

## EEG THETA WAVES AND PSYCHOLOGICAL PHENOMENA: A REVIEW AND ANALYSIS

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In this paper, studies which have explored the relation between EEG theta waves and psychological phenomena in normal human subjects are reviewed. It is noted that increases in theta activity occur in conjunction with several kinds of psychological processes. The importance of considering properties of theta activity, such as amplitude, rhythmicity and scalp topography when analyzing the relation between theta and psychological processes is emphasized. Although there is some evidence for a relationship between theta and psychological processes, it is concluded that the degree to which properties of theta activity are systematically related to specific psychological processes is not yet known.

### 1. Introduction

EEG theta waves were first reported by Walter and Dovey (1944), who observed their occurrence in cases of sub-cortical tumor. Since that time, several relatively independent lines of research have explored the relation of EEG theta waves to various psychological phenomena in man. It is the purpose of the present paper to critically review these studies, and to clarify the major issues and problems that are found in the literature. This paper will not be concerned with theta activity found in various pathophysiological conditions (Aird and Gastaut, 1959; Cigánek, 1961; Cobb and Muller, 1954; Kuhlo, Heintel, and Vogel, 1969), purely developmental aspects of theta (Kellaway and Petersén, 1968; Matousek and Petersén, 1973; Pond, 1963), drug effects and theta (Clark and Rosner, 1973; Okuma, Shimazono, and Narabayashi, 1957), or the well-known hippocampal theta rhythms found in several species (Winson, 1972) during various kinds of activity. Hippocampal theta is excluded from consideration in this review because it is extremely difficult to observe in man (Bennett, 1971; Douglas, 1967). Finally, this paper will not specifically address the issue of the neurophysiological basis of theta waves, since the literature to be reviewed has not been concerned with the elucidation of neurophysiological substrate.

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## 2. Definition of terms

### 2.1. EEG terms

A recent statement by the International EEG Federation (Chatrian, Bergamini, Dondey, Klass, Lennox-Buchthal, and Petersén, 1974) defined the bandwidth of theta waves as ranging from 4 to under 8 Hz. This is the definition of theta bandwidth that will be used in this paper. In the literature, slightly different definitions of theta bandwidth are sometimes found, e.g., 5–7 Hz, 4–6 Hz, etc. An investigation of the possibility that differences in defining theta bandwidth are in some way related to different experimental outcomes was carried out by the present author. No evidence was found for an effect of bandwidth definition on experimental results.

A second issue that should be noted here concerns the use of bipolar vs. monopolar electrode derivations. Both of these methods are used in the studies to be reviewed. As Gibbs and Gibbs (1950) have noted, certain waveforms are more or less detectable depending on whether bipolar or monopolar derivations are used. Although there does not appear to be evidence for a systematic relation between the type of electrode derivation used and experimental outcomes in the studies to be reviewed, it should be realized that the use of both bipolar and monopolar recording may constitute a source of variability in these studies.

### 2.2. Psychological terms

Most of the studies to be reviewed indicate that the psychological variables which are most consistently related to changes in theta activity can be subsumed under the general heading of 'attention'. The subject of attention has been the target of much recent work in psychology and neurophysiology (Broadbent, 1971; Evans and Mulholland, 1969; Kahneman, 1973; Moray, 1969; Mostofsky, 1970; Näätänen, 1975), but the concept still remains enigmatic and difficult to precisely define. The approach which has provided the most useful framework for this paper is found in the work of Posner (Posner and Boies, 1971; Posner, 1975). Posner, like several recent theorists, has rejected the view of attention as a unitary construct, and has attempted to provide a differentiated model in which an analysis of the various components of attention is possible. The three attentional components which Posner (1975) identifies are alertness, selectivity, and conscious effort. Alertness is viewed as pertaining to pre-stimulus processes which affect the receptivity of the organism to a wide class of stimuli. Selective attention refers to the processing of one source of information rather than another. The third aspect of attention refers to an intensive dimension, reflecting conscious or effortful processing of information. Although this presentation is somewhat oversimplified, these distinctions will provide a useful framework for analyzing studies concerned with theta activity and psychological function.

### 3. Theta in hypnagogic, rapid eye movement, and sleep deprivation states

#### 3.1. *The hypnagogic state*

Literature concerned with the drowsy, hypnagogic state has been reviewed in detail elsewhere (Schacter, 1976). In this section, the relevant parts of this literature will be summarized, and relevant studies not reviewed in the Schacter (1976) paper will be discussed.

Studies reported by Davis, Davis, Loomis, Harvey, and Hobart (1937), Dement and Kleitman (1957), Foulkes and Vogel (1965), Liberson and Liberson (1965), and Stoyva (1973) converge to suggest that the major EEG correlate of the hypnagogic state is a low voltage, irregular theta wave carrying superimposed faster components in the beta range. This theta activity is generally spread diffusely over the cortex. Characteristic changes in the EEG are observed when sensory stimuli are presented in the hypnagogic period. In contrast to the classical alpha blocking response observed during sensory stimulation in alert wakefulness (Adrian and Matthews, 1934), sensory stimulation in the presence of low voltage theta activity during drowsiness induces alpha activity (Blake and Gerard, 1937; Fischgold and Schwartz, 1961; Loomis, Harvey, and Hobart, 1938; Morrell, 1966; Oswald, 1962). The importance of this phenomenon for elucidating the functional characteristics of theta activity appearing in various psychological conditions will be seen later.

