 (3.08). Twenty individuals met the criteria for low depression with an average CESD-score of 5.29 (2.54). Additionally, four individuals were excluded from the analyses due to an incomplete EEG recording during the long-term memory task.

The results of a 2 x 2 x 3 ANOVA of memory (working memory, long-term memory), task (shallow, deep) and group (high depression, moderate depression, and low depression) revealed a main effect of memory ($F[1, 53] = 8.88, p < .05$) and task ($F[1, 53] = 2.84, p < .05$) but these effects did not significantly differ among the depression groups. In addition, the interaction between memory and task was significant ($F[1, 53] = 274.59, p < .05$). Refer to Appendix B for descriptive statistics.

To obtain the strongest test of the predicted difference in cognitive processing between high and low depression individuals, I compared only the two extreme groups. A 2 x 2 x 2 ANOVA of memory (working memory, long-term memory), task (shallow, deep), and group (high depression, low depression) was performed. There was no main effect of memory. However the main effect of task was significant ($F[1,36] = 152.52, p <$

.001) and the task effect differed by group ($F[1,36] = 5.25, p < .05$). Further, the interaction of memory and task was significant ($F[1,36] = 214.71, p < .001$) as well as the 3-way interaction of memory x task x group ($F[1,36] = 4.9, p < .05$). Overall memory performance did not differ by depression group.

Follow-up *t*-tests showed that the high depression group exhibited better working memory for the shallow processing task than for the deep processing task ($t[17] = 14.11, p < .001$). However, there was no task effect in long-term memory indicating no benefit of the levels-of-processing in long-term memory for individuals with high depression. The low depression group also showed better working memory for the shallow processing task than for the deep processing task ($t[19] = 7.47, p < .001$). Importantly, the low depression group showed the memorial benefit of deep processing on the long-term memory task ($t[19] = 2.52, p < .05$).

3.2 EEG Results

For working memory, the EEG data revealed significant ‘old/new’ effects within the left prefrontal region (electrodes fp1, f3, f7, fc1, fc5, ft9) for the reorder task condition ($F[1, 47] = 8.28, p < .05$). Follow up *t*-tests revealed significant electrophysiological differences within the healthy control group during the 700 – 1000 ms following the presentation of the stimuli in the left prefrontal region (electrodes fp1, f3, f7, fc1, fc5, ft9) when comparing the old/new effects based on correct hits and correct rejections (i.e. accurate memory responses) of reorder items ($t[19] = 3.18, p < .05$). These effects were not observed in individuals with moderate or high depression. Finally, there were no significant electrophysiological changes detected in any group (high, moderate,

or low depression) when comparing old/new effects of rehearsal items, $p > .05$. Refer to Appendix B for ERP graphs.

For long-term memory, no significant electrophysiological changes were detected in any brain region for any of the depression groups when comparing old/new effects.

Chapter 4

Discussion

The initial comparison of memory performance in the high, moderate, and low depression groups did not reveal any meaningful patterns related to levels-of-processing memory effects. However, because only individuals with CESD scores of 25 or higher only meet the criteria for a high level of depression and those individuals with a CESD score of 15 or below are considered not to have depression, I compared memory performance for these two groups to obtain a more clear comparison of depressed and non-depressed individuals. The comparison of high and low depression groups revealed that both groups performed better on the easier, shallow processing task (i.e. rehearsal) than the more difficult, deep processing task (i.e. reorder) during encoding on working memory tasks. This outcome can be attributed to the fact that working memory is limited in regards to the duration and the amount of information that can be processed. For the working memory paradigm, participants were given a brief duration of time (2 seconds) to make a memory decision which explains why the participants performed better on the shallow processing task (which requires less time to process) than the deep processing task (which imposed a greater cognitive demand and, thus, more time to process the information).

