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DIRECT CURRENT POTENTIAL ACTIVITY OF THE BRAIN
IN RELATION TO
SUCCESS AND FAILURE TO RECALL DREAMS

by

PENELOPE K. MCGREGOR, B. A.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of

Master of Arts

Department of Psychology

Carleton University

Ottawa, Ontario

August, 1992

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DIRECT CURRENT POTENTIAL ACTIVITY OF THE BRAIN
IN RELATION TO
SUCCESS AND FAILURE TO RECALL DREAMS

submitted by Penelope K. McGregor, B. A.
in partial fulfillment of the requirements for
the degree of Master of Arts

A handwritten signature in cursive script, reading "Robert Hoffman", positioned above a horizontal line.

Thesis Supervisor

A handwritten signature in cursive script, appearing to read "Bilto", positioned above a horizontal line.

Chair, Department of Psychology

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August, 1992

Abstract

This study examined whether Direct Current potentials (DC), which are bioelectric potentials of the brain that occur at very low frequencies, $< .1$ Hz (Gumnit, 1974; Hillyard, 1973), could differentiate success and failure to recall a dream upon awakening from Stage 2 sleep in a laboratory setting. Thirty four right-handed subjects (17 males, 17 females) spent a night in the laboratory. DC activity was recorded from the C3 recording site referenced to linked mastoids (A1, A2). The wakeup protocol resulted in 35 failures to recall a dream upon awakening which were compared to 47 successful recall awakenings. The change in DC activity from four minutes pre-awakening over the course of the wakeup protocol and following the subject's instructions to go to sleep were examined and compared between success and failure to recall using MANOVA profile analysis. The results indicated no differences between success and failure to recall in terms of either pre-awakening DC levels, the change in DC activity over the course of the wakeup protocol, or the frequency of positive and negative shifts in DC upon arousal from sleep. However, subsidiary analyses on 12 subjects who provided both a success and a failure to recall, using a within subjects repeated measures analysis indicated that successful recall awakenings had a statistically significantly greater mean absolute change from pre-awakening DC to Recall DC, $F(1, 11) = 6.2, p = .03$, and from pre-awakening DC to Question DC, $F(1, 11) = 5.28, p = .04$. These results are taken as a preliminary suggestion that further examination of the relationship between dream recall and DC activity is necessary. A secondary purpose of this study was to examine phasic DC activity upon arousal from sleep in humans. DC activity showed a statistically significant change from pre-awakening to post-awakening, $F(7, 74) = 3.55, p = .002$. DC moved in a positive direction when the subjects were awakened from sleep and then returned to its pre-awakening levels when the subjects were told they could go back to sleep.

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Table of Contents

	Page
Abstract	ü
Acknowledgements	iii
Table of Contents	iv
List of Tables	vi
List of Figures	vii
Introduction	1
1.1 Electrophysiological Correlates of Dream Recall.....	2
1.2 Direct Current (DC) Potentials	18
1.3 The Proposed Relationship Between DC Activity and Dream Recall	31
1.4 Hypotheses	32
Method	34
2.1 Subjects	34
2.2 Apparatus	35
2.3 Procedure	35
2.4 Experimental Awakenings	36
2.5 Classification of Reports into Success or Failure to Recall	37
Results	39
3.1 Data Preparation.....	39
3.2 Analyses	44
3.3 Comparisons Between Successful Recall Awakenings and Failed Recall Awakenings.....	44
3.3.1 Profile Analyses Comparing Success and Failure to Recall.....	46
3.3.2 Frequency of Positive and Negative Changes	55
3.4 Analyses on Subjects Who Had Both a Success and a Failure to Recall.....	56

3.5 REM Analyses	58
Discussion	61
4.1 Interpretation of the Results and their Implications	61
4.2 Suggestions for Future Research	75
Conclusion	78
References	79
Appendix A: Research Application Form.....	86
Appendix B: Follow-up Information.....	87
Appendix C: Instructions Upon Arrival at the Lab	88
Appendix D: Consent Form	89
Appendix E: Wakeup Protocol	90
Appendix F: Instructions to Raters.....	91

List of Tables

Table	Description	Page
1	Means and Standard Deviations of the DC Variables.....	45
2	Pearson Correlations Between Time of Night and DC Variables	47
3	Frequency of Positive and Negative Changes in DC Upon Arousal from Sleep	57

List of Figures

Figure	Description	Page
1	Schematic Diagram of an Awakening Showing Periods Used in Data Analysis.....	40
2	Example of an Awakening. Subject #31, Third Wakeup, Success	42
3	Average DC for Each Period	48
4	Average DC for Each Period Collapsed Across Groups	52
5	Difference Between Each Period and the Pre-awakening Period.....	53
6	DC Activity During the Transition from Stage 2 to REM	60
7	Transition from Stage 2 to REM Averaged Across 7 Subjects	60

Introduction

Dreaming is believed to be ongoing throughout the night in all individuals (Foulkes, 1962; Goodenough, 1978), yet there is much variability in individual tendencies to recall dreams upon awakening. While some people remember dreams every morning, others never recall a dream, and within an individual recall ability can be very consistent or quite variable. To date, neither psychological nor psychophysiological measures have provided consistent correlates of dream recall that account for any significant proportion of the variance in dream recall (Moffitt & Hoffmann, 1986; Moffitt, Hoffmann, & Galloway, 1990; Morel, Hoffmann, & Moffitt, 1991; Pivik, 1991). Thus, the mechanisms which account for the success and failure to recall a dream upon awakening are not yet clearly understood. The purpose of this study was to examine the success and failure to recall a dream upon awakening from Stage 2 sleep, as it relates to a particular form of brain electrical activity known as direct current potentials (DC). Direct current potentials have been found to vary with changes in the sleep-wake cycle (e.g. Hoffmann, Bonato, Moffitt, Armitage, & Wimmer, in submission) and have not yet been utilized in the study of dreaming in general, and, dream recall in particular.

A brief review of the literature on dream recall and the studies which have attempted to relate recall to the electrophysiology of sleep as measured by electroencephalography (EEG) will be provided. A review of direct current (DC) potentials in animals and humans will follow, focussing on the relationship between DC and the sleep-wake cycle, and cognitive performance. A rationale will then be provided for linking DC to the study of dream recall. The general research question that was addressed by this study was; does DC activity upon arousal from Stage 2 sleep differentiate success and failure to recall a dream? A secondary purpose of this study was to examine DC activity upon arousal from sleep in humans.

1.1 Electrophysiological correlates of dream recall

Self-reported home dream recall is normally distributed in the population, ranging from those who report recalling about one or two dreams a month to frequent recallers who report recalling dreams at least four or five times a week (Moffitt et al., 1982, 1990). Within individuals, the consistency of recall also varies, so that a consistent recaller may always remember dreams four or five times a week, whereas an inconsistent recaller may only sometimes reach that level of recall (Moffitt et al., 1990).

It is widely accepted that all people are involved in some type of mentation throughout a night of sleep (Goodenough, 1978; Foulkes, 1962). Why then, do some people recall dreams and others not; why do we remember dreams sometimes when we wake up and not others? Years of research into the possible correlates of dream recall have failed to come up with a clear answer to these questions.

Variability in dream recall likely involves a complex set of interrelated factors that may include personality, memory factors, and brain activity (D. Cohen, 1974). The problem remains that even within each of these areas, correlates of dream recall are small and inconsistent. The relationship between brain activity and dream recall is the focus of the current study, so the electrophysiological correlates of success and failure to recall a dream in a laboratory situation will be discussed in the following literature review.

It should be noted at this point that dream recall variability can refer to essentially two different types of recall. One is the spontaneous home dream recall reported when individuals are asked how often they remember their dreams when they wake in the morning. As mentioned previously, home dream recall rates are normally distributed in the population (Moffitt et al., 1982). Dream recall success and failure also refers to an individual's ability to recall a dream when they are awakened from various stages of sleep in a laboratory situation. Dream recall following awakenings from rapid eye movement sleep (REM) has been recorded in the range of 80% (Goodenough, 1978) to 92%

(Foulkes, 1962). The rate of recall from non-REM (NREM) awakenings is slightly less, but can be as high as 87% (Foulkes, 1962) depending on the interview technique, awakening procedure, recall criteria, and stage of NREM sleep (Foulkes, 1966).

Laboratory studies have shown that even those who report infrequent dream recall at home do recall dreams when awakened in a laboratory (Goodenough, 1978). It is these studies that have provided the basis of the conclusion that dreaming is ongoing in all people.

Studying laboratory recall is one way of developing an understanding of spontaneous individual differences in dream recall as it allows a look at specific instances of success and failure to recall a dream. Electrophysiological correlates of success and failure to recall can also be studied in a laboratory situation.

In the past, studies which examined the electrophysiological correlates of dream recall have focussed on EEG. Aserinsky and Kleitman's discovery that dream recall was highest during periods of low voltage, mixed frequency EEG accompanied by bursts of eye movement (REM sleep) marked the beginning of a great deal of research into the electrophysiological correlates of dream recall (Aserinsky & Kleitman, 1953). The arousal indicated in the EEG of REM sleep was believed to be the basis of recall, and this notion was supported by findings that dream recall was lower during the presumed lower electrophysiologically-aroused NREM sleep (Dement & Kleitman, 1957; Goodenough, Lewis, Shapiro, Jaret, & Sleser, 1965; Kamiya, 1961; Wolpert & Trosman, 1958).

The simple REM-arousal-dreaming; NREM-low frequency, high amplitude-non-dreaming model was popular for some time. However, when researchers looked more closely at data on awakenings from NREM sleep, they noted that NREM dream recall rates were higher than had previously been thought. When the definition of recall was changed to include less detailed reports, Goodenough, Shapiro, Holden, and Steinschreiber (1959), Kamiya (1961) and Foulkes (1962) found NREM dreaming rates ranging from 35% (Goodenough et al., 1959) to 74% (Foulkes, 1962). Foulkes defined dreaming as 'some

item of specific content'. When subjects were awakened from NREM sleep and reported dreaming but could not provide the content, recall rates were 87% (Foulkes, 1962).

Foulkes (1962) demonstrated that dreaming, depending on its definition, is ongoing throughout the night. The validity of NREM dream reports as recollections of the mentation ongoing prior to awakening is now firmly established (D. Cohen, 1979; Foulkes, 1985; Herman, Ellman, & Roffwarg, 1978). Thus, it is no longer tenable that dreaming only occurs during REM sleep.

Several studies have examined the pre-awakening electrophysiology as it relates to dream recall in order to further clarify the presumed relationship between EEG activity and dream recall. Pivik (1978) reviewed the research on dream psychophysiology and concluded that there is not much to be gained by further examination of the relationship between dreaming and electrophysiology. Pivik provides ample evidence that the traditional REM-dreaming, NREM-non-dreaming dichotomy is defunct. The search for phasic events (such as middle ear muscle activity, periorbital integrated potentials, spindles, k-complexes and theta bursts, for example) which would correlate with dream recall and/or dream content has also not been very fruitful (Pivik, 1978). In 1978, Pivik concluded that research into the psychophysiology of dreaming was no further along than it was in 1953 with the discovery of the REM-dreaming connection. Despite the research that has been performed since 1978, Pivik maintained this conclusion in a recent review (Pivik, 1991).

Moffitt and Hoffmann (1986) responded to Pivik's conclusions with a plea for a continued interest in dream psychophysiology using more sophisticated EEG analysis and statistical techniques. These authors maintain that the psychophysiological correlates of dreaming are much more subtle than those that have been researched in the past. Many early studies looked at global sleep stages for correlates of recall, often using visual stage scoring techniques. However, it is well known that within a given stage there is a great deal of specific information that a stage score simply does not capture (Hoffmann, Moffitt,

Shearer, Sussman, & Wells, 1979). The availability of inexpensive analog-to-digital conversion techniques has made it possible to apply computer quantification techniques to the analysis of EEG. These techniques, mainly fast Fourier transforms (FFT) and period-amplitude analysis, provide a great deal more information than the simple stage scores. A detailed discussion of the benefits of using computer quantification techniques to study sleep psychophysiology can be found in Hoffmann et al. (1979) and Sussman, Moffitt, Hoffmann, Wells, and Shearer (1979). Moffitt and Hoffmann (1986) assert that a change in the techniques used to examine psychophysiological correlates of dreaming may prove that dream psychophysiology is still a valid research problem.

EEG research using more sophisticated computer techniques, as discussed by Moffitt and Hoffmann (1986; see also Hoffmann et al., 1979; Sussman et al., 1979), has been performed in recent years, primarily due to reduced costs of microcomputer technology. A few of the most recent studies will be reviewed briefly to update the state of EEG research and dream recall.

The majority of the research into dream psychophysiology has centered around the thesis that dream recall is somehow facilitated by, or related to, cortical activation. As early as 1968, Pivik and Foulkes suggested a linear cortical activation model in which increases in electrophysiological arousal correspond to increases in dream recall. This simple proposal accounted for the fact that recall is better following awakenings from the more activated REM sleep than from NREM awakenings, that recall is higher from Stage 2 than from Stage 3, which results in higher recall than Stage 4, and for the fact that recall increases over the course of the night as sleep lightens. Pivik and Foulkes (1968) did not account for recall success and failure within a given stage of sleep and they did not specifically measure cortical arousal in this study. Antrobus (1986) has suggested that the level of cortical activation indicates the activity of the working memory and regulates the production and retrieval of dreams. The functional state-shift hypothesis (Koukkou &

Lehmann, 1980, 1983, in press), a prominent theory of dreaming and dream recall, has provided a specific theory about the relationship between cortical activation, as measured by EEG, and success and failure to recall a dream.

The concept of cortical activation should be discussed at this point as the distinction between cortical activation and fast frequency EEG is an important one. In the literature, fast frequency EEG activity has frequently been equated with activation, and slow frequency EEG with deactivation. However, cortical activation is inferred, and the assumption that fast frequency EEG indicates activation has been put to the test by findings which indicate slower frequency EEG activity in the theta range (4 to < 8 Hz) during intense cognitive activity (Schacter cited in Pigeau, 1983). These findings indicate that slower frequency activity does not necessarily mean deactivation. Despite the fact that recent literature has shown that fast frequency EEG should not be assumed to indicate activation, and that slow frequency activity does not necessarily mean deactivation (Armitage, personal communication), this link persists in many of the studies that will be reviewed in this paper. In order to avoid this problem, fast frequency EEG activity will be referred to as such, and where cortical activation is used, it will be noted that this is a variable that has been inferred by the author of the particular paper being discussed.

The functional state-shift hypothesis (Koukkou & Lehmann, 1983, in press) postulates that the brain is in different states during sleep and waking, and these states are associated with different processing strategies, memory stores and EEG characteristics. Based on the ideas of state-dependent learning, anything that is encoded in one state will be difficult to retrieve in another state. In addition, the greater the difference, as defined by EEG, between the encoding and retrieval states, the more difficult it will be to retrieve information. This explains why it is difficult to remember things in wakefulness that occurred during sleep. It also provides an hypothesis as to why dream recall is so variable. Dream recall is facilitated when the dream is encoded in a state most similar to waking, like

REM, for example. The EEG characteristics of REM sleep are closer to the EEG characteristics of waking than are the EEG characteristics of NREM Stages 3 and 4, which have slow-wave, high-amplitude activity. Dream recall is hindered when the dream is encoded in a state that is electrophysiologically distinct from waking, such as NREM Stage 4 for example. The greater the similarity between the EEG in which the dream was encoded and the waking EEG, the greater the recall ability.

This theory lends itself to direct empirical testing. Since the functional state is defined by the EEG, it is possible to directly compare waking and sleeping states in relation to dream recall. Specifically, the higher and longer the EEG activation during dreaming, as seen in increased high frequency EEG activity or decreased low frequency delta and theta activity, the better the recall during wakefulness (Morel, 1991). EEG "activation" in this case refers to EEG that is fast frequency or similar to the activity of waking EEG. An advantage of this theory is that it can be applied to recall from both REM and NREM stages as it refers to specific types of EEG activity rather than to sleep stages.