Numerous psychological phenomena have been found to accompany the low-voltage theta EEG in the hypnagogic period: autonomous and often vivid visual and auditory imagery (Foulkes and Vogel, 1965; Stoyva, 1973), a variety of kinesthetic experiences (Davis et al., 1937; Oswald, 1962), and various alterations in thought processes (Vogel, Foulkes, and Trosman, 1966; Vogel, Barrowclough, and Giesler, 1972) are among the most prominent. An important cognitive correlate of the hypnagogic period concerns the organism's decreasing ability to interact actively with the environment. Foulkes and Vogel (1965) and Davis et al. (1937) have noted a decrease in awareness of the environment as subjects move into the diffuse, low-voltage theta phase of drowsiness. Similarly, Oswald (1962) has argued that the appearance of low-voltage theta activity in the hypnagogic period signifies a decline in cortical vigilance during which interaction with the environment is markedly impaired. Liberson and Liberson (1965) noted an almost linear increase in motor reaction time to auditory signals as subjects entered the low-voltage theta phase of drowsiness. Kamiya (1961) required subjects to press a switch in order to avoid noxious auditory stimulation, and found that as alpha is replaced by the EEG of drowsiness, rate of pressing declines from a steady level often to zero. Fischgold and Schwartz (1961) found that the production of a motor response to a visual stimulus becomes less consistent as subjects move from relaxed wakefulness into the EEG defined drowsy period. Simon and Emmons (1956) studied the retention of verbal material presented during drowsiness and sleep. Within the drowsy period, it was found that when the alpha rhythm disappeared and was replaced by

the low-voltage theta activity, the probability of response or later recall is lower than when the alpha rhythm is present.

Studies of the averaged evoked potential (AEP) provide further information concerning organism-environment relation in the hypnagogic period. Several studies have reported an amplitude increment of the second negative component of the AEP (N2; latency approximately 265 msec) in response to auditory stimulation during the low-voltage theta phase of drowsiness (Fruhstorfer and Bergström, 1969; Fruhstorfer, Partanen, and Lumio, 1971; Ornitz, Ritvo, Carr, LaFranchi, and Walter, 1976). These authors suggested that increased N2 amplitudes indicate increased cortical responsiveness to auditory stimuli during drowsiness, as noted by Schacter (1976). However, information concerning the N2 component found in AEP studies of alert subjects suggests a different interpretation. Wilkinson, Morlock, and Williams (1966) showed that P2 and N1 amplitudes are smaller on missed auditory signals than on correctly detected ones; to the contrary, N2 amplitudes are larger on missed signals. Wilkinson and Morlock (1967) found that when subjects made a motor response to an auditory stimulus (vs. ignoring it), larger P1, N1, and P3 amplitudes were produced. In contrast, N2 amplitude was larger when subjects ignored the stimulus. They also found increased N2 amplitude to accompany slow reaction time to auditory stimuli; no relation between amplitude and reaction time was found for other AEP components. Bostock and Jarvis (1970) found decreased amplitude of N1 and P2 when reaction time to auditory stimuli was slow; increased N2 amplitude was found during slow reaction time. These studies suggest that increased N2 amplitude indicates impaired response to auditory stimuli. Thus enhanced N2 amplitude to auditory stimuli accompanying low-voltage theta in the hypnagogic period may be seen as an indicator of the organism's inability to interact actively with the environment at this time.

The various findings reviewed in this section suggest that the theta activity observed during the hypnagogic period is indicative of a lowered pre-stimulus level of alertness which is accompanied by impaired ability to process and respond to environmental information. Precisely which information-processing functions are impaired and which are left intact during the low-voltage theta of drowsiness is not yet clear. Williams (1973), based on his review of the literature concerned with information-processing during sleep, noted that sensory transmission is not grossly impaired during sleep. A similar conclusion seems appropriate with respect to the hypnagogic period. For instance, several authors have reported that external stimuli are readily incorporated into ongoing hypnagogic mentation (Hollingworth, 1911; Slight, 1924; Varendonck, 1921), and early studies by deManaceine (1897) indicated that subjects are highly influenced by suggestions in the hypnagogic period. However, these studies lack adequate rigor and detail, and must be interpreted cautiously. Sokolov (1963) has noted that EEG rhythms are extremely responsive to stimulation in the drowsy period. This observation was confirmed by Tizard (1966), who found a highly significant tendency for more evoked EEG changes to occur as theta activity increased in drowsy subjects. Failure to register information

in memory does not seem to be principally responsible for impaired information-processing in the hypnagogic period: McDonald, Johnson, and Hord (1964) found habituation of galvanic skin response and finger vasoconstriction measures upon repeated presentation of auditory stimuli in drowsy subjects characterized by low-voltage theta EEG. Similarly, Molinari and Foulkes (1969) have reported that short-term retention (of internal mentation) is not markedly impaired in the drowsy period. Whether the impairment in information-processing during the hypnagogic period is due to loss of the 'sensory-motor link' (Fischgold and Schwartz, 1961), transfer of information from short-term to long-term memory, or retrieval of information from long-term memory (Williams, 1973) is not yet known.

One problem that arises in studies which have related changes in psychological function to low-voltage theta EEG observed in the hypnagogic period concerns the possible influence of phasic (vs. tonic) EEG phenomena (Grosser and Siegal, 1971). The most prominent phasic EEG phenomenon observed in the hypnagogic period is the so-called vertex sharp wave (Hess, 1964) which is generally seen toward the end of the drowsy state. Foulkes and Pope (1973) have suggested that this EEG pattern may be related to hypnagogic mentation. Whether or not the presence of this wave is related to the processing of environmental information in the drowsy period is not yet known. However, future studies concerned with psychological function and theta activity in the hypnagogic state must be careful to separate tonic and phasic EEG phenomena. Another problem concerns the significance of the fast frequencies which are often superimposed on theta waves in the drowsy period. Studies which examine the proportion of theta-to-fast frequencies in relation to psychological function would be desirable.