In a normal population, studies have demonstrated that information initially processed at a deep level (i.e. associative processing) is more likely to be recalled on long-term memory tasks than information processed at a shallow level (i.e. item-specific processing). This phenomenon is commonly referred to as the levels-of-processing effect

(Craik & Lockhart, 1972; Craik & Tulving, 1975; Morris et. al., 1977; Kapur, Craik & Tulving; 1994). As expected, individuals with low depression showed a similar pattern of memorial benefit related to levels-of-processing as well as corresponding left frontal activity during associative processing. These individuals displayed memorial benefits of items that were deeply processed on long-term memory tasks. In contrast, individuals with high depression did not show a benefit for levels-of-processing. Because levels-of-processing effects depend on the cognitive processes of working memory and because individuals with depression have consistently reported impairments in working memory, these findings coincide with prior studies of memory deficits in depression (Rose & Ebmeier, 2006; Nebes, Butters, & Mulsant, 2000).

In support of the behavioral data, the EEG results revealed significant ‘old/new’ effects within the left frontal region in individuals without depression (i.e. low depression) when they are deeply processing information during working memory. Old/new effects based on averaged ERPs reveal the memory recognition differences between correctly studied items (old) and correctly rejected non-studied items (new). Examining the ERPs associated with these differences in memory recognition allows researchers to analyze the encoding processes involved in forming successful memories. No old/new effects were observed in individuals with moderate or high depression, possibly due to disorders of executive function in the left frontal region. Neuroimaging studies, which support these findings, have also reported dysfunctions in the frontal brain regions of individuals with Major Depressive Disorder (Channon, Baker, Robertson, 1993; Lyness, Eaton, & Schneider, 2004; Fossati et. al., 1999; Beats, Sahakian & Levy,

1996; Okada et. al., 2003; Harvey et. al., 2005). More recently, an fMRI study of non-medicated individuals with major depressive disorders also demonstrated a dysregulation of activity within the prefrontal cortex during a working memory task (Matsuo et. al., 2007). No old/new effects were found during the long-term memory condition in any of the depression-level groups. These findings of old/new effects in LPFC in individuals with low depression but not for those individuals with high depression may indicate that the levels of processing intervenes during the encoding process (measured by working memory task in the present study) to influence successful memory, instead of retrieval which was measured on long-term memory tasks in the present study.

In conclusion, individuals with depression did not show a benefit for associative processing, as my hypothesis predicted. Nor did they reveal any electrophysiological differences between successfully remembered items versus later forgotten items, which reflects the impairment of deep, relational processing. These neural findings suggest that impairment in levels-of-processing is related to disorders in the left prefrontal cortex during encoding in depression. Individuals with depression have great difficulty when deeply processing a complex task and do not have a memorial benefit for deeply processed items. In contrast, non-depressed individuals exhibited better long-term memory, as well as corresponding activity in the left frontal regions, for items that had been deeply processed during working memory. In sum, this study demonstrated the nature of the cognitive deficit in depression. In particular, the impairment of deep processing during encoding with behavioral and neural evidence.