The relationship between cortical EEG and dream recall has been examined in seven recent studies. The findings of these studies will be discussed briefly, following an explanation of the two EEG analysis techniques used in these studies. All of these studies use either power spectral analysis (FFT) or period-amplitude analysis.

Fast Fourier transforms describe complex wave forms in terms of their sine and cosine components. A power measure, reflecting the goodness of each sine wave fit, is provided for each EEG frequency or frequency band. This method is a frequency-domain analysis of EEG. The power measure reflects the energy in a given EEG measure and is calculated using the area under the rectified curve (Pigeau, 1983). As the power measure is based on the area under the curve, it is somewhat biased toward slow frequency, high amplitude EEG, since high frequencies will not have high power even if they predominate. This technique does not permit an examination of time in a given frequency independent of

the amplitude. In a comparison of spectral analysis and period-amplitude analysis, Ktonas and Gosalia (1981) show that FFTs cannot differentiate low-amplitude, high-frequency EEG from high-amplitude, low-frequency EEG. Period-amplitude analysis, on the other hand, can distinguish between the two. In addition, two epochs that look very similar in FFTs can be quite different when examined by period-amplitude analysis. For example, an epoch with many medium amplitude waves could not be distinguished from one with a couple of very high amplitude waves (Ktonas & Gosalia, 1981). The advantage of FFT techniques for analyzing EEG is that it is possible to examine very narrow discrete frequency bands. For example, one could examine only 12.2 Hz activity. This type of analysis has little to offer sleep research.

Period analysis, in contrast, examines EEG in the time domain. Period analysis measures the time intervals between successive zero-voltage crossings or instances of zero slope in the EEG (Pigeau, 1983). The original period analysis algorithms (Salzburg, Birch, McClennan, & Corel, 1957) only examined zero-cross events. First derivative or zero slope analysis was added in the late 1960s. Full wave zero-cross analysis measures three successive zero-voltage crossings, while half wave zero-cross measures two successive zero-voltage crossings (Hoffmann et al., 1979). The number of zero-crosses in one second defines the EEG frequency. Delta activity is in the range of .5 to < 4 Hz, 4 to < 8 Hz is theta, 8 to < 12 Hz is alpha, 12 to < 16 Hz is sigma, and 16 to 32 Hz is beta. The zero-cross measures provide the percentage of time in a given frequency. At the end of a sampling period, usually a 30 second epoch, the percentage of all zero-crosses that are delta, theta, alpha, sigma and beta can be determined, summing to 100% for each epoch. A given epoch could, for example, be described as 10% beta, 20% sigma, 30% alpha, 20% theta and 20% delta, reflecting the relative predominance of each EEG band. Both full-wave zero-cross analysis and half-wave zero-cross analysis preferentially quantify slow frequency EEG activity and are not particularly sensitive to fast frequency events.

A first derivative analysis detecting instances of zero-slope can be included to quantify faster frequency events for which zero-crossings are less likely to occur. Most of these events occur off the baseline and would not be detected by zero-cross analysis. First derivative analysis measures the fast frequency EEG activity that is superimposed on the slow frequency activity (Hoffmann et al., 1979). Just as the percentage of time in a given frequency is measured in zero-cross analysis, the proportion of all first derivatives that are beta through delta can be determined, and they also sum to 100%.

Period analysis allows the examination of time-in-frequency, independently of the amplitude of a particular frequency. In addition, period analysis can provide a power-in-frequency measure as well as a total EEG power value. Power is calculated as the area under the half-wave zero-crosses or the cumulative voltage of all zero-crosses in that frequency (Hoffmann et al., 1979). Both spectral analysis and period analysis can provide power measures either for each frequency category or averaged across categories for an overall power measure. Although power is calculated in a different way in spectral analysis and period analysis, statistical analyses have shown that the two approaches yield comparable information with respect to power measures (Pigeau, Hoffmann, & Moffitt, 1981). The main advantages of period analysis are that it allows the examination of time in the frequency independently of the amplitude or power of the particular frequency, and it yields more information about the wave form than do FFTs.

The results of the recent EEG studies provide some support for the idea that increased fast frequency EEG leads to increased dream recall, but the findings continue to be controvertible (Morel, 1991). Two studies examining awakenings from REM sleep found some support for the fast frequency EEG-recall link (Lehmann, Dummermuth, Lange, & Meier, 1981; Meier, 1989). Using power spectral analysis in REM sleep, Lehmann et al. (1981) found that successful recall awakenings were characterized by significantly less power in all frequencies (.4 Hz to 14 Hz) than the 20 second period prior

to awakenings without recall. These differences were greatest in the parietal-vertex electrode placements. Since power depends in part on amplitude, then higher power values suggest more low frequency, high amplitude activity, and less cortical activation is inferred. In this study and a study by Meier (1989), the traditional link between cortical activation and fast frequency EEG is measured by low power values. The results of Lehmann et al. (1981) support the association between dream recall and faster frequency EEG suggested by Koukkou and Lehmann (1983). However, Lehmann et al. (1981) observed that REM periods without recall were shorter than REM periods with recall, but power values did not vary with the length of the REM periods. Given that Koukkou & Lehmann (1983) propose that more time spent in a state with fast frequency activity similar to waking (REM) leads to better recall, this latter finding that longer REM periods did not show more "activation", or less power, contradicts their theory.

Meier (1989) looked at the differences in 16 seconds of pre-awakening EEG between dreams with content, dreams without content, and no dreams reported from REM awakenings. EEG was measured from parietal and temporal-parietal sites. Meier also found significantly lower power values in all frequencies (2 Hz to 25 Hz) associated with recall. Power values were highest for no recall, intermediate for contentless recall, and lowest for recall. Meier concludes that these findings are in support of Koukkou and Lehmann's (1983) hypothesis. However, this study has a methodological problem which seriously undermines that conclusion. Meier does not report whether the 2 Hz to 25 Hz power was measured as total power, or how it was broken into separate frequency bands if it was not total power. If total power was used, this measure would be highly correlated with the slower, high-amplitude EEG activity and is confounded because it mixes slow and fast EEG together in one measure. Secondly, if this analysis indicates that the amplitude is decreasing in all frequencies, the results are somewhat meaningful, as it would indicate less slow EEG activity associated with recall. If, however, these findings suggest that the

incidence, rather than the amplitude, of all frequencies is decreasing, then the fact that less fast frequency EEG is associated with recall directly contradicts Koukkou and Lehmann's thesis. Because these data were analyzed using FFT's, it is impossible to distinguish whether it is amplitude or incidence that is decreasing as recall increases. An additional problem with this study was that the differences disappeared when comparisons between levels of recall were made within subjects. Due to the methodological problems, this study provides equivocal support for the functional state-shift hypothesis of Koukkou and Lehmann.

Antrobus, Ehrlichman, Wiener, and Wollman (1983) looked at 3 minutes prior to REM awakenings, categorized as either high or low power periods. In this study, EEG was recorded from the temporal-parietal sites referenced to the vertex. Based on Koukkou and Lehmann's (1980) proposal that as the cortex becomes more active (more fast frequency EEG) recall should be better, these authors assumed that within REM more activation, as measured by lower power values, should be related to longer reports. These authors compared the high power REM periods and low power REM periods in terms of total recall word count (TRC) and four visual imagery scales. It was assumed that greater TRC would be associated with greater cortical "activation". Antrobus et al. (1983) found, however, that neither TRC nor the imagery scales were associated with cortical activation as measured by spectral power. Wollman and Antrobus (1987) also failed to find any relationship between spectral power in each of six frequency bands (delta, theta, alpha, sigma, beta and above 30 Hz) and total recall count, looking at pre-awakening EEG from REM periods. EEG was measured from central and temporal-parietal sites referenced to the vertex. The findings of these two studies do not support a relationship between increased fast frequency EEG and increased recall, since power spectral values were not related to amount of information recalled from REM.

Only two studies have looked at EEG frequencies and dream recall in NREM sleep. Moffitt et al. (1982) used period analysis to look at the 5 minutes pre-awakening tonic EEG data of high and low frequency recallers awakened from both REM and Stage 2 sleep. EEG was measured from central sites. Significant interactions were found between subject type (high or low recallers) and recall. In the pre-awakening EEG from Stage 2 awakenings, nonrecall was associated with more delta power and time in the delta frequency band and less sigma zero cross for the frequent recallers compared to the infrequent recallers. In the 4 minutes post-awakening from both REM and Stage 2 awakenings, recall was associated with more eye movements and more alpha first derivative for both frequent and infrequent recallers. Recall was associated with less beta first derivative for frequent recallers and less sigma first derivative for low recallers in the post-awakening period. Williamson, Csima, Galin, and Mamelak (1986) looked at 32 seconds prior to awakenings from Stage 2 sleep using power spectral analysis. EEG was recorded from frontal and central sites. These authors found that increasing dream recall was associated with a significant increase in mean frequency in the sigma-beta band from recordings on the right side of the brain. While this trend was also observed from the left hemisphere, it was not significant. Mean frequency is essentially a frequency measure with amplitude removed, so it is not a power value. Recall was not associated with the spectral power values. Like Moffitt et al. (1982), Williamson et al. (1986) also found that power within Stage 2 in the theta-delta bands decreased with increasing recall, but this difference was not significant.

The six studies reviewed above show some support for the proposed relationship between increased fast frequency EEG, or low power EEG, and increased dream recall, with the exception of work from Antrobus and colleagues (Antrobus et al., 1983; Wollman & Antrobus, 1987). Dream recall was related to more fast frequency EEG in the pre-awakening period as measured by lower total power values in REM sleep (Lehmann et al.,

1981; Meier, 1989), greater amounts of sigma zero-cross and lower amounts of delta zero-cross and delta power for high dream recallers in awakenings from Stage 2 sleep (Moffitt et al., 1982), and increased mean frequency of the sigma-beta band for awakenings from Stage 2 sleep (Williamson et al., 1986).

A study by Morel (1991) addressed some of the problems not covered by earlier research on EEG correlates of dream recall. With the exception of Moffitt et al. (1982), most studies look at the pre-awakening EEG only, and compare success and failure to recall. Focus on the pre-awakening EEG does not directly address the proposal by Koukkou and Lehmann (1983, in press) that recall is facilitated when the dreaming and waking states are closer together, nor does it address the possibility that it is the post-awakening period that affects dream recall. In order to test the thesis that recall is facilitated when two states are close together, both the pre-awakening and post-awakening states must be compared. Morel examined the pre- and post-awakening EEG, and the difference between the pre- and post-awakening EEG using period analysis. Morel focused on awakenings from Stage 2 because it allows a more even sampling of successes and failures to recall a dream than in REM awakenings. In order to better control for the confounding effects of subject variability, the majority of Morel's subjects were self reported medium dream recallers (recall a dream between one to five times a week). Use of frequent recallers would not provide enough instances of failure to recall, and use of infrequent recallers has been shown to be problematic because it often leads to large within group variability in how the subjects respond to experimental procedures and so affects recall ability and performance (Purcell, Mullington, Moffitt, Hoffmann, & Pigeau, 1985).

As Morel (1991) provided a more detailed analysis of the relationship between recall and NREM EEG, a detailed review of the paper will be presented. Morel (1991; Morel et al., 1991) examined the EEG of 40 subjects awakened from Stage 2. Fifty successful recall awakenings were compared with 38 failures to recall using period analysis

to look at the 5 minutes pre-awakening EEG, 30 seconds post-awakening EEG, and the pre-awakening to post-awakening EEG difference scores. In the pre-awakening interval there were no significant differences between recall and failure to recall on any of the EEG measures. Muscle activity approached significance, with greater pre-awakening muscle activity associated with failure to recall. Although the difference was not significant, average total power did show greater values associated with non-recall, as would be expected under Koukkou and Lehmann's (1983, in press) hypothesis. The post-awakening interval did reveal some significant differences. Significantly greater EMG activity was observed for successful recall compared to recall failures. The difference was in the opposite direction for the sigma first-derivative measure, with more sigma first-derivative preceding failure to recall than successful recall.

Examination of the difference scores between pre-awakening and post-awakening EEG on 19 of the EEG measures also revealed significant differences for the EMG and sigma first derivative measures (Morel, 1991; Morel et al., 1991). In direct contradiction to the theory of Koukkou and Lehman, Morel found that there was a greater change from pre- to post-awakening for the successful recall events than for the nonrecall events on both EMG and sigma first-derivative measures. Given that the two events were not different pre-awakening and were different post-awakening, Morel concluded that this result is due to post-awakening differences.

To summarize, Morel (1991) was not able to replicate previous findings that more fast frequency activity pre-awakening is associated with increased dream recall. Morel found no differences in the pre-awakening period. The lack of significant difference between success and failure to recall at the pre-awakening period suggests that it is not encoding or dream generation that differentiates these two events, rather it is an issue of recall. This finding is of particular importance, as pre-awakening EEG has been the focus of much of the theorizing and research on psychophysiological correlates of dream recall.

The most important results of Morel's study are those relating to the shift from the pre-awakening to the post-awakening period, and in particular the findings in the post-awakening period. The study contradicts Koukkou and Lehmann's hypothesis that recall is better when sleeping and waking states are more similar, as larger differences between the pre-awakening and post-awakening periods resulted in better recall. Finally, Morel's finding that the post-awakening period did show significant differences between success and failure to recall, combined with the lack of any significant difference pre-awakening, suggests that it may be the post-awakening period that has the greatest impact on success and failure to recall. The fact that recall was associated with less sigma first derivative activity, combined with Moffitt et al.'s (1982) findings of more alpha first derivative activity, suggest that the faster EEG frequencies post-awakening are differentiating success and failure to recall. Alpha activity may be related to intensive cognitive processing focussing on internal processes (see Pigeau, 1983 for a discussion). Morel et al. (1991) speculated that the lower sigma activity may be an indicator of unblocked sensory receptivity and thus greater arousal. The exact meaning of the sigma findings is speculative at best.

Morel et al. (1991) concluded that it is a difference in the pattern of arousal in the transition from sleep to wakefulness that differentiates successful from unsuccessful recall. The finding that there is a significant difference in the post-awakening period suggests that recall is facilitated by a transition from sleep to wakefulness that involves moving to a greater state of alertness upon awakening.

Other theoretical literature in the area of dream recall points to the process of waking up as the key to success and failure of dream recall (e.g. Koulack & Goodenough, 1976). In addition, empirical studies exist which support the proposal of Morel et al. (1991) that successful dream recall is associated with greater arousal upon awakening.

Koulack and Goodenough (1976) have proposed an arousal-retrieval model to account for dream recall. According to these authors memory has two stages whereby information must be processed in the short-term memory in order to facilitate later retrieval from long-term memory. Under this model, dreams can only be remembered if the sleeper is awakened during the life of the short-term memory trace, which presumably lasts only a few seconds. If the dreamer is not awakened or aroused, the events occurring in sleep may still be encoded in long-term memory, but the dreamer will not have had the opportunity to obtain retrieval cues while the events were being processed in the short-term memory trace. The degree of arousal during this waking period will be a determinant of recall, according to the model. Furthermore, any distractions by events or thoughts more salient than the dream that occur at awakening will interfere with dream recall, as they may interfere with the dream material and take over the limited capacity of the short-term memory trace.

The proposal that arousal during learning affects the ability to recall is supported by empirical research (Koulack & Goodenough, 1976). Several sleep-learning studies have shown greater learning and retention in those subjects with greater or extended arousal following the presentation of the stimulus to be learned (Evans & Orchard, 1969; Jus & Jus, 1972; Jus et al., 1969; Koukkou & Lehmann, 1968). These studies all involved the presentation of stimuli while the subjects were asleep. Koukkou and Lehmann (1968) and Evans and Orchard (1969) used alpha rhythms as the measure of arousal. Jus and Jus (1972) and Jus et al. (1969) used such measures as K-complexes, sigma, alpha, beta bursts, EMG and EKG to measure arousal.