### 3.2. *The REM state*

Numerous investigators have observed that the low-voltage theta-mixed frequency EEG observed in REM sleep is difficult to distinguish from the EEG in the hypnagogic period (Giora and Elam, 1974; Johnson, Lubin, Naitoh, Nute, and Austin, 1969; Larsen and Walter, 1970; Rechtschaffen and Kales, 1968), although the findings of Itil (1970) suggest that the two can be distinguished. Thus we might ask whether the psychological functions observed in the presence of low-voltage theta during the hypnagogic period are similar to those observed in the REM period. That there is psychological similarity between the two states is indicated by the difficulty of distinguishing hypnagogic mentation from REM mentation (Foulkes and Vogel, 1965; Foulkes, Spear, and Symonds, 1966; Vogel, Barrowclough, and Giesler, 1972) and by the observation that certain information-processing capacities in the REM period more closely resemble information-processing capacities during the drowsy period than those found in other sleep stages (Lasaga and Lasaga, 1973; Williams, Morlock, and Morlock, 1966). However, response threshold is higher in the REM than the hypnagogic period (Dement and Kleitman, 1957).

A clear and detailed answer to this question is not possible at the present time, primarily due to the tonic-phasic problem described earlier. The REM period is replete with phasic EEG phenomena such as 2–3 Hz ‘sawtooth waves’ (Rechtschaffen and Kales, 1968), bursts of alpha activity (Johnson, 1970), periorbital phasic integrated potentials (Rechtschaffen, 1973), and sleep spindles (Dummermuth, Walz, Scolo-Lavizzari, and Kleiner, 1972), which make it difficult to directly relate findings on psychological parameters of the REM state to background theta activity. Future research which attempts to assess the psychological significance of theta activity in REM as well as hypnagogic states must specifically control for phasic EEG phenomena.

### *3.3. Sleep deprivation*

Early studies of the EEG during total sleep deprivation (SD) clearly showed that alpha activity is significantly depressed during the course of deprivation. Several authors (Malmö and Surwillo, 1960; Tyler, Goodman, and Rothman, 1947) argued that the low-voltage EEG which replaces alpha indicates heightened arousal level resulting from subjects’ efforts to remain awake. These authors pointed to the increased activity of several autonomic variables as evidence of this interpretation.

However, the majority of evidence concerning the EEG in SD strongly supports the position that during incidents of alpha depression, theta activity is dominant, and is related to episodes of extreme drowsiness. Armington and Mitnick (1959) reported the effects of auditory stimulation on EEGs recorded from an occipital-vertex derivation in 10 subjects before, during, and after 98 h of SD. They note that in the well-rested subjects the typical alpha blocking response to auditory stimulation is observed. In sleep-deprived subjects, alpha enhancement is observed in response to auditory stimulation. Armington and Mitnick also observed that the waveform which replaces the alpha rhythm in SD is similar to the one observed in the transition from wakefulness to sleep, and concluded that lack of alpha in SD is due to drowsiness. Johnson, Slye, and Dement (1965) also found alpha enhancement to sensory stimuli during prolonged SD (264 h) in their one subject. They further noted that if the low-voltage, mixed frequency pattern observed in their subjects during SD indicated heightened arousal, then alpha activity should be observed when the subject is permitted to relax and go to sleep. However, when the subject was permitted to sleep, his EEG showed high-voltage delta activity as well as spindles, but no alpha was observed. The authors noted that this supports the position that their subject was in a drowsy state. Further evidence comes from a study by Naitoh, Pasnau, and Kollar (1971), who found that the percentage of delta and theta activity increases with length of SD, while alpha decreases and beta shows little change.

One of the early enigmas of SD research was the finding that performance on various perceptual and motor tasks did not markedly deteriorate over the course of SD (Kleitman, 1963). Bjerner (1949) pointed out that failure to observe changes in

performance during SD resulted from the failure to separate relatively brief periods of poor performance from longer periods of time during which the subject could perform well. Bills (1931) had called such episodes 'blocks', and operationally defined them as reaction times which are more than twice the mean reaction time (RT) for a particular test and signal. He posited that 'blocks' increase in frequency during conditions of fatigue.

Bjerner (1949) studied the relation between RT and performance on a serial RT task in 5 subjects during 48 h of SD. The RT task lasted approximately 12 min and was performed about 10 times by each subject. Bjerner used a criterion similar to Bills' to define performance blocks (which Bjerner called 'delayed actions'). He found that delayed actions are accompanied by a significant deficit of alpha activity. Bjerner noted that frequencies in the theta and delta range replace alpha, and suggested that the lapses of cerebral functioning which accompany delayed actions might be brief periods of sleep. Unfortunately, little detail is presented concerning method of EEG analysis. Williams, Lubin, and Goodnow (1959) studied performance during SD in a total of 37 subjects, undergoing either 72 or 98 h of SD. EEG was recorded from bipolar occipital–vertex electrodes, and analyzed automatically for presence or absence of alpha activity. Concerning the relation between EEG and performance, Williams et al. (1959) analyzed the EEG during the 1 sec interval before and the 1 sec interval after the occurrence of a critical stimulus in an auditory vigilance task. They found that when subjects did not respond to the critical stimulus, significantly less alpha is present in the analyzed intervals than when subjects either correctly responded, correctly withheld a response, or incorrectly responded. The authors interpreted the lack of alpha during errors of omission as evidence of brief periods of extreme drowsiness. Mirsky and Cardon (1962) studied 8 subjects during 66–70 h of SD. Four subjects completed an auditory vigilance task and 4 subjects completed a visual vigilance task. Both sets of subjects were instructed to press a response key when a designated critical stimulus was presented. The EEG, recorded bipolarly from C3–CZ and CZ–C4 (International 10–20 System, Jasper, 1958), was analyzed in the  $\frac{1}{2}$  sec before and  $\frac{1}{2}$  sec after presentation of the critical stimuli by measuring the duration of the slowest wave occurring in this 1 sec interval. The major finding was that during errors of omission greater amounts of theta and delta activity are observed than when subjects respond correctly.