Appendix A
EEG Setup and Materials

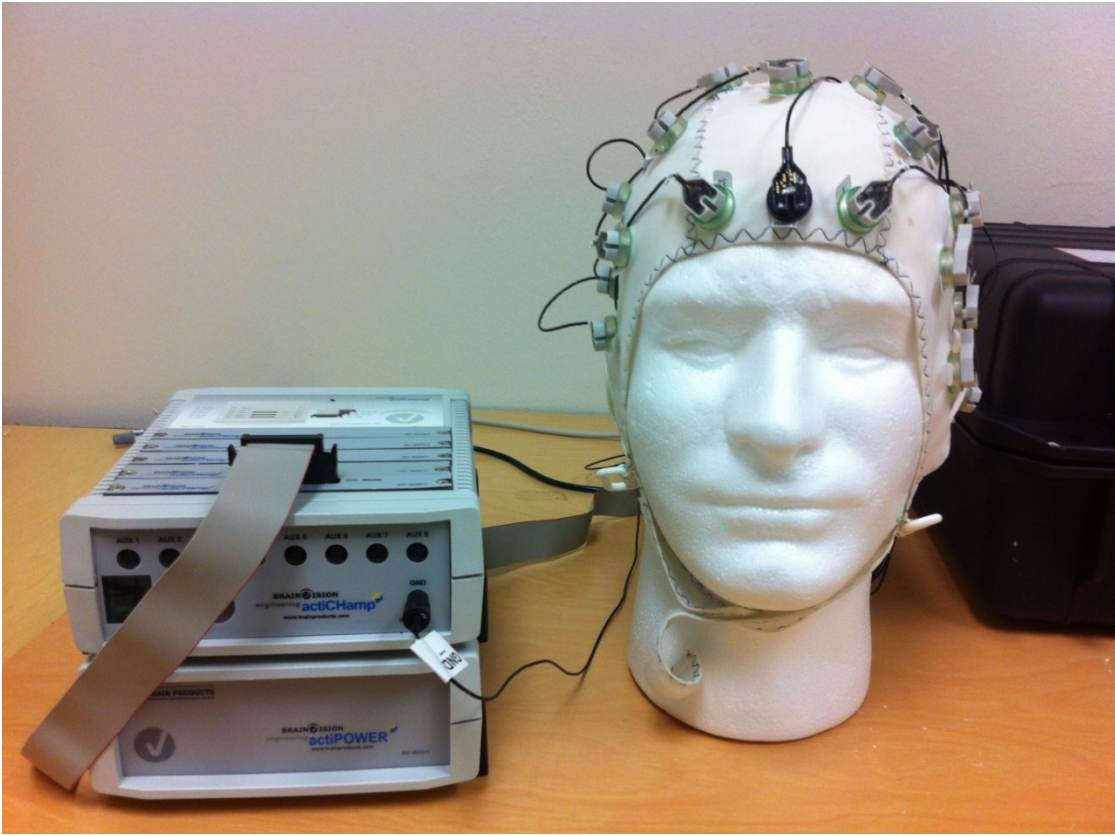


Figure A-1 Battery Powered EEG Setup

32Ch Standard Cap for actiCap for actiCHamp – high elasticity fabric

● Green Holders: Label 1-32, Hardware Channel 1 – 32

● Black holder: Label & hard-wired Gnd

Electrode Names and Number Labels

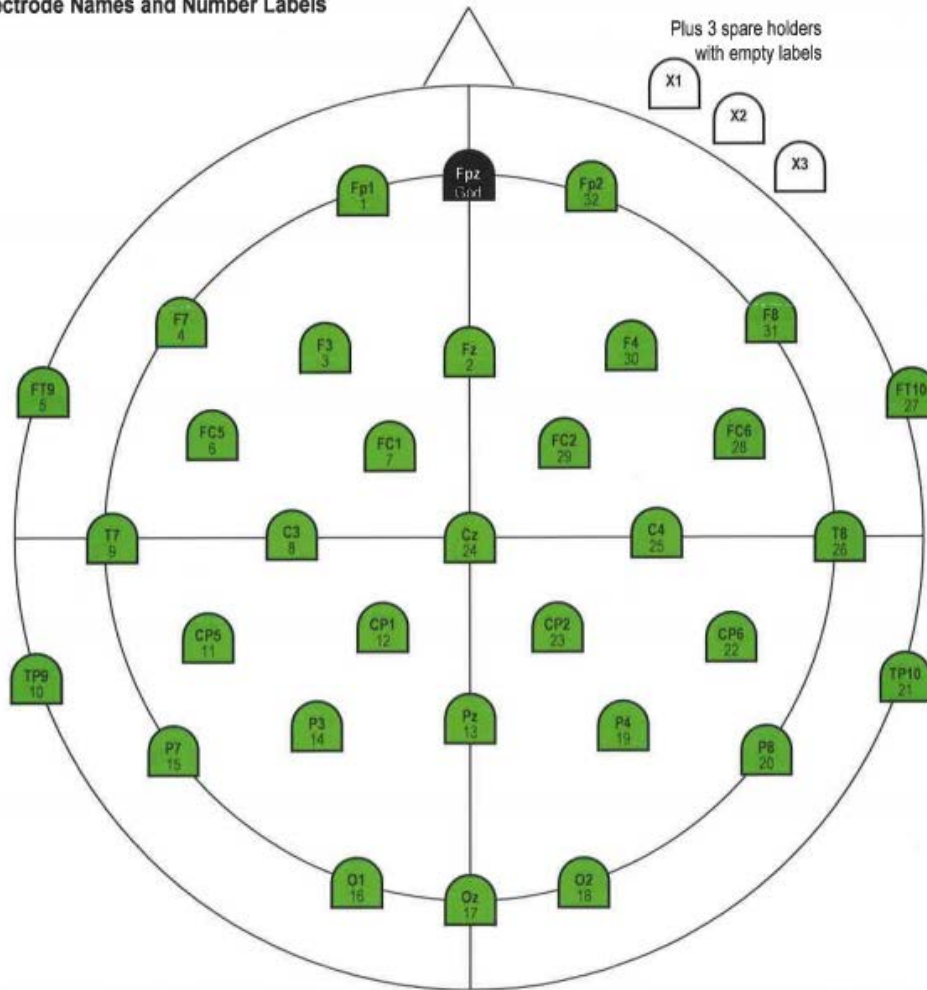





Figure A-2 EEG Cap Channel Set Up

Item-Specific Processing

“Rehearsal” + 1  + 2  + 2 







3  Correct Match 

Figure A-3. Shallow (item-specific) processing working memory task paradigm.

Associative-Processing

“Reorder” + 3  + 3 

1  + 3 



2  Correct Match 

Figure A-4. Deep (associative) processing working memory task paradigm.

Long-Term Memory Task



Figure A-5. Long-term memory paradigm.

Appendix B
Experimental Results

Study task	High (N = 20)	Moderate (N = 18)	Low (N = 18)
Rehearsal			
Hit	0.81 (0.03)	0.77 (0.04)	0.88 (0.17)
FA	0.17 (0.03)	0.17 (0.03)	0.13 (0.02)
Reorder			
Hit	0.56 (0.02)	0.52 (0.03)	0.55 (0.19)
FA	0.39 (0.02)	0.44 (0.02)	0.42 (0.01)

Table B-1 – Mean (SD) proportions of working memory judgments by groups of varying depression.

	High	Moderate	Low
Study task	(N = 20)	(N = 18)	(N = 18)
Rehearsal			
Hit	0.74 (0.03)	0.72 (0.03)	0.74 (0.02)
FA	0.26 (0.06)	0.22 (0.02)	0.25 (0.04)
Reorder			
Hit	0.77 (0.03)	0.75 (0.03)	0.79 (0.02)
FA	0.26 (0.06)	0.22 (0.02)	0.25 (0.04)

Table B-2 – Mean (SD) proportions of recognition (LTM) judgments for items studied with different tasks by groups varying in levels of depression.