Studies which have awakened subjects and presented them with some material to be remembered also showed recall performance to be associated with arousal. In a series of studies by Goodenough and colleagues, subjects were awakened a number of times in the night and shown a stimulus word that they were to read aloud (Goodenough, Sapan, Cohen, Portnoff, & Shapiro, 1971; Portnoff, Baekeland, Goodenough, Karacan, &

Shapiro, 1966). The subjects were then either permitted to return to sleep or were kept awake. Subjects who received arousing instructions immediately after saying the stimulus word recalled more words the next morning than those who were not aroused and were permitted to return to sleep. The techniques used to keep the subject aroused were such things as performing a psychomotor task or testing their two-hand coordination.

The importance of arousal in dream recall is also seen in studies that show recall is better from abrupt REM awakenings than from gradual awakenings (e.g. Goodenough et al., 1965). Abrupt awakenings allow the subject to access the dream material so that it can be processed while still in short-term memory. The material in short-term memory then provides the necessary cues to retrieve the rest of the dream, as it was encoded, during preceding sleep. At the point of awakening then, only distraction by competing events will interfere with recall. Studies have shown that being given a task to perform will interfere with recall (Cohen & Wolfe, 1973). Events from the previous day, recalled on awakening, are also distracting and will interfere with dream recall (D. Cohen, 1974; Goodenough, Witkin, Lewis, Koulack, & Cohen, 1974).

The arousal-retrieval theory (Koulack & Goodenough, 1976) fits well with the interpretation of Morel's findings and offers a theoretical basis for an explanation of dream recall success and failure that incorporates both arousal and distraction. Together, this research suggests that the process of waking up and the period following awakening are critical to successful recall. Rather than use the term arousal, which can have many definitions, it seems more appropriate to refer to the nature of the state shift that occurs when a subject is awakened from sleep. (Note: When the term "arousal" is used in this paper it will be used to refer specifically to the process of awakening from sleep. It will be obvious to the reader when the term is being used in a broader sense than the one just described.) If the nature of the state shift is the key factor in accounting for successful dream recall during experimental awakenings, specifically, if a weaker or less complete

state shift and higher levels of distraction during awakening account for failure to recall, it seems reasonable to expect that some electrophysiological measure of brain activity and attention would show differences between successful and failed recall events. However, previous EEG research reviewed in this paper indicates that low EEG power and fast frequency EEG activity, assumed to be measures of cortical activation and arousal, do not show any consistent relationship with dream recall. In addition, Morel's (1991) findings suggest that the post-awakening period is more important than the pre-awakening period in affecting dream recall. Contrary to the functional state-shift hypothesis (Koukkou & Lehmann, 1983), Morel's findings suggest that a greater state-shift facilitates successful dream recall. Direct current potential activity, an alternative electrophysiological measure that is associated with awakening and with cognitive task performance, may enhance our understanding of the electrophysiological correlates of dream recall. These potentials may be useful in describing the state shift and in predicting success or failure of dream recall.

1.2 Direct Current (DC) Potentials

Direct current potentials are bioelectric changes in the brain that occur at very low frequencies (Gumnit, 1974), usually less than .1 Hz (Hillyard, 1973). They are referred to as direct current, or DC potentials, because of the use of direct coupled amplifiers in original attempts to measure them, but are also referred to as steady potentials, slow potentials, standing potentials and sustained potentials (Gumnit, 1974). In this paper they will be referred to as direct current potentials, or DC.

EEG and DC measured from the scalp are both extracellular field potentials which arise from the bioelectric activity of cells in the brain. The two types of potentials differ mainly in the way they are amplified and recorded (Speckmann & Elger, 1982), and possibly in their cells of origin. Both EEG and DC can be recorded against an inactive reference point with an upper frequency limit of 100 Hz. Standard electroencephalography measures field potentials recorded at a time constant of one second or less, while DC

recording is conducted with an infinite time constant enabling much slower potentials to be recorded, in addition to the higher frequency potentials commonly seen in EEG (Speckmann & Elger, 1982).

EEG and DC potentials are believed to originate from the summation of the excitatory post synaptic potentials (EPSPs) and inhibitory post synaptic potentials (IPSPs) of the nerve cells in the cortex (Anch, Browman, Mitler, & Walsh, 1988). Glial cells, which are found between the nerve cells, are also thought to contribute to the production of cerebral potentials (Goldring, 1974; Speckmann & Elger, 1982). Unlike nerve cells that produce action potentials when stimulated (EPSPs and IPSPs), glial cells undergo slow depolarizations believed to account for part of the shifts in DC potentials (Goldring, 1974). DC potentials may arise from a combination of some or all of EPSPs and IPSPs of nerve cells, and slow depolarizations of glial cells. Given that all three types of membrane changes can occur simultaneously and that a surface potential is the algebraic sum of all of the changes occurring, it is difficult to locate the exact origin of the DC shifts (Goldring, 1974).

The behaviour of DC potentials in relation to the sleep-wake cycle is of most relevance to this paper. The majority of this research was carried out on animals in the 1960s (Bechtereva, 1974). This review will focus on findings of changes in DC potentials in relation to the transition between waking and sleeping, changes across the night, during prolonged periods of wakefulness, and during cognitive performance. DC in the transitions from sleeping to waking and the relationship between DC and attention during cognitive performance are of most relevance here.

Although a history of research on DC activity in animals is not directly relevant to the current study, it provides evidence of the relationship between DC activity and the sleep-wake cycle, so it will be reviewed briefly. In a review of early animal studies Bechtereva (1974) points out that DC potentials consistently show shifts in transitions from

wakefulness to sleep, changes in the depth of sleep, and in transition to slow wave sleep (SWS) or to REM sleep. DC also changes when a sleeping animal is stimulated and when the animal is awakened, either gradually or abruptly. The direction of the potential shift (positive or negative) is not always consistent across studies and depends on the reference points used as well as on spatial characteristics of recording. A comparison of studies is complicated by the fact that researchers omit details of recording and analysis techniques so that it is difficult to discern why studies lead to different findings. In an attempt to facilitate an understanding of the findings of the animal studies, the location of electrodes for recording will be given, when possible, following the first mention of the study. A review of the animal studies will be organized in terms of research interest. DC in transition from wakefulness to sleep will be discussed first, followed by a discussion of DC in transition to SWS or to REM. Finally, DC in response to stimulation and arousal from sleep will be considered.

The transition from wakefulness to sleep has been consistently linked with a change in DC levels and a reduction of DC oscillation levels in animals (Caspers, 1963). The development of sleep, moving to more slow waves, usually corresponds to positive DC shifts (Caspers, 1961a, 1961b, 1963, 1965; Caspers & Schulze cited in Bechtereva, 1974; Tabushi, Hishikawa, Ueyama, & Kaneko, 1966). This shift ranged from 1.5 mV to 500-800 μ V. The recording technique used by Caspers is only given in articles that are written in German, so they are currently unattainable. Various regions of the intact cortical surface referenced to the bone of the front portion of the muzzle were the recording placements in one of Caspers' studies (1961b) so it is possible that a similar setup is used in all of his studies. Caspers (1963) observed that the transition from awake to asleep involved a positive shift from the mean waking level in rats with implanted electrodes. Tabushi et al. (1966) recorded from the dura over the gyrus sigmoideus anterior, gyrus sigmoideus posterior, dura lateralis, and from the hippocampus and mesencephalic reticular

formation of the cat. The same results were obtained if the recording system used either the nasal portion of the frontal bone or the occipital bone as a reference point. In the transition from wakefulness to sleep, DC shifted in a positive direction (Tabushi et al., 1966).

Several studies have observed shifts in DC in the transition from SWS to REM sleep and in the transition to SWS from other stages. Caspers (1965) found a positive shift in the transition from SWS to REM sleep, and greater positivity with increasing SWS. Kawamura & Sawyer (1964) observed a negative shift in the change from SWS to REM sleep in subcortical electrodes in rabbits, and a positive shift in the transition to SWS. Kawamura and Sawyer usually had DC electrodes implanted in the motor cortex and the hypothalamus. It is not clear in this study which results come from which recording areas, and it appears that the reference electrode could have been on either the frontal or occipital bone. Tabushi et al. (1966) also observed a negative shift in DC in the transition from SWS to REM sleep in the cat and a positive shift in the transition to SWS. Kawamura & Pompeiano (1969) found a negative shift upon entrance into REM sleep in the frontal and occipital cortices of the cat referenced to the occipital bone. In contrast, Wurtz (1965) and Wurtz, Goldring, and O'Leary (1964) found a negative, rather than positive, DC shift during SWS and positivity during REM sleep. Both of these studies used a transcortical recording technique in which electrodes on the surface of the cortex in the dura over the sigmoid, middle suprasylvian and posterior lateral gyri of cats were referenced to electrodes in the white matter next to each surface electrode. The use of a transcortical recording technique is believed to account for the differences in the direction of the shift in the Wurtz studies compared to other studies (Kawamura & Sawyer, 1964). Many studies find that DC becomes constant during full SWS and will shift with changes in the depth of sleep and when external stimuli are presented (Caspers, 1963, 1965; Caspers & Schulze cited in Bechtereva, 1974; Wurtz, 1965).

Stimuli presented to an animal during sleep that did not awaken the animal caused a small DC shift in the opposite direction to the shifts seen when sleep deepens. Arousal from sleep brought DC back to its original level with a return to faster oscillations (Caspers & Schulze, cited in Bechtereva, 1974). Caspers (1963) noted that arousal from sleep is usually accompanied by a negative DC shift followed by a return to the waking level. A gradual spontaneous awakening led to a gradually rising curve followed by a negative shift. This shift reached its peak when EEG showed high-frequency low-amplitude waves. A provoked awakening, usually induced by tactile stimulation or presentation of conditioned stimuli, was always accompanied by a steeper negative DC shift in which maximum voltage was reached as arousal began. If wakefulness persisted, DC remained negative, whereas arousal followed immediately by sleep resulted in a return to levels observed before arousal. Caspers (1963) also observed that spindle activity was associated with negative DC deflections. Kawamura & Pompeiano (1969) observed a negative DC shift when awakening a cat from slow wave sleep with auditory stimulation. Kawamura & Sawyer (1964) observed a negative shift upon stimulation or arousal from sleep, as did Tabushi et al. (1966). According to Bechtereva (1974) the majority of studies with animals find that DC potential shifts in a negative direction during arousal from sleep. However, Wurtz (1965) and Wurtz et al., (1964) observed a positive shift in arousal. Again, these differences are likely due to the use of transcortical recordings rather than an extracerebral reference electrode.

To summarize, the majority of studies find negative DC shifts in the transition to REM sleep and in shifts from sleep to wakefulness, and positive DC shifts associated with falling asleep and increases in SWS (Bechtereva, 1974). When studies show opposite changes in polarity, it is still most often the case that the observed shift in REM is in the same direction as that observed during arousal from sleep, which is opposite to the shift observed when the animal falls asleep. Despite inconsistencies between studies in terms of

the direction of the DC shifts, every study recorded distinct changes in polarity associated with transitions from wakefulness to sleep and vice versa. Different recording techniques are thought to account for the differences in findings (Bechtereva, 1974).

The study of DC potential activity in human sleep has been minimal. Since this study addresses DC behaviour in the sleep of humans and its potential relationship to sleep mentation, a review of the available studies using human subjects will provide insight into whether DC behaves similarly in humans as in animals, and what kinds of DC activity we might expect to observe in this study.

The earliest attempts at studying DC potentials in human sleep led to contradictory results. Davis, Davis, Loomis, Harvey, and Hobart (1939) attached electrodes to frontal (F1, F2), central (C3, C4), and occipital (O1, O2) areas, and behind the ear above the mastoid process (A1, A2) with a reference electrode on either the chest or the mastoid to examine DC potentials in the sleep of 7 humans. The DC potential was measured every 15 minutes for only 2 to 3 hours of sleep. The authors found no change in the slow "random" fluctuations of DC when the subject fell asleep, moved to deeper sleep defined by slow, high amplitude waves, or awoke, either gradually or abruptly. This lack of change related to sleep was consistent in all seven subjects and between all possible electrode pairs. They concluded that there was no correlation between the DC potential and sleep stage. The graphs reported in their paper, however, do indicate a gradually increasing negativity in DC (from -2 to -8 mV) across the three hour recording period. In addition, the graphs indicate changes in the positive direction ranging from approximately 1 mV to 4 mV when the subjects were waking up spontaneously. Other recordings presented graphically do show small positive shifts in awakenings. Unfortunately the authors do not discuss this so it is difficult to discern the time frame of these shifts.

King (1946) examined DC activity on the human scalp measured from the forehead referenced to the back of the neck of seven subjects. King found several interesting

changes in the DC activity with changes in sleep and wakefulness. DC was examined before going to sleep, during sleep, and on into wakefulness, so recording periods ranged in length from 5 to 7 hours. DC potential differences, calibrated in millivolts and plotted from a zero baseline, showed a gradual lowering of the potentials, moving towards greater negativity at sleep onset, a maintenance of low values during sleep and a return to presleep levels at the termination of sleep. DC potential differences changed as much as 60 mV in one subject during sleep, but on average these changes were in the range of 8 mV. Subjects showed greater potential differences before and after sleep than during sleep. In addition, the DC activity was less variable during sleep than in waking, and during sleep there was less variability between subjects in the DC activity than in waking.

Graphs presented in this study indicate notable changes in DC activity upon awakening (King, 1946). One subject showed a change of 5 mV immediately following awakening. It is not clear in this paper, but it appears that these awakenings were induced rather than spontaneous. Wakeup activity of the DC was quite variable between subjects. Unfortunately, the author only provided a detailed examination of the DC activity surrounding awakening for two subjects. Nonetheless, King's work does provide evidence of a phasic DC shift in humans upon awakening. These findings are of particular importance, as the DC activity during awakening will be of interest in studying its relationship to dream recall in experimental awakenings.

The discrepancies between King's (1946) findings and those of Davis et al. (1939) are discussed by King. As mentioned previously, Davis and colleagues only examined very short periods of sleep (2-3 hours), whereas King studied 5 to 7 hour periods. In addition, Davis et al. used different electrode placements. Most importantly, however, King pointed out that the graphs in the Davis study do show a decline in DC potential differences in sleep very similar to that observed by King. The negative conclusions of Davis et al. can be attributed to the fact that their specific purpose was to examine DC

changes in relation to changes in sleep stages, which were not observed, whereas King was simply looking at differences in the DC activity during waking and sleeping.

Later studies showed findings similar to those seen in animal studies. Starobinetz (cited in Bechtereva, 1974) observed a positive shift in sleep onset and a further increase in positivity during the development of SWS. DC activity then stabilized during the presence of delta activity and sleep spindles. Studies by Avramov (cited in Bechtereva, 1974) in humans with implanted electrodes, showed that DC in humans slows down in oscillations around sleep onset, decreases in amplitude, and shifts from baseline. DC activity becomes more stable as sleep develops with the baseline shifting further from its initial level. Awakening is then accompanied by a shift of the DC in the opposite direction of that seen in falling asleep, a return to its initial baseline level, and return to faster oscillations. Unfortunately, the work of both Starobinetz and Avramov are reported in Russian and are not available for closer examination.

Since these early studies in the 1960s, research examining DC potentials in relation to the human sleep-wake cycle has been minimal. Recently, Hoffmann, Moffitt, Armitage, and Jones (1988) studied the DC activity in 11 subjects over the course of a night's sleep. DC was recorded from the C4 electrode referenced to A1. The average DC of all subjects showed a clear decline across the night towards greater negativity. The difference between the DC level at the beginning and end of the night was statistically significant. The slope of the change was maximal at the start of the night, and followed a negative decelerating trend with one increase in slope about two hours into the night. This study clearly indicated a change in scalp DC in humans associated with the sleep-wake cycle.

A second study (Hoffmann et al., in submission) was performed to further confirm the relationship of DC to sleep. Thirteen subjects slept a normal night and 12 were sleep deprived. The non-deprived subjects showed the same DC trends as found by Hoffmann et al. (1988); DC decreased across the night, moving towards greater negativity. DC

returned to baseline after awakening, but this return was very slow and gradual over the course of the day. The sleep deprived subjects showed a smaller decrease in DC throughout the night than that exhibited by the non-deprived group. This was followed by a rise in DC that continued until the end of the 24 hour experimental period. The findings of this study led the authors to suggest that DC level might index fatigue; as fatigue increases, DC increases in positivity. This study is particularly important because it shows that DC responds to manipulation of the presence or absence of sleep.