An important study by Williams, Granda, Jones, Lubin, and Armington (1962) examined the covariation between the EEG and performance during 64 h of SD in 7 subjects. An auditory RT task was used in which subjects pressed a response switch when a critical stimulus occurred. EEG (recorded from an occipital–vertex derivation) in the 1 sec prior to the onset of the critical stimulus was analyzed by counting the number of waves present in this interval. Testing was carried out prior to, during, and following recovery from SD. The EEG frequency in the critical 1 sec interval showed a unimodal peak at 9–10 Hz for baseline and recovery trials. However, by day two of SD, EEG frequency distribution in the critical 1 sec interval is

bimodal: in addition to a peak at 9 Hz, a secondary peak develops at 6 Hz in 5 of the 7 subjects. Either subjects respond correctly within  $\frac{1}{2}$  sec or they miss the signal entirely. Correct responses are associated with the 9 Hz mode, and omissions are associated with the 6 Hz mode. Correlation between EEG and RT reaches a peak ( $r = -0.64$ ) on day two of SD. However, it is noted that there is little correlation between EEG and RT in the 2 subjects who failed to develop a theta mode. Williams et al. (1962) posited that '...in order for a high correlation to exist between RT and EEG, the EEG frequency distribution must develop a secondary mode in the 4–7/sec. range' (p. 68). The authors concluded that 'As sleep loss increases, the 6/sec. theta rhythm becomes a very accurate indicator of lapses' (p. 69). The force of this conclusion is limited somewhat by the use of visual EEG analysis in this study; replication of this study using, say, spectral analysis, would be desirable.

In sum, these studies indicate that in SD 'lapses' are accompanied by poor performance on detection tasks, and that theta activity appears to be the principal EEG correlate of these lapses. The reviewed studies suggest that in SD theta activity indicates a lowered level of pre-stimulus alertness which impairs information-processing functions. The question of which information-processing functions are impaired is not well understood, as evidenced by a recent symposium on the topic (Chase, 1972, pp. 323–361), but most concern is with memory functions. Studies which are able to identify those cognitive functions that are impaired during the lapses of SD could provide important insight into the relation between theta activity and psychological processes. It would be interesting to know if the same information-processing functions are impaired in SD lapses and the hypnagogic period, since the characteristics of theta activity observed in these two conditions are quite similar.

#### **4. Theta in problem-solving, perceptual processing, learning, and memory**

Recent studies concerned with cognitive activity as reflected in various EEG frequency bands have provided important data concerning theta activity and several classes of cognitive processes in alert persons. For the sake of expositional clarity, these studies will be grouped under the headings of problem-solving, perceptual processing, and learning and memory. Several studies present data on tasks which fall into more than one of these categories, e.g., several of the perceptual processing studies contain memory components, and several of the problem-solving studies contain perceptual processing tasks. An effort has been made to review these studies in the most appropriate sections.

##### *4.1. Theta and problem-solving*

An increment in theta activity during problem-solving had been noted by Arellano and Schwab (1950) and Mundy-Castle (1951). However, these studies provide



little detail concerning the precise effects which were encountered, and are thus of questionable value. Mundy-Castle (1951) noted that theta was augmented during mental arithmetic and sensory imagery tasks in about 10% of his sample, but no quantitative data attesting to the strength of these effects are presented, nor are statistical analyses offered. Similarly, Ford (1954) reported an increase of low frequency, high amplitude EEG activity over frontal areas during mental arithmetic, but did not provide detailed information concerning the exact frequencies of the observed activity. More recently, Volavka, Matoušek, and Roubíček (1967) used automatic frequency analysis to study the effect of eye-opening and mental arithmetic on delta, theta, alpha, and beta frequency bands. EEG was analyzed from bipolar leads P4–T6 in 12 subjects. It was found that eye-opening and mental arithmetic lead to a significant reduction in both theta and alpha activity; beta activity increased during mental arithmetic and decreased during eye-opening.

A study by Vogel, Broverman, and Klaiber (1968) examined the EEG from occipital and parietal areas in alpha, beta and 'slow' (<7 Hz) frequency bands during a simple and a complex mental arithmetic task. One problem in interpreting the results of this study is that the theta and delta bands are considered together as the 'slow' category. Studies to be reviewed later in this section show that the theta and delta bands are not affected in the same way by problem-solving tasks; thus the results of the Vogel et al. (1968) study may be only partially applicable to the question of theta and problem-solving. Vogel et al. present results from two samples. In both samples, the EEG was visually analyzed.

In their first sample, comprised of 36 male college students, no correlation was found between performance on either the simple or difficult mental task and EEG in any frequency band. Their second sample consisted of 25 male high school students. Data from these subjects indicated that amount of slow occipital activity is positively and significantly correlated with efficient performance on the difficult task. No relation between slow wave activity and performance was found on the simple task, and no relation was found between amount of alpha or beta activity and performance on either task. Thus the major result of the Vogel et al. (1968) study is that EEG frequencies which are usually associated with drowsy and sleep-like states are positively related to the performance of a relatively difficult cognitive task, but not to the performance of a relatively simple one. Noting the apparently paradoxical nature of this finding, Vogel et al. posited the existence of two types of inhibitory processes, both related to EEG slow waves. In 'Class I' inhibition, as seen in drowsy and sleep states, slow waves represent the inactivation of entire response systems and activation processes. In 'Class II' inhibition, which Vogel et al. assert accompanies efficient performance, slow waves represent '... a selective inactivation of particular responses so that a continuing excitatory state becomes directed or patterned ... the inhibition of activated but non-relevant (or non-reinforced) pathways' (1968, p. 172). The implications of this conceptualization will be discussed shortly.