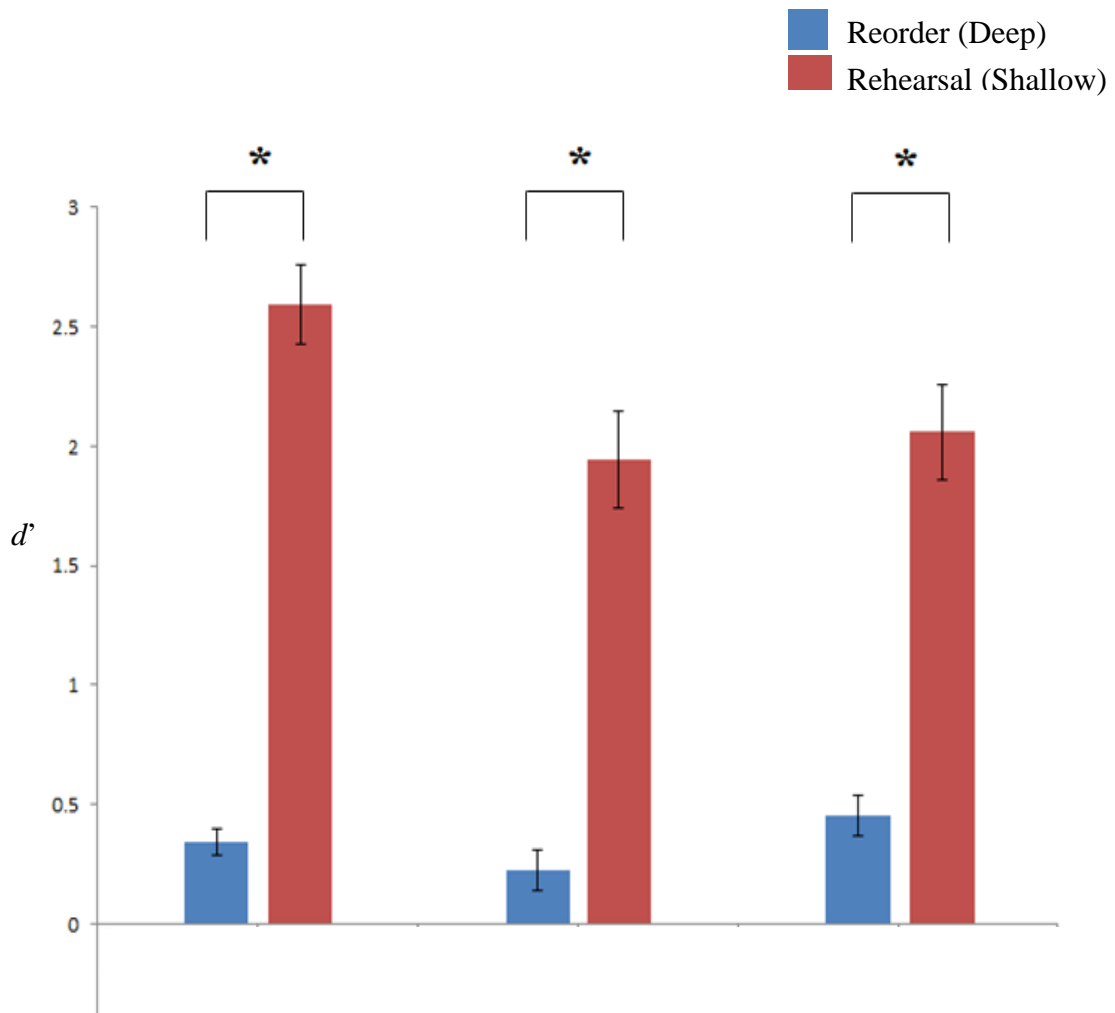


Figure B-3 – Working memory performance in individuals with high, moderate and low depression with different study tasks.