To review, studies of DC activity in sleep do show a relationship between DC and the sleep wake cycle. Davis et al. (1939) and King (1946) both present data which indicates that DC potential differences decrease gradually during sleep and increase again upon awakening. Avramov also reported a shift in DC back to baseline upon arousal from sleep, but a detailed examination of these results is not possible. Hoffmann et al. (1988, in submission) did not find abrupt DC shifts when their subjects were awakened. The shift in DC activity upon awakening has not been observed as consistently in humans as in animals. There are two possible reasons for this discrepancy. One is that the human recordings were in the range of millivolts, which is not sensitive enough to detect those changes observed with animals. However, it may also be the case that no changes were observed because the human studies were not focussing on the specific awakening period and were essentially examining a more tonic form of DC activity. For example, Hoffmann et al. (in submission) looked at the averaged hourly change in DC potentials from baseline, a technique which does not allow a second by second examination of phasic shifts in DC potential surrounding awakening. Hoffmann et al. (1988) did not report DC activity following awakening. Specific examination of DC activity in humans surrounding evoked awakenings remains to be performed.

It should be noted that the Hoffmann et al. studies (1988, in submission), Davis et al. (1939) and King (1946) observed increasing negativity of the DC across the course of a

night, whereas the majority of animal research revealed increasing positivity with the onset and development of sleep. These differences may be due to the differences in the location of the recording and reference electrodes and the relative polarity of the recording and the reference electrode. The animal studies all used implanted electrodes, whereas human recordings are made from the scalp, with the exception of Avramov (cited in Bechtereva, 1974). In animals the reference electrode is usually placed on the nasal bone or the occipital bone, whereas human studies usually used the mastoid or chest as a reference. The quality and types of amplifiers used in each study will also affect the results. These technical differences make direct comparison of the results of the human and animal studies rather difficult.

Despite the potential utility of DC potentials in studying sleep-related phenomena, little work has been done because of the technical difficulties inherent in DC measurement (Bauer, Korunka, & Leodolter, 1989; Hillyard, 1974; Speckmann & Elger, 1982). One reason for the lack of research into human scalp DC is the disagreement over possible artifactual contaminations in DC recordings. Hoffmann et al. (1988) have performed several manipulations to eliminate possible artifactual interpretations of DC activity. It has been argued that DC changes are merely a linear artifact due to the drying of electrode paste or polarization of electrodes. The study by Hoffmann et al. (in submission) clearly eliminates this possibility, however, since electrode impedance was measured every hour, and electrodes were reapplied if it exceeded 5K ohms. Since previous research by these authors found DC changes at much higher impedance levels the authors did not feel that the maintenance of impedance levels at <5 Kohms would dramatically affect the results. In addition, Hoffmann et al. (in submission) found a curvilinear trend, rather than a linear one that could be explained by the drying of electrode paste.

Attempts to remove contamination in recording due to electrodermal secretions by heavily abrading the skin (impedance <1 Kohm) did not change the results of the earlier

study (Hoffmann et al., 1988). With regard to skin potential artifacts caused by changes in temperature, the magnitude of the DC change in Hoffmann et al. (in submission) covered an average range of 20 mV. Snodgrass, Rick, and Menkin (1944) found changes of 1 mV per 1 degree centigrade, so it is unlikely that a DC change as large as 20 mV could be accounted for by changes in skin potential due to changes in temperature. Hoffmann et al. (1988) reported previous studies in which DC was recorded while either an ice cube was placed on the electrodes or a hot air blower was directed at the electrodes. The cold reduced the DC level by moving the recording towards 0 volts and heat increased the DC level, but not at the magnitude of change observed in the more recent study (Hoffmann et al., in submission).

Amplifier drift was also eliminated as a possible source of artifact by Hoffmann and colleagues (Hoffmann et al., 1988). Although statistical evaluation of the drift throughout the night showed a significant change, it was in the opposite direction of the change shown by the subjects and was much smaller in magnitude (.18 mV) than the changes observed in the study (15 mV).

Additional support for DC as a valid measure of brain activity comes from the overwhelming majority of studies reviewed above that show changes in DC activity with changes between sleeping and waking states in both humans and animals (e.g. Avramov cited in Bechtereva, 1974; Caspers, 1961a, 1961b, 1963; Davis et al., 1939; King, 1946; Starobinets cited in Bechtereva, 1974). Inconsistencies in directions of changes have been accounted for by differences in recording techniques. In addition, Hoffmann et al. (in submission) have successfully shown that DC activity responds to manipulations of sleep. Moreover, in studies using implanted electrodes in animals, DC activity changes in response to stimulation of the reticular formation, suggesting that DC is, in fact, a measure of brain electrical activity (see Caspers, 1961b for a discussion). Finally, Caspers and

Speckmann (1974) have shown that the administration of agents like carbon dioxide, which reduce the efficacy of brain function, effectively alters brain DC levels.

The strongest argument against scalp DC being an artifact of phenomena other than brain activity comes from a study by Cowen (1974). Cowen attempted to determine the location of the source of DC potentials by studying:

every conceivable voltage generating tissue and structure of the head ... both under maximal stimulation and maximal inhibition ... Structures studied were: the various layers of the scalp itself; scalp sweat glands; the nervous and vascular supply of the scalp; the structures of the orbit; the muscular distribution of the head; the skull; the meninges; and finally the vascular supply of the cortex and the cortex itself (pg. 321).

Cowen concluded that "no structure played any significant DC generating role except the cortex" (pg. 321). In sum, it seems unlikely that DC changes in relation to the sleep-wake cycle are due to artifact; it appears that they are, in fact, valid measures of changes in brain activity that correlate with changes in the sleep-wake cycle.

The relationship between brain DC activity and cognitive performance is also relevant to this study. Hoffmann et al. (in submission) examined changes in DC activity across 25 minute testing sessions in which subjects were performing various tasks. These tasks included a Stroop color and word task (Stroop, 1935), a vowel/consonant discrimination task, letter recognition, and a working memory test. Over the course of the test session, there was a significant drop in DC to more negative levels. The observed change ranged from -0.25 to -2.5 mV. Further analyses revealed that this drop was smaller in later test sessions, a finding which was attributed to the fact that subjects were practised and were thus less attentive. In addition, the sleep deprived subjects showed less of a negative drop, and in some cases a positive DC change. This finding was interpreted as an inability of sleep-deprived subjects to "drive" the DC down during testing, a phenomenon

perhaps indicative of their inability to attend. Additional support for this conclusion comes from findings that a type of phasic DC activity known as contingent negative variation is attenuated following sleep deprivation (Naitoh, Johnson, & Lubin, 1971) and disturbed sleep (Yamamoto, Saito, & Endo, 1984).

A closer look at research on the contingent negative variation (CNV) provides further evidence that slow potentials shift during task performance. The CNV, originally observed by Walter, Cooper, Aldridge, McCallum, and Winter (1964), is a slow potential in the microvolt range that can be recorded from the human scalp when a subject is given one stimulus, followed by a second stimulus to which the subject might have to respond. The CNV is a slow negative shift observed in the time interval between the first and second stimulus presentations. Much research has eliminated the possibility that the CNV is due to eye movement, and there is evidence to show that it is not simply a readiness potential driven by motor preparedness, as it occurs when only sensory-perceptual tasks are presented without the motor response (J. Cohen cited in Hillyard, 1974). The CNV, then, can be considered a cognitive readiness potential (Walter, 1964).

The CNV is a well known and reliable measure of a slow potential that relates to cerebral functions and cognitive activities (Yamamoto et al., 1984). In addition, the CNV has been found to be related to attention, motivation and readiness (McCallum, 1969; McCallum & Walter, 1968; Rebert, McAdam, Knott, & Irwin, 1967; Tecce & Scheff, 1969; Walter, 1964).

McCallum and Walter (1968) found an attenuated CNV if subjects were presented with distracting stimuli, along with the presentation of the two linked stimuli. Distracting stimuli could be an experimenter talking, or even a preoccupation with a full bladder. Thus, it appears that the more attentive or focussed an individual is to the task at hand, in this case responding to the second stimulus, the greater the amplitude of the CNV.

In a similar study, Tecce and Scheff (1969) used letters or numbers spoken by the experimenter, either before or within the interval between the two stimuli, to distract the subject and test the effects of attention on the CNV. Distraction led to a reduction in the CNV amplitude. The authors concluded that "the amplitude of contingent negative variation is a sensitive measure of attentional processes in humans" (pg. 333).

In sum, CNV research and DC activity during cognitive performance indicate that DC activity is sensitive to cognitive task performance and to manipulations of attention. Koulack and Goodenough (1976) suggested that two factors influence the ability to remember a dream. Initially, subjects must be sufficiently aroused upon awakening; the state shift from asleep to awake must be strong and complete. The application of DC to this aspect of recall has already been discussed. Secondly, the subject must be able to attend to the pre-awakening material without being distracted. When a subject is awakened and asked to recall a dream, they are being asked to perform a cognitive task which involves memory, attention, and information processing (Koulack & Goodenough, 1976). Thus, the research reviewed that shows a relationship between DC activity and cognitive performance provides further support for the argument that brain DC could be expected to show a relationship with dream recall.

1.3 The proposed relationship between DC activity and dream recall

The combined results of DC and CNV research lead to two possible links between DC activity and dream recall in experimental awakenings. Koulack & Goodenough (1976) proposed that remembering a dream requires the subject to be sufficiently aroused, or to make a strong state shift, during the length of the short term memory trace and to be without distraction from the task at hand, which is to remember the pre-awakening mentation. Morel et al. (1991) have also suggested that it is the process of awakening and the post-awakening period that determine successful recall. Many of the studies of DC potentials reviewed found that DC shifted upon awakening to levels similar to those

observed in waking, or at least moved in the direction of the DC activity observed in waking (Caspers, 1963; Kawamura & Pompeiano, 1969; Kawamura & Sawyer, 1964; King, 1946; Tabushi et al., 1966). If DC shifts upon awakening in humans, we can speculate that a greater DC shift upon awakening would indicate a stronger state shift and thus might facilitate recall.

With respect to the cognitive requirements of recall in the retrieval period, CNV and DC research on cognitive task performance suggest a relationship between DC and dream recall may be observed during the retrieval period. CNV research shows that the magnitude of a CNV is attenuated when the subject is distracted or not attending to the task at hand (e.g. Tecce & Scheff, 1969). Work by Hoffmann et al. (in submission) has shown that inferred decreases in attention to cognitive tasks, either due to sleep deprivation or practice effects, decreased the magnitude of the DC change which occurred during task performance. We might expect to observe differences between success and failure to recall in the DC potential following prompting to recall dreams, since it is after that prompt that the subject is required to focus on the pre-awakening mentation. Successful dream recall might be associated with a greater shift in DC potential during the retrieval period, since distraction, interfering with recall (Koulack & Goodenough, 1976), would likely attenuate the DC shift.

In addition to providing a new and unique test of the electrophysiological correlates of success and failure to recall dreams, this study will provide an opportunity to study the effects of awakening on DC levels in a relatively large sample.

1.4 Hypotheses

1. a) In order to replicate Morel's (1991) study, the DC activity pre-awakening will be compared between success and failure to recall. With respect to the pre-awakening DC activity, no specific hypothesis was made.

1. b) Koulack and Goodenough (1976) and Morel et al. (1991) suggested that it is the process of awakening that differentiates success and failure to recall, and that successful recall is associated with a stronger state shift from asleep to awake. Morel et al. (1991) suggested that, compared to failure to recall, successful recall is associated with movement to a level of alertness upon awakening that is closer to that of full awakening. It is expected that if DC shifts when the subject is awakened, successful recall will be associated with a larger shift in DC from its pre-awakening level, assuming that a greater DC shift indicates a stronger state shift.

2) A hypothesis about the direction of the DC shift upon arousal from sleep is difficult since studies which show such a shift in humans did not examine them closely and those that did found much subject variability (Davis et al., 1939; King, 1946). However, the animal literature shows that upon arousal from sleep DC shifts in the opposite direction to the shift observed in the development of sleep. In addition, Avramov, who was working with human subjects, also found that arousal from sleep was accompanied by a shift of the DC in the opposite direction to that seen in falling asleep (Avramov cited in Bechtereva, 1974). Given that human research on scalp DC shows that DC moves in a negative direction during sleep (Davis et al., 1939; King, 1946; Hoffmann et al., 1988, in submission), it is expected that DC will shift in a positive direction during awakening.

3) With respect to the DC activity while the subject is responding to the task of recalling the dream, it is assumed that the subject must stay awake and attentive in order to recall the dream to the experimenter. Hoffmann et al. (in submission) and CNV research showed negative shifts in DC potential during cognitive tasks which are attenuated by fatigue, distraction or lack of attention (McCallum & Walter, 1968; Naitoh et al., 1971; Tecce & Scheff, 1969; Yamamoto et al., 1984). Therefore, it is expected that during this period successful recall will be associated with a greater DC shift in the negative direction than failure to recall.

4) The use of time of night as a covariate may be necessary in order to control for the fact that tonic DC changes over the course of a night's sleep (Hoffmann et al., in submission), so the baseline levels will be different in awakenings made at different times of the night. In the experimental protocol, sometimes as many as four awakenings were obtained from the same night. For this reason, the relationship between time of night and the DC variables used in this study will be examined. It is expected that any DC changes observed during awakening and during the recall period will be smaller earlier in the night. This hypothesis is based on the fact that tonic DC is closer to awake baseline earlier in the night and drifts further away as sleep progresses. In addition, studies which show that CNV and DC shifts in performance are attenuated when the subject is fatigued (Hoffmann et al., in submission; Naitoh et al., 1971) suggest that DC changes might be smaller earlier in the night when the subject is less rested.

Method

This study was part of a larger study of dream recall and EEG, the results of which have been discussed extensively in the introduction to this paper (Morel, 1991; Morel et al., 1991). EEG and DC were recorded during the same experiment using exactly the same protocol.

2.1 Subjects

Forty undergraduate students participated in the study for course credit (Appendix A). Two samples of twenty subjects were run in the laboratory. DC information was only available for 34 of the 40 subjects. There were 17 females and 17 males varying in age between 18 and 34 years, with a mean age of 20.1 years (males= 20.9 years; females = 19.3 years). Twenty-nine of the 34 subjects reported a home dream recall level in the intermediate range (recall a dream between one to five times a week). Of the remaining subjects, two were infrequent recallers, recalling a dream about once a month, and three

were frequent recallers who reported remembering a dream every morning. Subjects were selected from these categories to ensure that an adequate sample of both success and failure to recall events would be obtained. All participants were right-handed, free of self-reported medical or sleep disorders and had been asked to refrain from alcohol, caffeine, or drug consumption on the day of the study. They were also asked to refrain from any atypical napping. All of this was to ensure that they did not disrupt their normal sleep pattern.

2.2 Apparatus

The equipment consisted of six Grass preamplifiers (P511J) with power supply, and a Tektronix (R5403) dual beam oscilloscope. The DC signals, recorded from C3 with linked ear references (A1, A2), were digitized on-line at 128 samples per second through 12 bit analog to digital (A/D) converters resident in a Packard Bell computer. DC was amplified by the oscilloscope using a gain of 100X. One second averaged DC data were stored on a hard disk on a Packard Bell computer and copied onto WORM optical laser disk for permanent storage. The A/D converter measures .05 mV per unit, so that is the smallest change that can be detected in this study. For the purpose of on-line visual stage identification, an Apple Macintosh IIfx computer sampled the EEG signals at 60 Hz and displayed the EEG patterns on a colour monitor. A gain of 10,000X was used for EEG and EOG recordings, with filter settings at .3 Hz and 100 Hz. A Sanyo audio cassette recorder was used to record the verbal reports. An intercom system was used for communication with the subject during the night.