Legewie, Simonova, and Creutzfeldt (1969) used computer analysis of the EEG

to investigate the numbers and average amplitudes of theta, alpha, and beta frequencies in eight male college students during the performance of five different tasks: (1) drawing a wavy line; (2) writing the word 'Dampfschiffahrtsgesellschaft'; (3) repeated mental arithmetic; (4) acoustic tracking; (5) optical tracking. All of these tasks were performed with eyes open, and all except task 5 were performed also with eyes closed. EEG was analyzed from F3–C3 and T5–O1 bipolar leads for the first minute of task performance, and then compared with the one minute rest period preceding the particular task. Results indicated that different effects of the various tasks were found only in the theta band; the tasks affected alpha and beta frequencies in a homogeneous manner. With eyes closed, the number of theta waves increased significantly in all four tasks fronto-centrally; tasks 1 and 3 produced significant theta increments in the temporo-occipital area, but these were of a smaller magnitude than those observed in the fronto-central leads. With eyes open, tasks 2, 4, and 5 produced significant theta increments fronto-centrally; in contrast, temporo-occipital theta activity insignificantly decreased in all tasks with eyes open. Changes in the number of theta waves during task performance generally showed a negative correlation with changes in alpha and beta frequencies. Changes in amplitude were small and inconsistent in all frequency bands. Thus the major findings of this study are that increments in the number of theta waves during mental activity are more frequent and pronounced in the fronto-central area than in the temporo-occipital area, and that only theta frequencies are differentially affected by the various tasks.

Ishihara and Yoshii (1972) conducted a detailed study of EEG changes during the performance of 15 different problem-solving tasks in a large sample of male juvenile delinquents (average age 17.8 yr). These authors noted previous work in which they found theta activity to accompany the performance of 'strenuous' continuous addition, and further noted that theta was maximal at the FZ electrode during task performance. They report that this FZ theta underwent '... conspicuous change as the kind of calculation varied...' (1972, p. 71). In the present study, Ishihara and Yoshii analyzed EEG activity from a bipolar FZ–CZ montage during task performance in 60 subjects (their original sample consisted of 270 subjects; however, 126 were eliminated due to the presence of recording artifacts, and 84 because no frontal theta was observed during problem-solving). Integrated output of frequency analyzers was used for EEG analysis. Multivariate factor analysis was carried out on problem-solving test results. Ishihara and Yoshii found that during performance of the problem-solving tasks there was an increment of FZ–CZ theta activity. It was also found that the integrated abundance scores of the theta band only were differentially affected by the various tasks. The integrated values in the other frequency bands showed no difference between the tasks. Further, the test which the authors claim required the least cognitive activity – marking 'xs' on a series of numbers – yielded significantly less FZ–CZ theta than the other 14 tasks. Conversely, the test which the authors assert required 'continuous concentration of attention' – a shape matching problem – yielded the most FZ–CZ theta. Regarding the factor analysis,

two factors were extracted which relate EEG theta scores to test scores. Ishihara and Yoshii interpreted the loadings of the first factor to indicate a factor of thinking, and the second to indicate a factor of working speed.

A subsequent study by Ishihara and Yoshii (1973) (presented in abstract form and without much detail) deserves mention here. They reported that when frontal theta appeared in eyes closed, resting subjects for three seconds or longer, subjects' introspection indicated that they were '... thinking continuously on only one theme and the field of their attention was narrowed' (1973, p. 701). Another brief report (Yamaguchi, Niwa, and Negi, 1973) presents similar findings: 50% of subjects who were carrying out continuous addition showed theta activity in the midfrontal region. Subjects' introspection indicated that the appearance of midfrontal theta was related to '... a state of concentration on the addition' (1973, p. 705).

Dolce and Waldeier (1974) used spectral analysis to investigate EEG activity during eye-opening, mental arithmetic, and reading compared to resting eyes-closed. EEG was analyzed from parieto-occipital and parietal leads in 10 subjects. The data of five subjects who showed the greatest percentage of eyes-closed alpha was used for analysis in the other conditions. Results showed that all three conditions significantly depressed the amount of alpha activity. Beta was increased during eye-opening and reading, but not during mental arithmetic. Delta was increased during eye-opening, mental arithmetic, and reading, with a greater increment produced during mental arithmetic than reading. Theta was increased by eye-opening only in the left hemisphere, and was significantly increased both cognitive tasks, with the increase greater during reading.

A final study relevant to this section was reported by Brown (1971). In this study, the intensity of different coloured lights was controlled by the output of bandpass filters which registered the amounts of theta, alpha, and beta activity produced by subjects. When a pre-set criterion of EEG activity in a given frequency band was reached, the luminance of a particular coloured light would increase. Subjects were required to describe the internal states related to the continuous appearance of each of the coloured lights. Brown found the following responses to be the most common associates of the colours which were activated by theta activity: 'Memory of problems, uncertainty, problem-solving, future planning, switching thoughts, solving mechanical or financial problems, daydreaming' (1971, p. 455). These results are generally consistent with the literature reviewed in this section which suggest a positive relation between theta activity and problem-solving.

Two problems must be considered before critically assessing the implications of the above studies. The first is what, if any, relation there is between the theta activity observed during problem-solving, and the so-called kappa rhythm which has been reported to accompany problem-solving behavior (Chapman, Armington, and Bragdon, 1962; Kennedy, Gottsdanker, Armington, and Gray, 1948, 1949a, 1949b). The major difference between the two is the higher frequency of the kappa rhythm. Kappa bandwidth is defined as 8–12 Hz (Kennedy et al., 1948) and median frequency was found to be 9 Hz (Chapman et al., 1962). Also, kappa was

reported to be most prominent at bitemporal leads (Kennedy et al., 1948). The studies reviewed in this section indicate that increments in theta activity during problem-solving can be found at a variety of leads, but are most prominent in the fronto-central area. A functional similarity between the two is that greater amounts of both kappa and theta are reported on difficult tasks than on easy tasks (Chapman et al., 1962; Ishihara and Yoshii, 1972). A further point of comparison concerns the percentage of the population in which kappa and theta are observed during problem-solving. Kennedy et al. (1949b) reported that kappa was observed in 30% of their subjects, Gibbs and Gibbs (1950) reported 11% incidence of kappa, and Chapman et al. (1962) noted that median percent time kappa on all tasks in their investigation was 4.8%. Ishihara and Yoshii (1972) reported that frontal theta was seen during problem-solving in 70% of their subjects; Tani (cited in Ishihara and Yoshii, 1972) offered an incidence of 50%. These several comparisons suggest that the kappa and theta activity seen during problem-solving types of activity may be different indices of a similar underlying process. Unfortunately, no studies have directly contrasted kappa and theta recorded simultaneously during problem-solving tasks. Studies employing this strategy are called for.