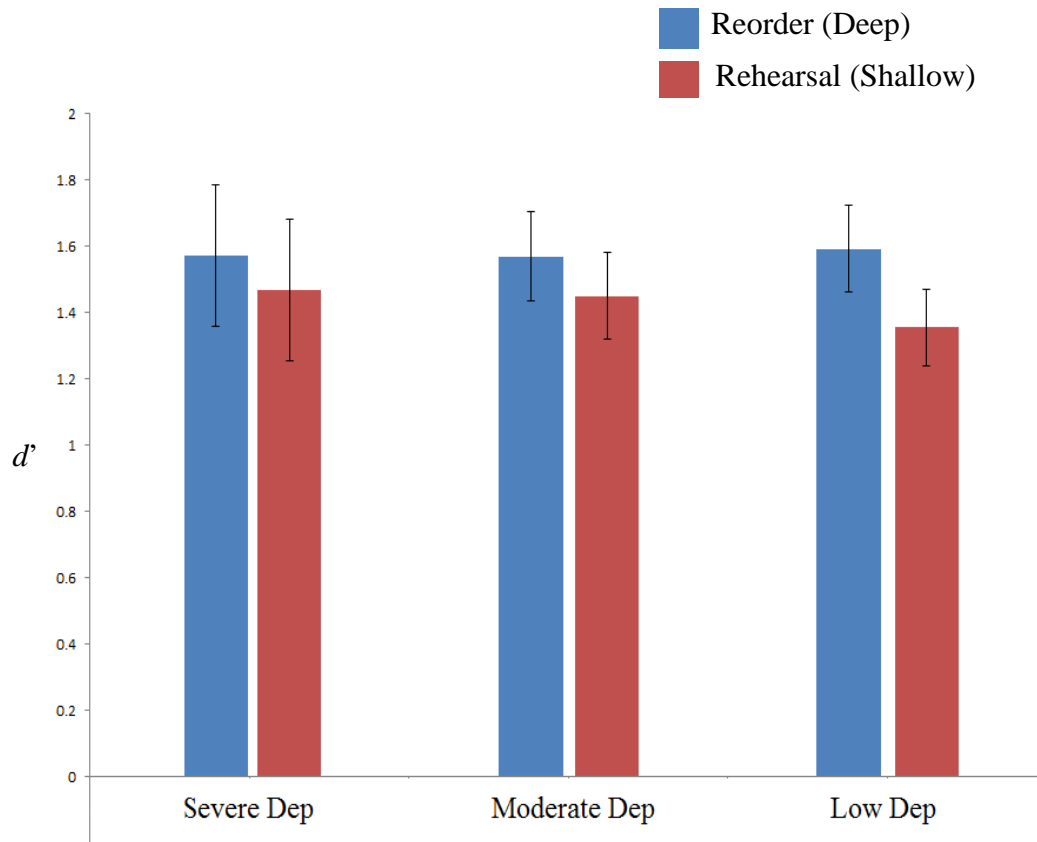


Figure B-4 – Memory discriminability on recognition (LTM) of items studied with different tasks by groups with different levels of depression.

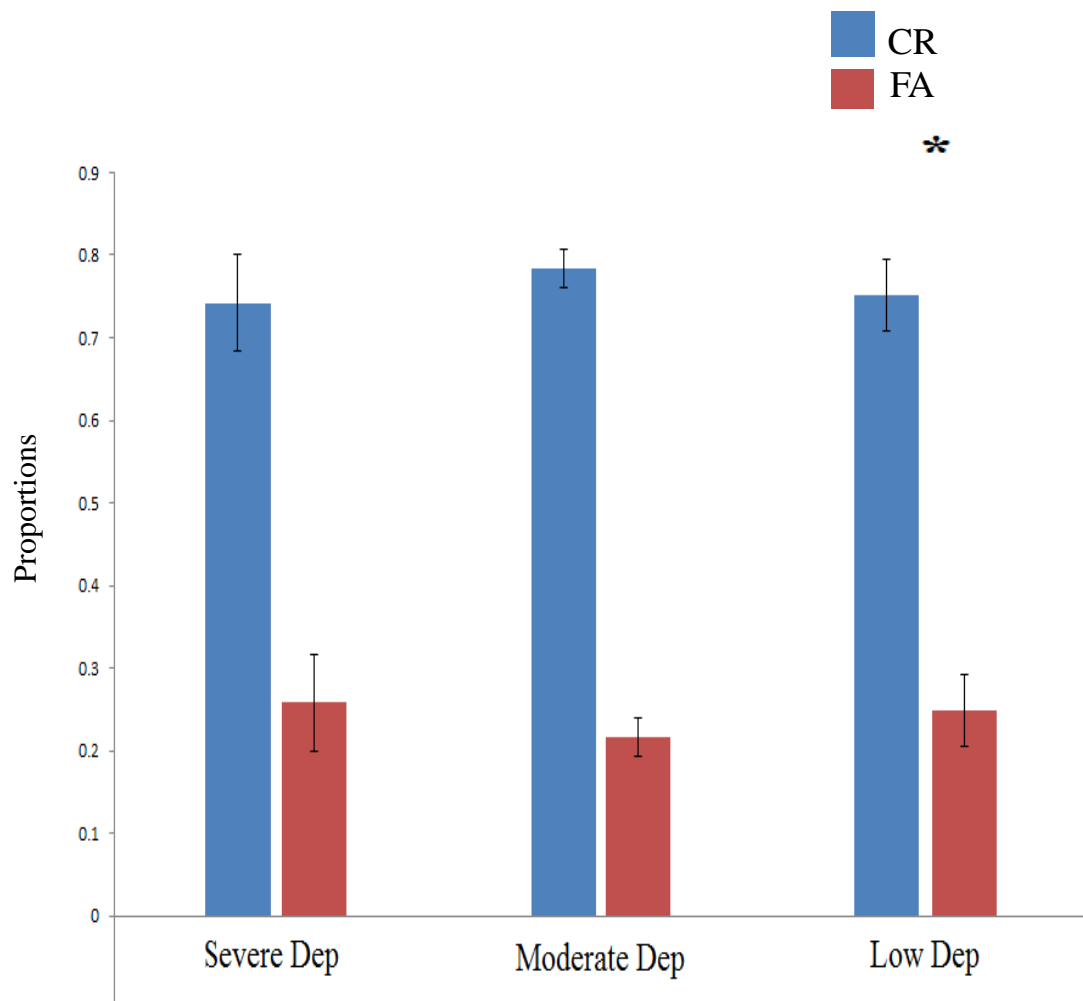


Figure B-5 – Memory judgments for new items on recognition by groups with different levels of depression.