2.3 Procedure

Subjects who met selection criteria (Appendix B) and who agreed to participate arrived at the laboratory one hour before the 11:00 PM bedtime. Upon arrival, they were given a tour of the laboratory to familiarize them with the surroundings. Subjects were then informed of the experimental procedures before they participated in the study (see Appendix C). They were told that investigators were interested in both recall and no recall

so they should feel no pressure to report something upon awakening. Following informed consent (see Appendix D), electrodes were affixed and subjects went to bed.

Monopolar silver-silver chloride (Ag/AgCl) scalp electrodes with electrolytic gel were used for recording at one central site (C3) referenced to linked ear sites (A1, A2). Silver-silver chloride electrodes are the most commonly used non-polarizable electrodes. It is important that non-polarizable electrodes be used in the recording of DC potentials (Tassinary, Geen, Cacioppo, & Edelberg, 1990; Walter, 1964). The electrodes were secured using collodion. A pair of submental electrodes recorded the EMG. The EMG amplifier was set to produce a voltage excursion of 2 V peak to peak at the start of the night. One electrode was placed at the supraorbital ridge of the right eye and another was placed at the infraorbital ridge of the left eye to record horizontal and vertical eye movements simultaneously. A ground electrode was placed on the forehead. Electrode impedance, which was only available for 15 of the subjects, was <5 K ohms.

The EEG, EOG and EMG signals were displayed on a monitor screen for on-line sleep stage identification during the night. The scoring criteria of Rechtschaffen and Kales (1968) were used to identify the appropriate Stage 2 periods where an awakening could be evoked. EMG readings were used to remove any recordings contaminated with muscle and movement artifacts and to locate the wakeup second in the EEG.

2.4 Experimental Awakenings

Each subject slept one 8 hour night in an electrically shielded sleep chamber. The experimenter called each subject by name over the intercom until the experimenter was satisfied that the subject was awake. This was validated by having the subject say "yes, I am awake", and by the appearance of some body movements and changes in the EEG. Once the subject was awake, the interviews were all performed by the same experimenter according to the standardized protocol shown in Appendix E. Recorded verbal reports were later transcribed in order to be scored as either success or failure to recall. Each time a

subject was awakened, subjects were read the instructions so that they would not be confused or forget the procedure. Once awakened, the subjects were asked to remain as still as possible and describe with as much detail as they could remember any experiences they were having before being called. The room lights remained off during the interview. The instructions to remain still were important to reduce body movement and distraction at the time of awakening as these may interfere with recall (D. Cohen, 1974) and may also confound effects on the DC, since studies find shifts in DC with movement (Caspers, 1963; Davis et al., 1939) and Morel (1990; Morel et al., 1991) found differences between success and failure to recall on the EMG measure. Following a verbal report, subjects were repeatedly asked if they had anything else to report until they had nothing left to report. When they were not sure anything had occurred or if they reported no recall, they were then asked to think for a moment and see if anything came back to them, and allowed up to 15 seconds to respond. Following the verbal reports subjects were asked to respond to four probes and a question characterizing their subjective sleep experience prior to awakening (Appendix E).

Subjects were awakened a maximum of four times during the night. All awakenings were made following an accumulated five minutes into Stage 2 sleep within each successive NREM-REM sleep cycle. The first awakening was made before REM onset, but following the accumulation of at least 10 minutes of Stage 4 sleep to ensure that sleep onset was not disturbed. The remaining Stage 2 awakenings were made at least 30 minutes after the termination of a REM period in order to preclude any effects of REM physiology on recall performance. The awakenings lasted 3 to 4 minutes each, on average.

2.5 Classification of Reports into Success or Failure to Recall

The transcribed verbal reports were classified by raters into four predefined categories of recall: successful, contentless, delayed and failure. Appendix F provides the scoring criteria used by the raters. For the purposes of the current study, only those

awakenings defined as clear successes and clear failures were examined. Delayed and contentless categories were not used but will be described for clarification of the reader's understanding of the success and failure categories. Successful recall was defined as any report of some content that could be described and attributed by subjects to the pre-awakening period. Reports could include dreaming, thinking, or feeling. The content of the reports could be a visual image, an experience in another sensory modality (with or without visual imagery) or an emotional experience (affect). Clear success (as opposed to delayed success) corresponded to any reports of some content that could be described by subjects immediately upon awakening. Contentless recall occurred when subjects claimed to have been dreaming or that something was going through their mind before being called but they could not say what it was or describe it. No content was available and there was an inability to remember any details of the sleep experience. In the case of delayed recall, this could be either delayed contentless recall or delayed successful recall. In both cases, subjects first claimed nothing was happening or that they were not sure. When asked to think about it, subjects claimed something was happening and described it (delayed success) or reported no content (delayed contentless). The report was scored as a failure to recall if, after being given the opportunity to think about it, subjects were still unable to report anything at all and had no impressions of dreaming or did not think a dream had occurred. The choice to examine only the extreme categories of recall was deemed to be most appropriate for the first study using DC potentials in examining recall, as it focuses on the extreme types of success and failure to recall and will facilitate a detection of differences should they exist.

Results

There were 35 cases in which the subject failed to recall a dream upon awakening, and 47 cases in which subjects successfully recalled a dream upon awakening, resulting in a total of 82 awakenings to be examined in this study. Each subject was awakened 2.4 times on average, ranging from 1 awakening per subject to 4 awakenings per subject. Eight subjects reported only failures to recall upon awakening, 14 reported only successes upon awakening, and 12 subjects provided incidents of both success and failure to recall.

3.1 Data Preparation

For each awakening, the time at which the subject's name was called, as recorded by the experimenter, combined with verification of a change in the EEG and EMG recordings, was used to determine the time at which the subject was awakened by the prompt from the experimenter. Since the second at which the subject's name was called had been recorded, and since the EMG changes drastically when the subject is aroused, this estimated time of arousal is precise within 1 or 2 seconds. In order to ensure that the analysis would capture any change that occurred when the subject's name was called, it was decided to consider the wakeup period from five seconds before the wakeup second that was pinpointed in the data set. For each awakening, then, the point five seconds before the visible wakeup in the EEG records was used as a reference point for the analyses. Figure 1 is a schematic diagram of the entire awakening which describes each period clearly. Reference to this figure will clarify the following description of how the data was set up for analysis.

Audio recordings had been made of each awakening. For each awakening, three periods of interest were timed. First, the length of time between when the experimenter said "x, wake up" until she finished saying "could you please describe with as much detail as possible any experiences you were having before I called your name" was recorded. As mentioned above, five seconds was added to the beginning of this period to ensure

- (1) Pre-awakening DC (4 minutes):
- (2) Wakeup DC: Subject is waking up and receiving recall instructions**
- (3) Recall DC: Subject is recalling any pre-awakening experience
- (4) Question DC: Subject is answering questions about sleep experience
- (5) Post-awakening DC periods 1 to 4 (each period is 30 seconds long): Subject has been told to go back to sleep

*These are not real data

** The length of periods 2, 3, and 4 are determined by audio tapes of the awakenings and are unique for each separate awakening.

Figure 1: Schematic diagram of an awakening showing periods used in data analysis.

capturing the wakeup change. Including the additional five seconds, the average length of this period, called the Wakeup period, was 18.94 seconds ($SD = 1.89$) for the failure awakenings and 19.55 seconds ($SD = 5.68$) for the successful awakenings. The second period of interest is the Recall period, which lasts from the time the experimenter completes the recall prompt, above, until the subjects can no longer recall anything and the experimenter says "OK". The average length of this period was 44.31 seconds ($SD = 16.86$) for the failure awakenings and 48.55 seconds ($SD = 30.33$) for the successful awakenings. The third period, called the Question period, is timed from the end of the recall period, when the experimenter says "OK", until the experimenter has completed a series of questions about the subject's sleep experience (See appendix E) and says "OK, you can go back to sleep now." The average length of this period was 76.69 seconds ($SD = 21.57$) for the failure awakenings and 75.60 ($SD = 18.63$) for the successful awakenings. DC was also examined after the subject was told they could go back to sleep. Two minutes after the experimenter says "OK, you can go back to sleep now" were broken into four 30 second periods. These are called the Post-awakening periods. To avoid confusion, the entire arousal and questioning period is referred to as the "awakening", and the period immediately following the prompt to awaken is referred to as the Wakeup period. A final period of interest is the Pre-awakening period. For this period, DC activity was examined four minutes prior to the Wakeup period. To review, then, there are eight periods of interest; the Pre-awakening period, the Wakeup period, the Recall period, the Question period and four Post-awakening periods.

Figure 2 shows an example of one awakening with the periods of interest marked on the graph. The four post-awakening periods are 30 second periods after the line in Figure 2 marked "end of questioning". An examination of the DC activity for each subject on graphs like the one pictured in Figure 2 indicated that since DC is fluctuating constantly, the best way to estimate any change between periods would be to take the average of the

Figure 2: Example of an awakening. Subject #31, Third wakeup, Success.

DC activity for each period. It was felt that the use of averages, rather than examining maximum peaks, would provide a clean measure of whether DC changed when the subjects were awakened that would not be severely affected by the constant fluctuations in DC activity. Averages for the Wakeup, Recall and Question periods were calculated using the time frames specific to each awakening. For the Pre-awakening period, the average of DC for four minutes before the specified Wakeup period was calculated. For the four Post-awakening periods, each of which were 30 seconds long, the average DC for those 30 seconds was calculated.

For each awakening, then, the initial step was to locate the wakeup second in the EEG files which indicate when the subject's name was called by the experimenter. Then the subject's audio tape of the entire awakening was timed. If their Wakeup period, from the time the experimenter called their name until the experimenter finished saying "could you please describe with as much detail as possible any experiences you were having before I called your name", lasted 15 seconds, then the average DC for those 15 seconds, plus the five previous seconds added to ensure capturing wakeup change, was calculated. Similarly, if their Recall period lasted 40 seconds, the average DC for the 40 seconds following the end of the Wakeup period was calculated. The same was done for the Question period. For every awakening, the average DC of four minutes prior to the beginning of the Wakeup period was calculated. Thus, for each awakening, there is a Pre-awakening DC value, a Wakeup period DC value, a Recall period DC value, a Question period DC value, and a DC value for each of the four 30 second periods after the subjects are told they can go back to sleep. These average DC values provide the dependent variables used in all subsequent analyses. Some of the analyses are performed on the difference scores between the DC for each period and the Pre-awakening period.

3.2 Analyses

The initial step in the analyses was to examine the distributions of each dependent variable and check for outliers. The distributions of the following variables were examined for normality and outliers; DC Pre-awakening, DC Wakeup, DC Recall, DC Question, DC Post-awakening 1, DC Post-awakening 2, DC Post-awakening 3, DC Post-awakening 4, DC Wakeup minus Pre-awakening, DC Recall minus Pre-awakening, DC Question minus Pre-awakening and each DC Post-awakening period minus Pre-awakening. Although some awakenings were outliers in the Wakeup, Recall and Question distributions, when these awakenings were compared to their own Pre-awakening DC levels in the Wakeup minus Pre-awakening, Recall minus Pre-awakening and Question minus Pre-awakening distributions, they were not outliers. This suggests that although some subjects' DC baseline was radically different from others, the behaviour of their DC with respect to their own baseline was similar to that of other subjects. Since the interest in this study is in changes in DC activity with respect to its own baseline all awakenings were retained for further analyses. Analyses performed on the average scores and on the differences from Pre-awakening DC, were done using a MANOVA profile approach, in which examination for outliers is done on segments, or differences between successive periods. There were no outliers that would affect such an analysis. Table 1 presents the means and standard deviations of all the variables used in the analyses.

3.3 Comparisons Between Successful Recall Awakenings and Failed Recall Awakenings

The first question that must be answered is whether or not the overall level of DC activity before any subject manipulation differs between success and failure to recall. To test this, the Pre-awakening period was compared between groups in an unpaired t-test. There was no statistically significant difference in the Pre-awakening DC between successful and failed recall events, $t(80) = -.64$, $p = .52$. The absence of a statistically significant difference in the pre-awakening period clears the way for a comparison of

Table 1

Means and Standard Deviations of the DC Variables

	<u>Pre-awakening</u>		<u>Wakeup</u>		<u>Recall</u>	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Success (n = 47)	1.882*	19.486	1.956	19.618	2.039	19.646
Failure (n = 35)	-.634	15.410	-.562	15.47	-.495	15.417
	<u>Question</u>		<u>Post-awakening 1</u>		<u>Post-awakening 2</u>	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Success	2.133	19.703	1.908	19.760	1.789	19.745
Failure	-.445	15.423	-.727	15.328	-.684	15.310
	<u>Post-awakening 3</u>		<u>Post-awakening 4</u>		<u>Wakeup minus Pre</u>	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Success	1.914	19.767	1.927	19.802	.072	.361
Failure	-.615	15.345	-.591	15.379	.073	.293
	<u>Recall Minus Pre</u>		<u>Question minus Pre</u>		<u>Post 1 minus Pre</u>	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Success	.157	.457	.25	.636	.025	.862
Failure	.138	.354	.189	.429	-.092	1.033
	<u>Post 2 Minus Pre</u>		<u>Post 3 minus Pre</u>		<u>Post 4 minus Pre</u>	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Success	-.093	.982	.032	.932	.044	1.023
Failure	-.051	.997	.019	1.004	.042	1.109

*All values are reported in millivolts

success and failure to recall in terms of the changes from baseline that occur during the awakening.

A second question pertaining to the baseline DC activity was whether or not DC activity differs across the night. If time of night has a statistically significant relationship to the DC variables, it would have to be used as a covariate or second variable in further analyses, since subjects were awakened at different times of the night. Two different procedures were used to check this possibility. First, correlations between time of night and the following DC variables were calculated; Pre-awakening, Wakeup, Recall, Question, Wakeup minus Pre-awakening, Recall minus Pre-awakening, and Question minus Pre-awakening. These correlations can be seen in Table 2. Time of night accounted for no more than 5% of the variance in any of these variables, and often much less than 5%. A second test of the effects of time of night involved dividing the night into thirds and categorizing the awakenings according to third of the night. Three two-way ANOVAs were performed with time of night and recall category as independent variables and either Wakeup minus Pre-awakening, Recall minus Pre-awakening, or Question minus Pre-awakening as the dependent variable. In each of the three ANOVAs, there was no statistically significant time of night effect, no statistically significant recall category effect, and no statistically significant interaction between recall and time of night. Taken together, these two sets of analyses indicated that time of night did not need to be considered as a variable in further analyses and that these particular DC variables are not affected by time of night.

3.3.1 Profile Analyses Comparing Success and Failure to Recall

Figure 3 shows a graph of the average DC activity in the eight periods for each group. This graph suggests that there may be a trend in DC over time, and that the level of DC activity is different for success and failure to recall. Based on this graph, it appeared that the most useful analysis would be one in which the periods were viewed as a repeated

Table 2

Pearson Correlations Between Time of Night and DC Variables

<u>DC Variable</u>	<u>r</u>	<u>r²</u>
Pre-awakening	.039	.002
Wakeup	.041	.002
Recall	.043	.002
Questioning	.046	.002
Wakeup minus Pre-awakening	.118	.014
Recall minus Pre-awakening	.176	.031
Question minus Pre-awakening	.239	.057

Figure 3: Average DC for each period.

measures or trial variable and success/failure as a between groups variable. Since Pre-awakening, Wakeup, Recall, Question, Post-awakening 1, Post-awakening 2, Post-awakening 3 and Post-awakening 4 are each taken from the same subject across time, they can reasonably be viewed as a repeated measure trial variable. This type of analysis answers three crucial questions in one analysis. First, does success/failure have a statistically significant effect on the overall level of the DC activity? Second, does DC activity change over trials, that is, does arousal from sleep statistically significantly affect the DC activity? Finally, the interaction term of this analysis addresses the most important question in this study, whether or not there is a difference in the pattern of DC activity between success and failure to recall.