A second problem that must be considered is eye movements. A major criticism of the kappa phenomenon was made by Harlan, White, and Bickford (1958), who attempted to show that kappa is generated by eyelid flutter. However, Armington and Chapman (1959) convincingly showed that although eyelid flutter does generate potentials similar to the kappa rhythm during problem-solving, when eyelid flutter potentials are eliminated, the kappa rhythm is still readily observed. In direct relation to the theta waves under consideration here, Harlan et al. (1958) often observed 3–6 Hz activity in frontal areas during problem-solving. They sought to attribute this activity to eyelid flutter. However, they noted that eyelid flutter is usually abolished by opening the eyes; in the studies reviewed in this section, theta activity is observed during problem-solving in both eyes open and eyes closed conditions. It is also important to point out that in most of the studies which have found a relation between theta and problem-solving, eye movement and eye-blink potentials were actively monitored and eliminated from the principal analyses. Thus the possibility that ocular potentials generate the frontal theta observed during problem-solving seems unlikely. Ocular potentials are always possible sources of artifact when recording electrical potentials from frontal scalp leads during mental activity (Tecce, 1972), and future studies of theta must carefully control for this factor.

A first question that must be asked in interpreting the reviewed studies is whether enhanced theta activity during problem-solving results from non-specific, pre-stimulus increments in alertness, or from task-specific operations. Though the issue cannot be finally decided here, a strong argument against a pre-stimulus preparation explanation concerns the findings of Legewie et al. (1969) and Ishihara and Yoshii (1972) that only theta frequencies are differentially affected by different tasks. If subjects were differentially preparing for the tasks, then changes in alpha

and beta frequencies should reflect this differential preparation; however, alpha and beta were affected by different tasks in both studies in a generally homogeneous manner. It is also relevant that the Legewie et al. and Ishihara and Yoshii studies presented tasks in a random or varied order, thus reducing the possibility that subjects might differentially prepare for tasks by successfully predicting task occurrence (Näätänen, 1975). In terms of the Posner (1975) model, the studies reviewed here do suggest that a combination of selective, narrowly focused processing, and intensive 'mental effort' are most consistently related to enhanced theta activity during problem-solving. It is difficult to know exactly what combination of these two factors yields maximal theta activity due to the lack of specification by experimenters of precisely what operations they think that their tasks require, and the consequent lack of measures which permit analyses of these operations. Also, it is not yet clear whether specific cognitive operations required by problem-solving tasks – beyond the basic operations of selective and intensive processing – contribute to observed theta increments. Indeed, with the exception of the Ishihara and Yoshii (1972) study, the major investigations reviewed in this section have employed some form of mental arithmetic as their basic problem-solving task; thus only a restricted sample of relatively simple problem-solving tasks has been investigated. Future studies should explore problem-solving tasks which required more complex and well-defined operations (Newell and Simon, 1972). Such studies might provide data on which to evaluate the possible relationship between theta activity and specific cognitive operations.

Another interpretive problem is raised by the Vogel et al. (1968) concept of Class II inhibition. Their conceptualization implies that theta activity observed during problem-solving at a given scalp electrode represents inhibition of the subjacent cortical area. On this basis, it would be expected that theta activity is most prominent over cortical areas not relevant to task execution (which are inhibited), and least prominent over cortical areas involved in task execution (which are activated). This problem is difficult to evaluate on the basis of the reviewed studies. One strategy that may be useful for exploring this issue is a systematic study of the cortical topographical distribution of theta activity observed during tasks which are constructed to elicit well-defined operations. Interpretation of such data in light of recent neuropsychological work concerned with the functional role of the various cortical areas in information-processing activities (Luria, 1973; Pribram, 1971) might provide a basis on which to evaluate the Vogel et al. (1968) hypothesis.

#### *4.2. Theta and perceptual processing*

A series of studies by Gale and his colleagues provide insight into the relation between theta and perceptual processing. In these studies subjects are exposed to various kinds of visual stimulation while their EEG is recorded transoccipitally. The integrated output of various bandpass filters is used to assess EEG changes. Gale, Christie, and Penfold (1971) studied the effects of stimulus complexity on EEG

alpha, beta, and theta abundance. Subjects were instructed to passively view a series of slides on which there were either 2, 4, 8, 16, or 32 white squares randomly distributed on a black background. Control slides were used in which a single white square which corresponded to the total area of 2, 4, 8, 16, or 32 individual squares was superimposed on a black background. Gale et al. (1971) found that alpha abundance decreased with increased stimulus complexity in the experimental condition, and that theta abundance increased linearly with ascending stimulus complexity in the experimental condition. No significant EEG effects were seen in the control condition. It should be noted that stimulus complexity and numerosity are confounded in this study.