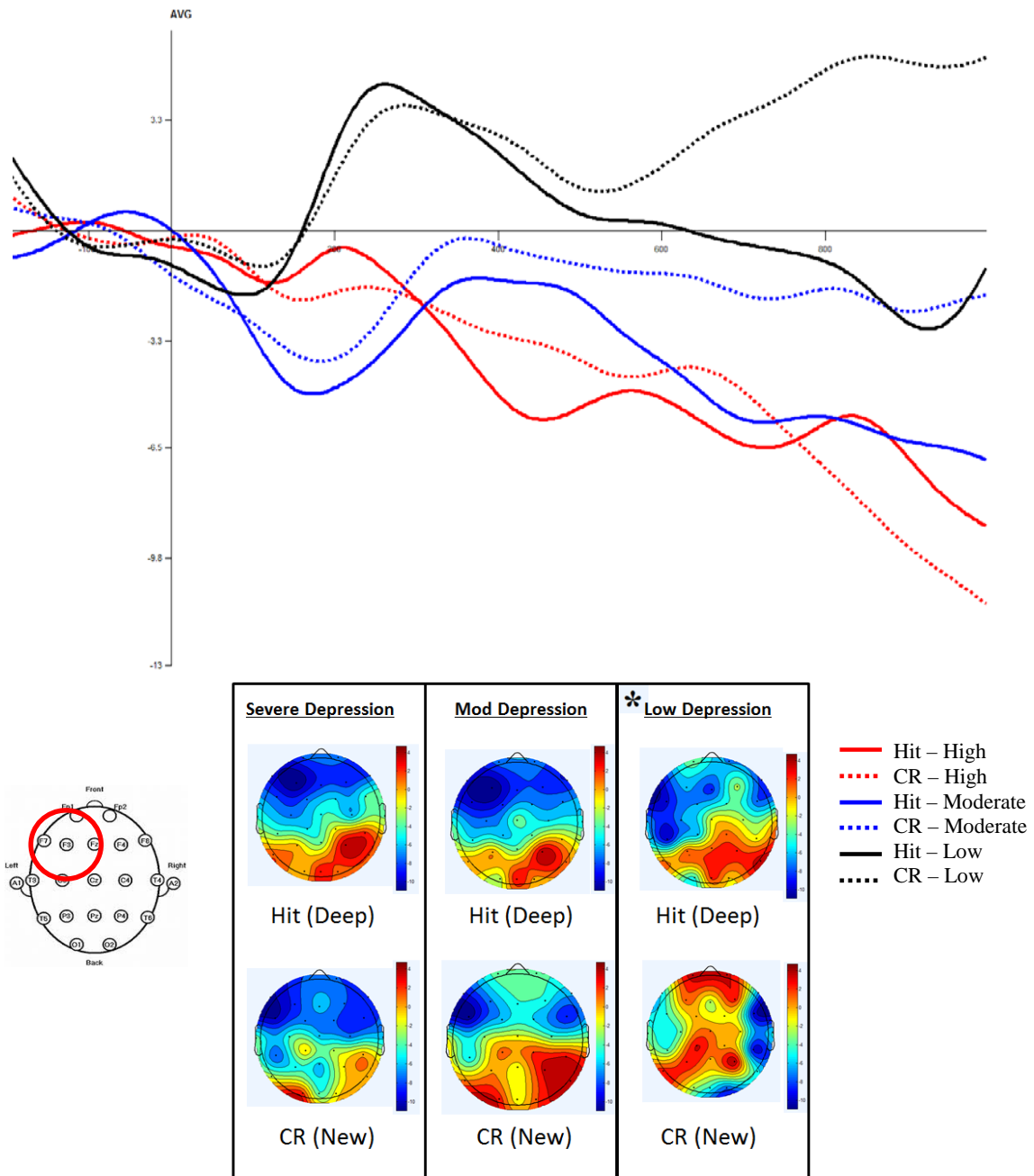


Figure B-6 – Electrophysiological waves in the left frontal cortex (fp1, f7, f3, fc5, and fc1) with items studied with the ‘Reorder’ task by groups varying in levels of depression in working memory.