In order to perform a repeated measures analysis, the assumption of homogeneity of covariance must be met (Tabachnick & Fidell, 1989). This assumption states that all pairs of levels of the within-subjects variable need to have equivalent correlations. The test for this assumption is the Mauchly test of sphericity. If this test is statistically significant, then the assumption is violated, and the preferable approach to analyzing this type of design is MANOVA Profile analysis, the multivariate approach to repeated measures (Tabachnick & Fidell, 1989). In profile analysis multiple dependent variables replace the within-subjects independent variable and the assumption of homogeneity of covariance no longer applies.

The data presented in Figure 3 was first tested for violation of the assumption of homogeneity of covariance. The Mauchly test indicated that the assumption was violated, $W = .00037$, $p < .0001$, so the MANOVA profile analysis approach was used to examine the data. The choice of the MANOVA approach requires that certain other assumptions be met. MANOVA requires that there be more cases than dependent variables in every cell. In this analysis there are 8 trials, or dependent variables, and the smallest cell has 35 subjects. MANOVA profile analysis performs its analysis on the segments or difference

scores between successive trials. It requires that these difference scores be normally distributed, however MANOVA is very robust to violation of this assumption as long as there are more than 20 cases in the smallest group and the sample size is not highly unequal (Tabachnick & Fidell, 1989). MANOVA requires homogeneity of variance-covariance matrices. This was tested using the Box's M test. According to Tabachnick and Fidell (1989), if the Box's M is statistically significant at $p < .001$ there is a problem. The Box's M for this analysis was $F(36, 18080) = 1.88, p = .001$. Tabachnick and Fidell recommend that you then use the Pillais criterion rather than Wilks Lambda to evaluate multivariate significance. MANOVA requires a linear relationship between pairs of segments. However, lack of linearity results in a more conservative test, and this problem is usually mitigated by large sample sizes. Multicollinearity and singularity among segments was not a problem for this analysis. Outliers were examined as discussed above and none were found.

The MANOVA profile analysis of the data in Figure 3 indicated that there was no statistically significant difference between success and failure to recall on the overall level of DC, $F(1, 80) = .40, p = .529$. There was also no statistically significant interaction between success and failure to recall and the trials or dependent variables, $F(7, 74) = .53, p = .808$. This is the most important test of this analysis and it indicates that success and failure to recall do not differ in how their DC activity varies over these eight periods of interest; the profile of the two groups does not statistically significantly deviate from parallel. Using the Pillais criterion recommended by Tabachnick and Fidell (1989), there was a statistically significant trial effect, $F(7, 74) = 3.55, p = .002$. Collapsing across success and failure, the mean Pre-awakening DC is .808 mV, the mean Wakeup DC is .881 mV, mean Recall DC is .957 mV, mean Question DC is 1.032 mV, mean DC in Post-awakening period one is .784 mV, mean DC in Post-awakening period two is .734 mV, mean DC in Post-awakening period three is .835 mV and mean DC in Post-awakening

period four is .852 mV. These means are plotted in Figure 4. They indicate that DC increases when the subjects are awakened and then decreases again when the subjects are told to go back to sleep.

Post-hoc analyses were performed to further examine the statistically significant trial effect. The question of interest for this study is whether or not DC changes when an individual is awakened. For that reason, the most meaningful post-hoc tests are those which compare each period to the Pre-awakening period. Each period was compared to the Pre-awakening DC in a separate two-tailed paired t-test ignoring success and failure. Figure 4 shows the trend in DC activity across the eight periods collapsed together for success and failure. A type of Bonferroni adjustment of the alpha level was used. The alpha level of $p < .05$ was divided by the number of comparisons (7), resulting in an alpha level of $p < .007$. There was no statistically significant difference between Wakeup and Pre-awakening DC, $t(81) = -1.976$, $p = .0515$. There was, however, a statistically significant difference between the Recall and Pre-awakening periods, $t(81) = -3.253$, $p = .0017$, and between the Question and Pre-awakening DC, $t(81) = -3.653$, $p = .0005$. Neither Post-awakening period 1, Post-awakening period 2, Post-awakening period 3 nor Post-awakening period 4 differed statistically significantly from the Pre-awakening DC. These post hoc comparisons support the finding of a statistically significant trend in DC across the whole awakening, and suggest that DC increases slowly upon awakening, and continues to increase while the subject is awake. When the subject is told to go back to sleep, the DC drops back down to its Pre-awakening level.

A second approach to examining this data set can be seen in Figure 5. In this figure, the difference between each period (Wakeup, Recall, Question, Post-awakening 1 to 4) and the Pre-awakening period is plotted. To verify the findings of the previous profile analysis, this data was set up to be examined with recall category as a between groups effect and each difference score as a repeated measures or trial effect. Once again

Figure 4: Average DC for each period collapsed across groups.

Figure 5: Difference between each period and the preawakening period.

the Mauchly sphericity test indicated that the assumption of homogeneity of covariance was violated, $\underline{W} = .00181$, $p < .0001$, so the MANOVA profile analysis approach was used. The requirements for a MANOVA discussed above were met, with the exception that the Box's M test was statistically significant, $F(28, 18699) = 2.33623$, $p < .0001$, so, as recommended by Tabachnick and Fidell (1989) the Pillais criterion was used to determine multivariate significance.

The MANOVA profile analysis on the data in Figure 5 indicated that there was no statistically significant difference between success and failure to recall on the levels of the difference scores ($F(1, 80) = .03$, $p = .87$), and no statistically significant interaction between success and failure to recall and the trials (difference scores), $F(6, 75) = .596$, $p = .733$. These results indicate, like the previous MANOVA, that the change in DC from Pre-awakening to Post-awakening does not differ for success and failure to recall. There was a statistically significant trial effect, $F(6, 75) = 3.40$, $p = .005$. Examination of the graph indicates that the difference between Pre-awakening DC and each period after the subjects are awakened gets progressively larger and then gets smaller again when the subjects are told to go back to sleep. These results only verify the findings of the first profile analysis, so no post-hoc tests were performed.

One final approach to examining the difference between success and failure to recall remains. Since the DC activity sometimes moves up upon awakening and sometimes down, this resulted in difference scores which were sometimes in the positive direction and sometimes negative. For this reason, it was felt that using the absolute values of the difference scores might provide a less variable dependent variable on which to compare success and failure to recall, thus increasing the possibility of finding a statistically significant difference. The absolute value of Wakeup minus Pre-awakening, Recall minus Pre-awakening and Question minus Pre-awakening were all compared between success and failure to recall using MANOVA profile analysis where recall category was the independent

variable and the three variables listed were viewed as the trials, or dependent variables. Once again, the Mauchly test of sphericity indicated that the assumption of homogeneity of covariance was violated, $\underline{W} = .65925$, $p < .0001$, so the MANOVA profile analysis approach was chosen. Box's M was statistically significant, $F(6, 37081) = 3.700$, $p = .001$ so the Pillai's criterion was used to determine multivariate significance. Despite this transformation, there was no statistically significant difference between success and failure to recall on the level of the DC difference scores, $F(1, 80) = 1.08$, $p = .303$, and no statistically significant interaction between dream recall category and the trials (absolute values of the difference scores), $F(2, 79) = 1.254$, $p = .29$. Once again, the only statistically significant effect was the trial effect, $F(2, 79) = 13.412$, $p < .0001$. The mean absolute value of the difference between Wakeup and Pre-awakening DC was .267 mV, ignoring recall category. The mean absolute value of the difference between Recall and Pre-awakening DC was .338 mV and the mean absolute value of the difference between Question and Pre-awakening DC was .457 mV. Since these means indicate that DC gets further away from baseline over the time that the subject is awake, just as the trial effect in the first MANOVA indicated, no post-hoc comparisons were made.

3.3.2 Frequency of Positive and Negative Changes

The above analyses suggest that DC changes in a positive direction when a subject is awakened from sleep. To strengthen this conclusion, the frequency of positive and negative difference scores was tested in chi-square analyses. It is also possible that the number of positive and negative changes in DC might differentiate success and failure to recall; one group might change more often in a positive direction and one in a negative direction. For each of the three difference scores taken when the subject was awake (Wakeup minus Pre-awakening, Recall minus Pre-awakening, and Question minus Pre-awakening), a contingency table analysis was performed to see if one group or the other had more positive or negative change scores. There were no statistically significant

differences between success and failure to recall in the frequency of positive and negative changes on any of the three difference scores. No adjustments to alpha levels were made as the probabilities were so far from statistical significance that such a consideration was not necessary.

Simple one group chi squares comparing the frequency of positive and negative changes, ignoring recall group, indicated that for each difference score there were statistically significantly more positive than negative changes. Since three chi squares were being performed the $p < .05$ was divided by three, resulting in a cutoff point of $p < .02$. Table 3 shows the frequency of positive and negative changes for Wakeup minus Pre-awakening difference scores, $X^2 (1, N = 82) = 9.561, p = .002$, Recall minus Pre-awakening difference scores, $X^2 (1, N = 82) = 9.561, p = .002$, and Question minus Pre-awakening difference scores, $X^2 (1, N = 82) = 8.244, p = .004$.

3.4 Analyses on Subjects who had both a Success and a Failure to Recall

A small number of subjects ($n = 12$) provided both a success and a failure to recall. A subsidiary set of analyses was attempted on these few subjects. This allows for a comparison of success and failure to recall within the same subjects thus decreasing the effects of individual variance. If a subject provided one success and one failure, that data was used as is. If a subject had more than one of either a success or a failure, the two similar awakenings were averaged together. For example, if a subject provided one failure and two successful awakenings, the Wakeup minus Pre-awakening scores for the successful awakenings would be averaged together and entered as a single estimate of Wakeup minus Pre-awakening for success. This method was chosen over randomly selecting one of the successful awakenings as it was deemed to be the best way to estimate the central tendency of the DC activity associated with successful recall for that subject.

Three separate one factor repeated measures ANOVAs comparing success and failure to recall within subjects were performed, one using the Wakeup minus Pre-

Table 3

Frequency of Positive and Negative Changes in DC Upon Arousal from Sleep

	<u>Difference Score</u>					
	<u>Wakeup minus Pre</u>		<u>Recall minus Pre</u>		<u>Question minus Pre</u>	
	<u>Positive</u>	<u>Negative</u>	<u>Positive</u>	<u>Negative</u>	<u>Positive</u>	<u>Negative</u>
Success	31	16	30	17	32	15
Failure	24	11	25	10	22	13
Total	55*	27*	55**	27**	54***	28***

*significant, $X^2(1, N = 82) = 9.561, p = .002$

**significant, $X^2(1, N = 82) = 9.561, p = .002$

***significant, $X^2(1, N = 82) = 8.244, p = .004$

awakening difference score as the dependent variable, one for Recall minus Pre-awakening and one for Question minus Pre-awakening. Since there are only two levels of the repeated measure (success and failure) in this case, the assumption of homogeneity of covariance does not apply. None of these repeated measures ANOVAs revealed statistically significant differences between success and failure to recall.

The same three one factor repeated measures ANOVAs were performed on the absolute values of the difference scores. There was no statistically significant difference between success and failure to recall on the absolute value of the Wakeup minus Pre-awakening difference score. However, using an alpha level of .05, there was a statistically significant difference between success and failure to recall on the absolute value of the Recall minus Pre-awakening difference score, $F(1, 11) = 6.2$, $p = .03$, and on the absolute value of the Question minus Pre-awakening difference score, $F(1, 11) = 5.28$, $p = .04$. Since this analysis was more for exploratory purposes, a more liberal alpha level was permitted. In both cases, the mean absolute change from Pre-awakening was larger for the successful recall events. For the Recall minus Pre-awakening difference score, the mean absolute change for successful awakenings was .438 mV and for failure awakenings it was .238 mV. For the Question minus Pre-awakening difference score, the mean absolute change for successful awakenings was .515 mV and for failure awakenings it was .256 mV.

3.5 REM Analyses

As expected, the results of the profile analyses comparing success and failure to recall indicated that both groups show a slow but statistically significant change in DC when they are awakened. The question of the origin or cause of this shift in DC upon awakening then becomes of interest. The EEG records during REM are closer to those during wakefulness than are records from NREM Stages 2, 3 and 4; that is, there is low amplitude, fast frequency EEG in both cases. In addition, REM is often associated with

greater cortical arousal than other stages of sleep. A change from Stage 2 sleep to REM sleep might, therefore, show a change similar to that observed in the shift from Stage 2 sleep to wakefulness. For purely exploratory purposes, such a analysis was considered. It is very difficult to find a case in which several minutes of Stage 2 sleep are followed immediately by several minutes of REM sleep, as the transition is not often clean and quick. Often subjects waver back and forth between Stage 2, Stage 1, and REM before there is any stable length of time in REM. However, using the scoring criteria of Rechtschaffen and Kales (1968) it was possible to find 7 subjects in which there was a clear Stage 2 to REM change. These stage scores were verified by a registered polysomnographic technologist. Figure 6 shows the average DC for every 30 second epoch for as many epochs of Stage 2 as it was possible to obtain followed by as many epochs of REM as possible, up to 5 minutes of both Stage 2 and REM. The line down the middle shows where the EEG changed from Stage 2 to REM. Figure 7 averages the data together for all seven subjects so that it can be put on the same scale as the data in Figure 4, thus allowing comparison between the change in DC when a subject wakes up and when a subject moves from Stage 2 to REM. By inspection it is clear that the DC is not changing when the subject moves into REM, so no statistical analyses were performed.

Figure 6: DC activity during the transition from Stage 2 to REM.

*Note: This graph is on the same scale as Figure 4 to aid visual comparison of the DC activity

Figure 7: Transition from Stage 2 to REM averaged across 7 subjects.

Discussion

4.1 Interpretation of the Results and their Implications

The hypothesis that DC activity would differentiate success and failure to recall a dream upon awakening was not confirmed. It was expected that successful recall would show a greater shift in DC upon awakening than failure to recall. The results indicated that neither Pre-awakening DC, nor the change in DC from Pre-awakening to Post-awakening viewed either as directional change or in terms of absolute values, showed any differences between success and failure to recall. The hypothesized relationship between DC activity and dream recall during the actual recall task was also not confirmed. It was expected that success and failure to recall would show a difference in DC activity during the recall task, and that successful recall would be associated with a greater DC shift in the negative direction. The results indicate that there were no differences between success and failure to recall during the recall period, and that for both groups DC activity continues to move in a positive direction during this period. It was expected that time of night would show a relationship with the DC activity, and that changes observed during awakening and during the recall period would be smaller earlier in the night. This hypothesis was not confirmed. There were no correlations between time of night and the following DC variables; Pre-awakening, Wakeup, Recall, Question, Wakeup minus Pre-awakening, Recall minus Pre-awakening and Question minus Pre-awakening. In addition, time of night had no effect on Wakeup minus Pre-awakening, Recall minus Pre-awakening and Question minus Pre-awakening when used as an independent variable in ANOVA procedures.

The hypothesis that DC would shift in a positive direction upon arousal was confirmed, as the effect of the change in DC from Pre-awakening throughout the awakening and into the Post-awakening periods was statistically significant. Post-hoc tests confirmed that, averaged across subjects, DC changed in a positive direction when the individual was awakened from sleep, continued to move in a positive direction while the

individual was awake and then dropped back to its pre-awakening level when the subject was told to go back to sleep. In addition, chi-square analyses indicate that the direction of the change that occurred during arousal from sleep was statistically significantly positive more often than negative.

The absence of any relationship between DC activity and success and failure to recall a dream upon awakening is an important finding given that this is the first study which attempted to examine such a relationship. There are two possible interpretations of these results. The first is that DC activity does not have any potential in adding to our understanding of dream recall. The second is that replication of this study with a better design may show that DC accounts for a small portion of the variance in dream recall. A more detailed discussion of these two interpretations follows.

With respect to the first interpretation, the comparisons of success and failure to recall in the main analyses of this paper suggest that DC is not related to dream recall. However, before such a strong conclusion can be made, it should be noted that the subsidiary analyses on those 12 subjects who provided both a success and a failure to recall indicated some differences between success and failure to recall. The absolute value of the difference between the Pre-awakening period and the Recall period, and between the Pre-awakening period and the Question period, showed statistically significant differences between success and failure to recall at an alpha level of .05. In both cases, the results indicated that the mean absolute change from Pre-awakening was larger for successful recall events.