Gale, Coles, and Boyd (1971) examined the effect of five conditions of visual stimulation on the EEG: (1) eyes closed; (2) eyes open in the dark; (3) viewing a blank screen; (4) viewing a black circle on a white background; (5) viewing the black circle with eight spokes radiating at 45° intervals. They found that abundance of alpha and beta frequencies decreased from conditions 1–5. Abundance of theta decreased in a similar manner for conditions 1–3, but significantly increased in conditions 4 and 5, where more complex stimuli were viewed. Gale, Spratt, Christie, and Smallbone (1975) used a similar experimental design, but attempted to assess the relative contributions of stimulus numerosity and stimulus variety to observed EEG changes. They found that alpha abundance was inversely related to both stimulus numerosity and variety, beta abundance was inversely related to stimulus numerosity, and theta abundance was directly related to stimulus numerosity, but not related to stimulus variety. These three studies suggest that increasing the number and complexity of visual stimuli which a subject passively views results in significant increases of theta activity. Gale et al. (1975) interpreted these effects in terms of the 'arousal value' of the stimulus, more arousing stimuli yielding increased theta abundance.

Walter, Rhodes, and Adey (1967) used spectral analysis in an attempt to distinguish between resting eyes open, resting eyes closed, eyes closed listening to tones, and visual discrimination tasks of one and three seconds duration on the basis of the EEG in four subjects. EEG was recorded bipolarly from P3–O1, P4–O2, CZ–FZ, and O1–O2 locations. Three autospectral parameters were studied: power, mean frequency within band, and bandwidth within band. Coherence<sup>1</sup> between recording locations was also computed. Stepwise multiple discriminant analysis was then used to select those spectral parameters which most adequately distinguish between the various conditions. It was found that among the four 'best' discriminating EEG variables, two were from the theta range: mean frequency of theta at CZ–FZ, and theta coherence between P3–O1 and CZ–FZ. Theta activity at CZ–FZ was most useful for discriminating the two resting conditions from the two visual discrimination conditions; theta is lower in frequency, higher in power, and

\* Coherence is a measure which expresses the strength of the linear relationship between EEG activity at various frequencies occurring simultaneously at two electrodes.

narrower in bandwidth for the visual discrimination tasks. Theta coherence between P3—O1 and CZ—FZ proved most useful for distinguishing the one second visual discrimination task from all other conditions: '... the strength of relationship between the theta band activity in two areas of subjects' scalps was stronger during the periods when they had 1 second for discrimination than when they had 3 seconds' (1967, p. 26). Relevant to these findings are EEG studies by these authors of astronaut Frank Borman before and during the Gemini GT—7 flight (Adey, Kado, and Walter, 1967). Using spectral analysis, they found a sharp increase in theta power in the few minutes just before take-off, compared to previously established baseline data. Theta power diminished during the flight, but remained above baseline levels. Coherence was high at theta frequencies just before and up to launch time before falling to near-baseline levels. The authors commented that 'These findings are interpreted as relating to strongly focused attention and orienting responses in an undoubtedly novel situation' (1967, p. 348).

Several studies have reported a relation between quantity of theta and performance on vigilance tasks in non-sleep deprived subjects. Daniel (1967) presented subjects with tape recorded digits at the rate of one per second in a one hour vigilance task. Subjects were instructed to press a key when a critical sequence of three consecutive and different odd digits appeared, e.g., 3—7—1. EEG was analyzed from a bipolar left occipital-vertex configuration. Two forms of analysis were employed. Quantified measures of the autocorrelogram were used, as the author had previously found this method to provide an accurate depiction of cortical arousal level (details in Daniel, 1965). Second, a zero-crossing analysis was used in which each EEG cycle was analyzed according to wavelength, and classified into the appropriate frequency band. Analysis of the EEG on correct vs. incorrect detections of critical stimuli showed no difference between quantified autocorrelograms in the 15 sec epochs preceding a correct vs. incorrect response. Zero-crossings analysis was performed on 1 sec EEG intervals in the 15 sec preceding and the 15 sec following correct and incorrect responses. No differences were found between correct and incorrect trials for any wavelength in the alpha range. However, there was a significant deficit of theta waves in the 3 sec preceding and 3 sec following an incorrect response. Daniel noted that this result could not be attributed to a few extreme subjects. Both high and low error subjects showed a significant theta deficit around errors, as did high and low theta producers.

A study reported by Haslum and Gale (1973) provides some support for Daniel's findings. Haslum and Gale required subjects to respond when a critical sequence of digits (four consecutive and different odd digits) was presented. Both auditory and visual stimuli were used. Each digit sequence was followed by a 5 sec rest period. It was found that integrated theta abundance (as measured by automatic frequency analysis of transoccipital recordings) is higher during an auditory signal than in the rest period following that signal, whereas the reverse was true for alpha. It was also found that as an auditory signal type more closely approximated the desired critical sequence, significantly less alpha and insignificantly more theta was observed. No

significant theta changes were observed when digit sequences were visually presented. Gale, Haslum, and Lucas (1972) obtained similar results using only auditory stimuli in a similar detection paradigm.

Results to the contrary of those reported by Daniel (1967) have been obtained by Beatty, Greenberg, Deibler, and O'Hanlon (1974). Beatty et al. trained two groups of subjects to either suppress or augment O1-P3 theta activity through biofeedback procedures. The performance of these subjects was then assessed on a visual monitoring task in which they were required to detect a prespecified critical signal embedded in video noise. Subjects performed the monitoring task during one session in which one group attempted to augment and one group attempted to suppress theta activity, and during another session in which they did not attempt EEG regulation. It was found that the best monitoring performance was achieved by the theta-suppress group in the EEG regulation session; the worst performance was achieved by the theta-augment group in the EEG regulation session. Intermediate levels of performance were observed in both groups during EEG-unregulated sessions. The theta-augment group performed significantly worse when regulating EEG, while the opposite was true of the theta-suppress group. The authors concluded that 'Regulated theta augmentation apparently causes a substantial deterioration of monitoring performance' (1974, p. 873).