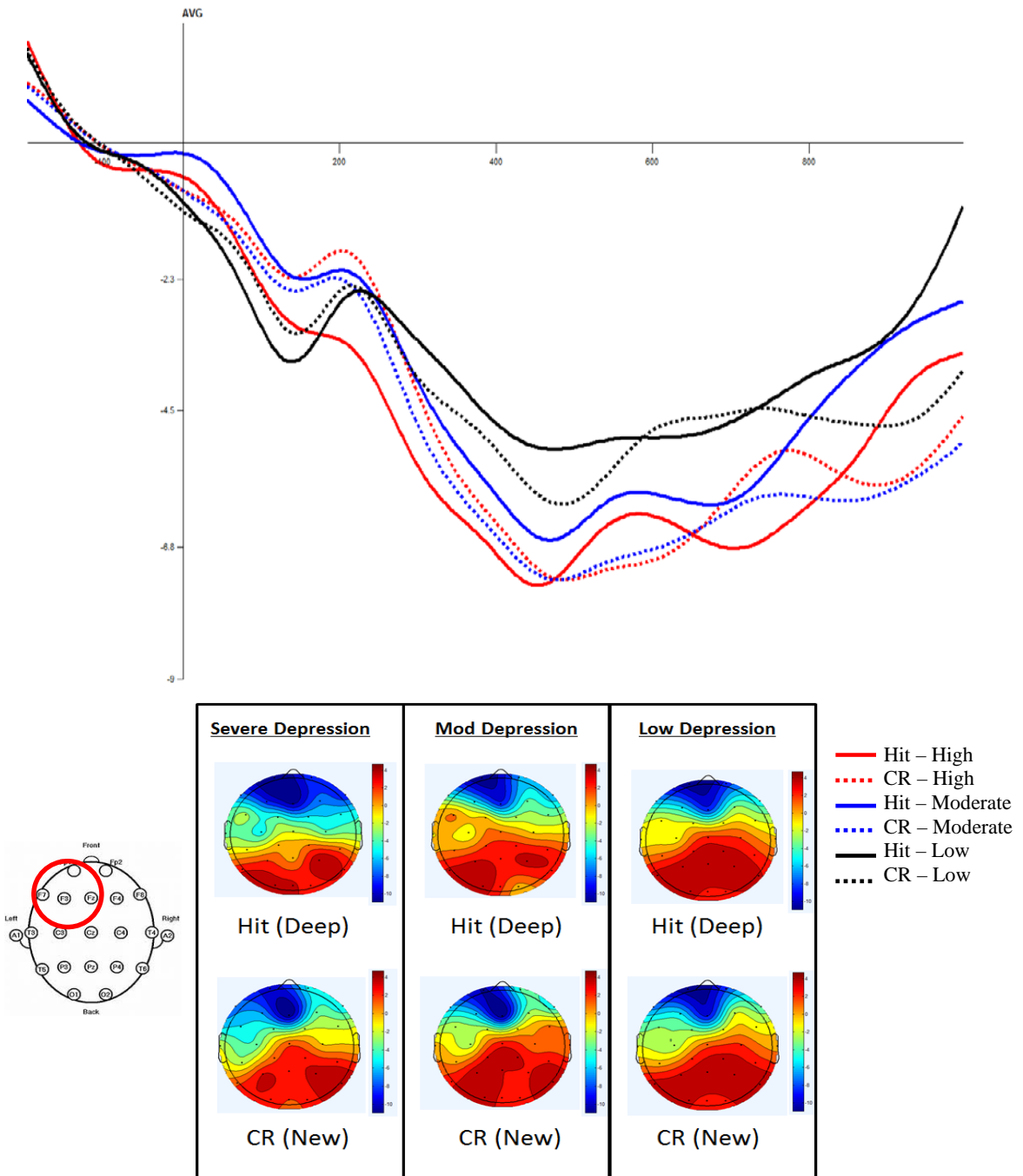


Figure B-7 – Electrophysiological waves in the left frontal cortex (fp1, f7, f3, fc5, and fc1) with items studied with the ‘Reorder’ task by groups varying in levels of depression in recognition (LTM).

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