Given the number of statistical tests performed in this study, and the fact that the results of the analyses on the 12 subjects who provided both a success and a failure to recall were only statistically significant at $p < .05$, no strong conclusions about a difference in DC between success and failure to recall can be made. Remember that for this analysis two or more awakenings were averaged together if there was more than one success or

failure, and then the data was transformed to absolute values. The nature of the calculations used to do this analysis makes a clear interpretation difficult. However, the results of these within subject analyses suggest that a replication of this study using only subjects who provide both a success and failure to recall in a within subjects analysis should be carried out before the pursuit of a relationship between DC and dream recall is aborted.

It was hypothesized that if any difference between success and failure was observed, it would be that success would show a greater change from Pre-awakening than would failure. This was expected because earlier studies (Morel, 1991) and theoretical work (Koulack & Goodenough, 1976) indicated that successful recall would be associated with a stronger state shift upon arousal from sleep. The preliminary analyses on the 12 subjects who provided both a success and a failure to recall suggest that successful recall might be associated with a greater change from Pre-awakening, but since this effect was only significant when absolute values were used at a liberal alpha level, interpretation of the direction of the shift and the meaning of this difference is premature. If the preliminary finding that successful recall is associated with a greater DC shift can be replicated, it would contradict Koukkou and Lehmann's (1983) functional-state shift hypothesis, which maintains that recall is enhanced when the post-awakening state is closer to the dream state. The results of the analyses on these twelve subjects suggest that the opposite may, in fact, be true; a greater state shift from the dreaming state to the waking state improves recall.

The results of the analyses on the subjects who had both a success and a failure to recall also suggest that individual variability in the direction of the DC shift upon arousal from sleep, particularly during the recall period, requires further examination. Since absolute values were the only scores to differentiate success and failure to recall in the analyses with only 12 subjects, this raises some questions about the direction of the DC shifts observed in this study. Analyses with the entire sample (82) showed a clear positive

trend in DC when the sign (positive or negative) of the change was included in the data. Neither that data, nor the absolute value data differentiated success and failure to recall in the larger sample. In addition, chi square analyses in the larger sample indicated that the frequency of positive and negative shifts did not differentiate success and failure to recall, as both groups showed significantly more positive than negative DC shifts. Data which contained the sign values did not differentiate success and failure to recall in the analyses with 12 subjects, but the absolute values did distinguish between recall and nonrecall in the Recall minus Pre-awakening and Question minus Pre-awakening difference scores.

There are possible explanations for the ability of absolute values to differentiate success and failure to recall in the smaller sample when directional values did not show a significant difference between recall and nonrecall. Visual inspection of the distributions indicates that with respect to both the Recall minus Pre-awakening and Question minus Pre-awakening difference scores there is considerably more variability in the scores for the successful awakenings. For the Recall minus Pre-awakening difference scores, twice as many of the differences are in the negative direction for the success group than in the failure group. Clearly, when those negative difference scores, which are also of greater magnitude than those for the failure group, are changed to absolute values they will result in a much larger mean absolute value change for the success group. For the Question minus Pre-awakening difference score, there is one negative difference score that is much greater in magnitude than any other difference score. This particular wakeup is likely an outlier, with respect to this subsample, which accounts for the significant result when absolute values are used with the Question minus Pre-awakening difference score.

It is interesting that the successful awakenings show more variability than the failure awakenings in this subsample, and it is particularly interesting that this is most evident during the actual recall task. Perhaps the direction of the shift change is interacting with some other variable to differentiate success and failure to recall. On the other hand, it

may simply be that a significant result appeared when absolute values were used because this truncates the variability in the scores, increasing the chances of a statistically significant result. The large variability of the difference scores in this subsample is likely due to the small sample size. A larger sample of subjects utilizing a within subjects analysis of dream recall with explicit examination of the direction of the DC changes is necessary before any conclusions can be made about what differentiates success and failure to recall. Further study of the individual variability in the direction of the DC shifts observed in this study is also warranted.

To summarize, no conclusions about the relationship between DC and dream recall can be made until the analyses using subjects who provide both a success and a failure to recall are replicated. If no relationship between success and failure to recall and DC can be found upon replication with a better design, then it would be safe to conclude that DC is not related to dream recall.

A second possible interpretation of the failure to find a relationship between DC and dream recall in this study is that dream recall is the source of confusion. The EEG literature reviewed in this paper indicates that there is very little consistent and strong relationship between EEG activity and dream recall. Many studies, covering a multitude of personality, electrophysiological and cognitive variables have attempted to explain dream recall, and yet the phenomenon remains a mystery (Moffitt & Hoffmann, 1986; Moffitt et al., 1990; Pivik, 1991). The lack of relationship between dream recall and DC probably speaks more to the issue of the complexity of the phenomenon of dream recall than it does to the utility of DC activity to contribute to our understanding of dream recall. D. Cohen (1974) suggested that dream recall will eventually be explained by a model that defines the interaction of pre-sleep, sleep and post-sleep conditions that include various measures of personality, cognitive style, interests and attitudes. Measures of brain activity may also fit into an interactive model that explains dream recall, but may not add to our understanding

of dream recall when examined by themselves. Given the state of our understanding of individual variability in dream recall, it seems that further studies using only one type of variable, such as personality or brain activity, are futile. To further our understanding of dream recall, future research should make use of the available information to design studies which combine those personality, cognitive and electrophysiological variables known to be related to dream recall in an attempt to find a set of variables which together explain this individual difference. If replication of this study using a within subjects design confirms the preliminary suggestion that there may be a relationship between DC activity and dream recall, then DC may prove to be another variable to add to the list of variables which sometimes accounts for a small part of the variance in dream recall. DC may be useful in an interactive model such as the one recommended by D. Cohen (1974).

The hypothesis that the actual recall task would show a relationship between DC and dream recall was based on previous findings that DC (Hoffmann et al., in submission) and CNV activity (McCallum & Walter, 1968; Naitoh et al., 1971; Tecce & Scheff, 1969; Yamamoto et al., 1984) showed negative changes during cognitive task performance that were affected by attention, distraction and sleep deprivation. It was expected that recall, viewed as a type of cognitive task performance, would cause a negative shift in the DC potential, and that this shift would be greater for successful recallers, who would presumably be attending more to the task at hand. Such an effect was not found. There were no differences between success and failure to recall during the actual dream recall period, and both groups continued to move in a positive direction, rather than a negative direction. One possible reason that the negative shift was not observed was that this design does not clearly follow the CNV paradigm, so that a contingent negative shift did not appear. In addition, the choice to use the average DC for the recall period eliminated the possibility of detecting this shift since maximum peaks were not examined. Perhaps an analysis that assesses the slope and rate of DC change would be able to detect whether a

negative shift occurred riding on top of the overall trend of DC in a positive direction. Finally, previous studies that examined DC or CNV shifts during cognitive task performance were operating from an awake baseline. It is quite possible that the shift in DC that occurs when an individual is awakened from sleep is so strong that it overrides any shift that might occur during cognitive task performance, so that it either doesn't occur or isn't obvious in the type of analysis used in this study.

Time of night did not show any relationship with the DC variables measured in this study. Given that Hoffmann et al. (1988, in submission), Davis et al. (1939) and King (1946), found that tonic DC moves in a negative direction over the course of a night's sleep, it was hypothesized that time of night would covary with the DC variables in this study. In particular, DC changes were expected to be smaller earlier in the night because tonic DC is closer to awake baseline earlier in the night, and because studies have shown that CNV and DC shifts during cognitive performance are attenuated when the subject is fatigued (Hoffmann et al., in submission; Naitoh et al., 1971). The absence of any relationship between the phasic measures of DC activity in this study and time of night are quite likely due to the fact that the subject was being awakened several times and this disrupted the usual tonic trend of the DC baseline over the course of the night.

The most profound and interesting finding of this study is that DC changes when an individual is awakened from Stage 2 sleep. Profile analysis using Pre-awakening DC, Wakeup DC, Recall DC, Question DC and four samples of DC following the command for the subject to go back to sleep indicated a significant trial effect in which DC moves in a positive direction when the subjects are awakened and then drops back to its pre-awakening level when they are told to go back to sleep. Post-hoc tests comparing each period to the Pre-awakening DC indicated that DC changes slowly when the individual is awakened, since Wakeup DC was not statistically significantly different from Pre-awakening DC. This finding rules out the possibility that the DC awakening shift is a movement artifact,

since EMG records change as soon as the subject's name is called. A more detailed discussion of artifacts appears in a subsequent section of the paper. Recall DC and Question DC were both significantly different from Pre-awakening DC. It appears that when the subjects were told they could go back to sleep the DC activity dropped back to its pre-awakening levels. This conclusion is confirmed by the finding that none of the Post-awakening DC levels were significantly different from the Pre-awakening DC levels. Profile analysis applied to the difference scores between each period and the Pre-awakening period confirmed the presence of a statistically significant trial effect in which DC changes when the individual is awakened, moves further away from the pre-awakening level as they remain awake, and then drops back to the pre-awakening level.

The implications of this change in DC upon arousal from sleep are profound. This is the first study in which phasic DC activity surrounding an abrupt arousal from sleep has been specifically examined in a large sample of humans. Animal research had already observed a DC shift upon arousal from sleep (Caspers, 1963; Caspers & Schulze cited in Bechtereva, 1974; Kawamura & Pompeiano, 1969; Kawamura & Sawyer, 1964; Tabushi et al., 1966; Wurtz, 1965; Wurtz et al., 1964). When an animal is awakened from sleep DC shifts in a direction opposite to that observed when the animal is going to sleep. Human research has found that DC moves in a negative direction when the individual falls asleep and as sleep progresses (Davis et al., 1939; Hoffmann et al., 1988, in submission; King, 1946). Based on these findings, it was expected that DC would shift in a positive direction when the subjects were awakened from sleep. This expectation was confirmed. Table 3 indicates that there are some cases in which DC changes in a negative direction, so there is some subject variability in this effect. However, the fact that the profile analysis shows a statistically significant positive shift even when these negative shifts are included in the averages suggests that the tendency for DC to shift in a positive direction upon arousal from sleep is quite profound. As mentioned previously, the reasons behind the

subject variability in the direction of the shift is something that should be considered in future research concerned with the activity of DC during arousal from sleep. None of the earlier literature which demonstrated such a shift in animals reported information on subject variability. It is quite possible that factors such as time of night, gender, or placement of the DC baseline could play a role in determining the direction of the shift. There was quite a wide discrepancy between subjects in terms of the overall level of their DC activity. For example, some subjects started at a much more negative place on the scale than did others. This could very well affect the direction of the DC shift observed upon awakening.

It was not possible to examine the overall trend in DC over the course of the night in order to attempt to replicate previous findings (e.g. Hoffmann et al., 1988, in submission) that DC moves in a negative direction while a subject sleeps. Visual inspection of plots of the entire night of DC activity for each subject indicated that DC was moving in a negative direction over the entire night. However, the fact that the subject is being awakened 3 or 4 times in the night makes an examination of this tonic trend in DC somewhat meaningless and not comparable to the other studies. The results of the profile analyses do show, however, that when the subjects were told to go back to sleep the DC suddenly moved in a negative direction back towards its pre-awakening level. The EEG was not examined to determine when the subject actually fell asleep again, so it is not entirely certain that this negative shift is due to the subject falling asleep. It may be caused by a sudden movement, such as the subject turning over when they are told to go back to sleep. Alternatively, it may be due to the fact that they are no longer orienting to the experimenter. Such a possibility remains to be explored. Certainly, subjects would be likely to return to sleep very quickly as most of them had a difficult time staying awake during the recall period. Thus, the results suggest that DC shifts in a negative direction when the individual goes to sleep, but such an effect was not directly examined in this study. Nonetheless, other studies have observed that effect and this study clearly indicates

that DC shifts in a positive direction upon arousal from sleep. Together the results of human DC studies indicate that DC moves in one direction during sleep and the opposite direction during arousal from sleep. These results fit with those observed in the animal literature.

The cause of the DC shift upon arousal from sleep is difficult to discern given that very little research on this measure exists and that the exact origin of DC activity is not clearly understood. Caspers (1961a, 1961b, 1963) suggested that DC activity reflects the activity of the reticular formation, and thus is a cortical measure of the general deep structure arousal level of the brain. It is understood that in this context, arousal refers not only to awakening from sleep, but is an inferred variable that can have gradations of its levels within wakefulness as well. The reticular formation is a network of neurons and fibres at the core of the brain stem (Bridgeman, 1988). According to Caspers (1961b), fluctuations of DC during the natural activity cycle are induced by "variations of ascending impulses originating in the non-specific projection systems of the brain stem" (pg. 249). Caspers (1963) presented several arguments to support this conclusion. DC shifts occur in major regions of both hemispheres in the motor, sensory and association areas, so he argued that it seems likely that these shifts are at least partly mediated by ascending impulses from the reticular formation. Research with rats has indicated that any arousing experience, such as tactile stimulation, being awakened from sleep, exploratory movement, increases in the activity level of the animal, or orienting responses, caused a negative shift in DC measured from the surface of the cortex. Caspers argued that increases in the excitation of the reticular formation translate into surface negativity. Any decrease in the activity state of the animal, such as falling asleep or performance of more rudimentary tasks like grooming showed positive DC shifts, which Caspers linked with a decrease in the excitation of the ascending reticular system. Although Caspers did not conclude that there is a direct causal link between stimulation of the reticular formation and DC, he presented

the following arguments which support such an interpretation. The naturally occurring shifts in DC were best imitated by stimulation of the reticular formation. In addition, concurrent recording of the reticular formation and cortical DC activity showed that a rise in reticular activity corresponded to negative DC shifts and a lowering of reticular activity corresponded to positive DC shifts (Caspers, 1963). Finally, evoked and spontaneous DC shifts were no longer visible when an animal was anesthetized (Caspers, 1963).

In current terminology, the ascending reticular activating system is a series of centers in the reticular formation of the brain stem thought to be involved in arousal (Bridgeman, 1988; Steriade & McCarley, 1990). At the time that Caspers was writing these papers, the ascending reticular activating system was believed to be the main area of the reticular formation involved in the regulation of sleep and wakefulness. Today, our understanding of the neurophysiology of sleep and wakefulness is much more complex than it was when Caspers was writing in the 1960s. A complete discussion of this topic is beyond the scope of this paper. Briefly, arousal is now believed to be largely controlled by a noradrenergic system centered in the locus coeruleus, which is near the reticular formation, and by the substantia nigra. The median raphe, which lies between the midbrain and hindbrain, is thought to be involved in the brain-stem control of sleep (Bridgeman, 1988). Caspers did not specify what particular area of the reticular formation was being recorded and/or stimulated. Since some of these areas are very close to the reticular formation, in particular the locus coeruleus, he may actually have been stimulating this area. Nonetheless, the reticular formation is still believed to be involved in regulating general arousal and excitability, as well as motor coordination (Bridgeman, 1988). Very recent research has observed an increase in the firing rates of neurons recorded from the midbrain reticular formation during the transition from sleep to arousal, which directly excite thalamic neurons that project to the sensory-motor areas of the cortex (Steriade & Glenn, 1982; Steriade, Oakson, & Ropert, 1982). So, although our knowledge has

advanced since the time of Caspers' work, his work with the reticular formation still suggests that the brain-stem mechanisms involved in regulating sleep and arousal may be involved in the origin of DC activity.

The results of studies on DC activity in humans, including the results of this study, fit nicely into Caspers' theory that DC reflects the excitation level of the reticular formation. Hoffmann et al. (1988, in submission) found that DC moves in a negative direction when an individual sleeps. The current study suggests that phasic DC moves in a positive direction when humans are awakened from sleep. These results fit those of the animal literature which found that increases in activity and arousal from sleep are associated with a shift in one direction and rest with a shift in the opposite direction, except that the direction of these shifts are reversed. The reason for the differences in the direction of the shift has been discussed previously; animal recordings are made from the cortical surface underneath the scalp and skull referenced either to the muzzle or the occipital bone, whereas human recordings are made from the scalp usually referenced to the mastoid bone. The difference in the choice of reference electrodes could account for the differences in the direction of the shifts. However, given that in both animal and human literature DC moves in one direction during sleep and the opposite direction during arousal from sleep, Caspers' theory involving excitation of brain stem systems responsible for arousal appears tenable. In the light of recent advances in our knowledge of the neurophysiology of sleep and arousal, it would be necessary to examine the role of specific areas in the brain stem in the generation and control of DC activity.

Under Caspers' interpretation of the origin of DC activity, one would expect that if DC reflects brain activation then DC should also change when the individual moves from Stage 2 to REM sleep, since REM sleep is often associated with greater cortical activation or arousal than other stages. Animal studies have found that DC shifts in the same direction during REM as when the animal is aroused from sleep (Kawamura & Pompeiano,

1969; Kawamura & Sawyer, 1964; Tabushi et al., 1966; Wurtz, 1965; Wurtz et al., 1964). The REM analysis attempted in this study did not indicate any change in DC when the individual moved from Stage 2 to REM sleep. This is not surprising, since it was extremely difficult to find instances where an individual made a clear jump in which several epochs of Stage 2 were immediately followed by several epochs of REM sleep. The sleep architecture of these subjects was likely disrupted by the fact that the subjects were awakened several times, making it even more difficult to find clear instances of a shift from Stage 2 to REM. Finally, those animal studies which observed a DC shift during the transition to REM were comparing this to DC activity during SWS and likely traced the DC over a longer period of time from the middle of SWS to a REM period. In terms of EEG activity SWS as recorded in animals, and also in Stage 3 or Stage 4 sleep in humans, is much further from REM sleep than Stage 2 so one would expect that there would be a more marked change in DC in the movement from SWS to REM than from Stage 2 to REM.

If Caspers' idea that DC reflects the excitation levels of the reticular formation is correct, then it seems logical that a greater DC shift upon awakening from sleep reflects a stronger state shift. If, as Morel (1991) and Koulack and Goodenough (1978) suggest, dream recall is facilitated by a stronger state shift from asleep to awake, then it is quite reasonable to expect that DC could differentiate success and failure to recall. The subsidiary analyses indicated the possibility of such a relationship between DC and dream recall. Caspers' work provides a theoretical basis for further exploration of a relationship between DC activity and dream recall, with a more appropriate within subjects design.

Hoffmann et al. (in submission) offer a slightly different explanation of the meaning of DC activity. These authors found that DC moved in a positive direction while the subjects were awake, and a negative direction while they were asleep. According to their interpretation, DC positivity reflects greater fatigue, and the negative trend in DC over the night is a type of restoration of the brain's capacity to perform. This conclusion came

from findings that sleep deprived subjects did not show such a strong negative trend in DC over the course of the time that sleeping subjects were showing this trend, and that DC shifts during cognitive performance were weakened in the sleep deprived subjects. It is possible to incorporate this theory into that of Caspers (1963). Perhaps brain DC has two components, tonic and phasic, which reflect different phenomena but interact with each other. Tonic DC may in fact be a measure of the general fatigue or preparedness of the brain. Riding on top of this are the phasic changes which reflect the excitation level of the reticular formation or some specific area in the brain stem involved in the regulation of sleep and wakefulness. The nature and strength of these phasic changes depends on the fatigue state of the brain, that is, on the placement or activity of the tonic DC. This might explain why there is variability in the direction of the DC shifts observed in this study.

The finding of a strong DC change upon arousal from sleep has implications for the debate over whether or not DC is an artifact rather than a bona fide measure of brain activity. The nature of these shifts, in which DC moves positively when the subjects are awakened and then negatively when they are told to go back to sleep, clearly eliminates any suggestion that DC is simply measuring a linear artifact caused by the drying of electrode paste or the depolarization of electrodes. Changes in electrodermal secretions or temperature as a possible explanation of DC activity can also be eliminated. One could argue that sweating, for example, causes DC to shift in one direction when the individual is awakened, but it would be difficult to apply this artifactual interpretation to the fact that DC then shifts back in the opposite direction when the subjects are told to go to sleep. A similar argument can be applied to the possibility of a temperature artifact. A temperature change might occur when the individual is awakened, but it is not likely to change in one direction when the individual is awakened and then abruptly move again in the opposite direction when the subjects are told to go back to sleep. It could be argued that the DC shift observed upon awakening from sleep is simply a movement artifact, caused by the

movement of the electrodes on the head when the individual wakes up. This interpretation is unlikely, however, given that EMG changes abruptly and dramatically as soon as the individual's name is called, yet the results of this study show that DC shifts gradually upon awakening. If the DC shift was due to a movement artifact, there should have been an immediate statistically significant change between Pre-awakening and Wakeup DC. In addition, visual examination of the DC plots did not show a visible change immediately upon the calling of the subject's name, whereas a dramatic change is clearly observable in the EMG records.

4.2 Suggestions for Future Research

As mentioned previously, the subsidiary analyses on the 12 subjects who provided both a success and a failure to recall indicated that there might be a relationship between DC activity and success and failure to recall. A study similar to this one but using a large sample of subjects who provide both a success and failure to recall would help to determine with more certainty whether a relationship between DC activity and dream recall exists, and whether future research connecting those two variables would be fruitful. It would be best if each subject could be brought in several nights and awakened only once at the same time of night until one success and one failure could be obtained. This would eliminate any variability introduced by the time of night of the wakeup. Success and failure could then be compared in a within subjects analysis.

Individual variability in the direction of DC shifts has been discussed several times in the summary of the findings of this study. Examination of the correlates and specifics of this individual variability will add to our understanding of DC activity, and may possibly reveal a relationship between DC activity and dream recall.

This was an archival study, so it was designed with EEG and not DC in mind. Now that one study of DC and dream recall has been performed, the design of a new study aimed specifically at this question, using information gained from this study, would be

appropriate. Future research would be enhanced if an event marker were used to mark the EEG and DC recordings at the exact time that the subject's name is called and when various aspects of the recall task are completed. The questioning which followed the dream recall task was not pertinent to this study and could be eliminated. This would make it easier to locate the actual recall period and to study when the subjects fall asleep again. Ideally, it would be useful to have every subject's awakening protocol last exactly the same amount of time. Unfortunately, this is difficult to do because some people are able to talk for a long period about their dream experience, whereas others aren't able to do so. At any rate, it would be advisable to specify the length of the wakeup period. The experimenter could ensure that each subject was aroused and responding and wait a specified amount of time before the recall prompt is given. Having subjects respond on a more comparable time frame would make comparison much easier and would allow for the use of other approaches to analyzing this type of data. For example, application of some type of time series analysis might enhance our understanding of the phasic activity of brain DC, and might even show differences between success and failure to recall that were not detectable with the analysis approach used in this study.

Electrode placements used to measure DC should be considered in future research. In this study the recording electrode was placed in the C3 position, which is over the motor cortex. There is no research on whether the kind of DC activity examined in this study varies depending on the recording site used in humans, so this potential source of variability should be explored. In addition, Morel (1991) used the parietal recording site to record EEG because it has been shown to be an important area involved in dreaming, dream recall and the production of dream images (Gabel, 1988; Greenberg & Farah, 1986; Murri et al., 1989). Choice of a different electrode placement for DC recording may help to reveal a relationship between DC and dream recall.

This study found a clear DC shift when the subject was awakened abruptly, but did not examine DC activity when a human awakens spontaneously from a night's sleep. Caspers (1963) noted that when an animal is aroused by some sort of stimulation the DC shift was much steeper and faster than if the animal awakened spontaneously. When the animal was allowed to awaken spontaneously, a gradually rising curve was followed by a negative shift in DC. As discussed previously, it seems quite clear that DC in humans moves in a negative direction when the subject sleeps (Davis et al., 1939; Hoffmann et al., 1988, in submission; King, 1946). Hoffmann et al. (in submission) noted that DC moved in a positive direction when the subject was awake, but this change was slow and gradual over the course of the day. Examination of the DC activity during gradual spontaneous awakening would help to paint the picture of DC activity in the human sleep-wake cycle.

Research with animals and Caspers' (1963) theory that DC activity originates from the activity of the reticular system suggests that DC relates more to arousal in general, rather than just to sleeping and waking. A study examining DC in a resting, but not sleeping, control group would help to determine whether the observed changes in DC have to do specifically with sleep and wakefulness or more generally with rest and activity. It would be interesting to see if the finding that orienting and movement in animals causes a DC shift (Caspers, 1961a, 1961b, 1963) could be replicated in humans.

Finally, the examination of DC activity in the transition from Stage 2 to REM was examined on only 7 subjects. This is an insufficient sample with which to make a strong conclusion about the relationship between DC activity and REM sleep in humans. Problems with this analysis were discussed above. A study specifically aimed at examining the relationship between DC activity and REM sleep in humans would be better able to address this issue.

Conclusion

The first attempt to explore a relationship between DC and dream recall suggests that DC does not have anything to offer to our understanding of dream recall. However, replication of this study using a more powerful within subjects analysis is recommended before the possibility of a relationship between DC activity and dream recall is abandoned. DC does show a clear shift when a human is awakened from Stage 2 sleep. This shift is gradual and moves in a positive direction when averaged across subjects. When the subjects are told to go back to sleep, DC shifts in the negative direction. Individual variability in the direction of DC shifts remains to be explored. The findings of this study add new weight to the data which suggest that brain DC is a bona fide measure of brain activity that bears a strong relationship with the sleep-wake cycle (Hoffmann et al., 1988, in submission). This study clearly indicates that further research on brain DC and the sleep-wake cycle would be fruitful.

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Appendix A**Research Application Form**

The Sleep and Chronopsychology Lab is looking for volunteer Psychology 100 students to participate in a research project. The Lab is looking for right-handed males and females. All subjects will be asked to sleep one night in the lab and will receive four course credit points for their participation. If you already have some of your credits, then participating in this study will allow you to complete your credits. Volunteers must be free of any major sleep problems (e.g. any trouble getting to sleep at night or any trouble staying asleep through the night), and must sleep between 7 and 8 hours regularly per night. Your participation will be greatly appreciated. If interested please enter the necessary information on the sign-up sheet provided. Thanks.

Appendix B**Follow-up Information**

In order to take part in this study, I need to know: Typically, how often do you remember your dreams upon awakening in the morning?

rarely, less than once a month..... _____

infrequently, about once a month..... _____

sometimes, one to two times per week.... _____

often, two to five times per week..... _____

every morning with rare exceptions..... _____

Are you right- or left-handed? You will sleep one night in the lab. You will be told what to expect when you first come to the lab. You will be awakened a number of times during the night and asked to describe your sleep experience. Approximately, how many hours do you sleep at night? Are you having any trouble getting to sleep at night? Are you having any trouble staying asleep through the night? Do you have any major health problems? Are you currently taking any medication? Have you ever had your EEG recorded? I'll ask you to refrain from alcohol, caffeine and drug consumption on the day of the study. Also, I would like you not to take any naps unless you typically do so. Are you interested? If so, let's schedule you. You are encouraged to bring your own pillow, and may bring anything else you are comfortable with (covers, etc.). If not, we are fully equipped.

21 of/de 2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Appendix C

Instructions Upon Arrival at the Lab

During the night, you will be awakened a number of times and asked to describe anything that was happening before you heard me call your name. In this study, I am equally interested in whether you recall something or not. It is important that you report whatever you can recall just before awakening even if you do not recall a full dream, that is if there were just sounds or images or body sensations or even nothing at all. Describe whatever was going through your mind before I called your name. When you hear me calling your name, let me know that you are awake by saying 'yes I am awake' or 'OK I hear you'. After you give your report you will be asked to respond to a few questions. Let's discuss these questions now so that you will know what to expect during the night. If you have any other questions about what is going to happen, feel free to ask me now before we set you up for the night. You are free to withdraw from the study anytime you want to.

Appendix D

Consent Form

LABORATORY FOR THE STUDY OF SLEEP AND CHRONOPSYCHOLOGY

Description of procedures:

Volunteers in this project are asked to spend one night sleeping in the laboratory chamber. For female volunteers, a female researcher will be present for the duration of the session.

Before the volunteer goes to bed, the researcher will attach electrophysiological electrodes on the scalp and facial skin of the volunteer using tape and collodion.

During the night, the researcher will monitor the volunteer's brain activity, muscle tension and eye movements from the instrument room. The volunteer will be able to speak with the researcher by voice intercom during the night. A number of awakenings will be performed during the night in order to elicit a description of the sleep experience, which will be audio-taped. The volunteer will not be significantly deprived of sleep time.

Agreement to participate:

I, _____, have read
(volunteer's name)

the above description and I agree to permit the researcher to carry out the required actions. I agree to hold them blameless for any inconveniences which my volunteering may cause me: e.g. minor disruption of my normal sleep routines, etc. I agree that any data collected by the researcher during my time in the Sleep Laboratory may be used for scientific research and I understand that such data will not be publicly identified as my own. Confidentiality will be maintained to the greatest possible extent.

Date: _____

Signature: _____

Witness: _____

Appendix E

Wakeup Protocol

1. [Name], wake up, keep your eyes closed and remain as still as you possibly can.
(Proceed once the subject shows clear sign of awakening: e.g., a response, some movement, EEG changes, etc.).
2. Could you please describe with as much detail as possible, any experiences you were having before I called your name.
Anything else?
When there is little or no recall, the subject will be asked to "think for a moment or so and see if anything comes back to you" (10-15 seconds.).
Whether there is recall or no recall, proceed with probes 3 to 7.
3. Where 1 is 'deep asleep' and 7 is 'wide awake', rate how you felt before you heard me call your name.
4. Where 1 is 'restless and agitated' and 7 is 'relaxed and sound', rate your sleep.
5. Where 1 is 'uninterested' and 7 is 'extremely interested', rate your motivation to recall any experience this wake-up.
6. Where 1 is 'easy' and 7 is 'difficult', rate the ease or difficulty you had in (trying to recall) recalling your experience.
7. What made your attempt to recall this experience 'easy/difficult'.
8. Thank you. You can go back to sleep now.

Appendix F

Instructions to Raters

Upon awakening subjects were asked: Could you please describe with as much detail as possible any experiences you were having before I called your name. If they appeared to have some recall of content subjects were repeatedly asked if they had anything else to report until they had nothing left to report. When subjects reported little (that they were not sure if any pre-awakening experience occurred or that they knew something occurred but they couldn't describe what it was or if they reported no recall), they were then asked to "think for a moment or so and see if anything comes back to you". The reports for each subject corresponds to a separate page. For each subject, the wakeups are presented in order and separated by an asterisk (*). The reports are to be classified into four categories:

1) Success: recall of some content attributed by subjects to the pre-awakening period. Reports could be of dreaming, thinking or feeling. The content may be a visual image, an experience in another sensory modality (with or without visual imagery) or an emotional experience (affect). Experiences describing thoughts related to the process of sleep are considered contentful. Ex: I felt I wasn't really asleep and thinking how I should be asleep. That would be a success.

A success is coded 1.

2) Contentless: In answer to instructions subjects first claimed to have been dreaming or that something was going through their mind before being called but they couldn't say or describe what it was. No content was available there was an inability to recollect any details of the sleep experience. When asked to think about it for a moment subjects were still unable to recall anything at all.

A contentless is coded 2.

3) Delayed recall: This category is divided into delayed success and delayed contentless.

3.1) Delayed success: subjects first claimed nothing was happening or at least that they were not sure. When asked to think about it, subjects reported some content (see success).

A delayed success is coded 3.

3.2) Delayed contentless: subjects first claimed nothing was happening or at least that they were not sure. When asked to think about it, subjects claimed with a relative degree of certainty that something was happening but they couldn't say or describe what it was (see contentless). Reports of subjects who when asked to think about it, were uncertain and claimed that maybe there was something or said "yes I suppose there was something", are categorized as failures.

A delayed contentless is coded 5.

4) Failure: after being given the opportunity to think about it, subjects were still unable to report anything at all. They didn't think anything was happening; their mind was blank; there was no impression of dreaming.

A failure is coded 4.

END

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FIN