The apparent discrepancy between the Daniel (1967) and Beatty et al. (1974) findings highlights a central issue which must be explicitly pointed out. However, let us first consider the implications of the studies reviewed under the rubric of perceptual processing as related to the problem-solving studies. The studies of problem-solving suggested that enhanced theta activity is not related to non-specific increments in alertness. The studies reviewed in this section suggest a similar conclusion. For instance, in the series of studies by Gale et al. (1971, 1971, 1972, 1975), all stimuli were presented in random order, thus minimizing the possibility of pre-stimulus differential preparation based on above chance stimulus prediction. Nonetheless, enhancement of theta was related to the perception of specific kinds of stimuli. In the Daniel (1967) study, changes in non-specific alertness do not account for changes in theta related to detection performance. Quantified autocorrelograms, which Daniel previously found to accurately reflect changes in level of alertness, are not different in the 15 sec epochs preceding correct and incorrect responses. Also, incidence of alpha did not discriminate correct from incorrect trials, which argues against a non-specific arousal level explanation. However, the Daniel finding that theta deficits are present in the three seconds before as well as after incorrect responses indicates that the actual processing of stimulus information may not be the critical variable related to changes in theta activity. The Daniel study does suggest that increased theta activity reflects the occurrence of processes which enhance the probability of detecting specific stimuli. In the context of Posner's (1975) model, a link between theta and processes of selective attention is suggested.

The seeming discrepancy between the Beatty et al. (1974) and Daniel (1967)



findings points out the danger of drawing conclusions about psychological events based solely on the observation that amount of theta activity is correlated with an experimental variable. For example, the hypnagogic and sleep deprivation studies reviewed earlier suggest that increased theta activity indicates a low level of alertness which results in inefficient processing of external stimuli. On this basis, the Beatty et al. findings are explicable: those subjects producing large amounts of theta are less able to efficiently process external stimuli than those subjects producing little theta, and thus commit more errors in the monitoring task. However, the Daniel finding that more theta accompanies efficient detection is compatible with the studies reviewed earlier which suggest that increments in theta accompany selective and effortful processing. The critical question is: given precise information about the amplitude, frequency, regularity, topographical distribution, and reactivity of the observed theta activity, can one differentiate between the theta waves which accompany two general classes of very different behavioural outcomes? The literature provides an equivocal answer to this question. It is fairly well established that theta waves which accompany hypnagogic and sleep-deprived states are low amplitude, irregular waves which are diffusely spread over the scalp, and turn into alpha upon sensory stimulation. Little information of this sort is available concerning theta observed during problem-solving and perceptual processing. As noted earlier, studies which had recorded at several scalp locations indicate that theta is maximally incremented in fronto-central areas during problem-solving. The situation is less clear concerning perceptual processing, as most studies have recorded EEG exclusively from posterior scalp regions. However, in the Walter et al. (1967) study, where activity from various scalp leads was analyzed, the strongest theta effects were found fronto-centrally. Similarly, little information is available on amplitude and regularity: Ishihara and Yoshii (1972) presented EEG excerpts which showed a relatively high amplitude, sinusoidal theta wave to accompany periods of concentration, and Walter et al. (1967) noted that during visual discrimination, theta is more sinusoidal than during resting periods. Also unexplored is the question of reactivity: If a sensory stimulus is presented while theta is present during problem-solving or perceptual processing, will theta turn to alpha, or will a different outcome be observed? Answers to questions such as these may be important for assessing the degree to which properties of scalp theta activity can discriminate between different psychological events.

#### *4.3. Learning and memory*

There are few studies which have considered theta frequencies during learning or memory tasks in alert human subjects. Thompson and Obrist (1964) found significantly fewer alpha waves and significantly more beta waves during learning of nonsense syllables than in control conditions, but noted that slow frequencies (<8 Hz) did not occur in sufficient quantity to merit analysis. Thompson and Wilson (1966) found that 'good' learners exhibited more beta and less slow activity (<8 Hz) than

'poor' learners during paired-associate learning. Freedman, Hafter, and Daniel (1966) presented subjects with nonsense syllables and required them to select and press one of four response keys as a paired-associate. An experimental group received tone feedback indicating whether their choice was right or wrong; a yoked control group received no feedback about their choices. Results showed that the experimental subjects produced more alpha and less theta during learning. Control subjects showed increased theta, which Freedman et al. (1966) suggested might be related to frustration in the no-feedback situation. Gale et al. (1975), in a study reviewed earlier, showed subjects stimulus patterns they had previously viewed, and those which they had not viewed. Subjects were required to identify which stimulus patterns they had already seen. It was found that while recognition performance correlated strongly with EEG abundance measures in the alpha range, little correlation was observed between recognition performance and theta abundance.

Though any conjectures based on so few studies must be considered as highly tentative, two possibilities are suggested by the failure to observe theta increments during learning and memory tasks. One is that since all of the above studies recorded EEG from posterior scalp regions, theta increments during learning and memory tasks might be observed in frontal areas. The other possibility is that operations which elicit theta in the problem-solving and perceptual processing studies are not required in the above studies of learning and memory. Research is needed to explore these and other possibilities.

## 5. Theta in hypnosis, meditation, and autogenic training

### 5.1. Hypnosis

Studies of the EEG in hypnotized persons have been marked by inconsistency. Numerous investigators have found the EEG during hypnosis to be indistinguishable from the waking EEG (Dynes, 1947; Ford and Yeager, 1948; Loomis, Harvey, and Hobart, 1936; Weitzenhoffer, 1953) while others have found a similarity between the EEG of hypnosis and the EEG of light sleep or drowsiness (Barker and Burgwin, 1949; Chertok and Kramarz, 1959; Israel and Rohmer, 1958). Still others have reported increases in alpha and high frequency beta activity during hypnosis (Ulett, Akpinar, and Itil, 1972). Several factors may be responsible for these discrepancies, including lack of standardized induction procedures (Ulett et al., 1972), interpersonal factors in subject-hypnotist relationship (Evans, 1972), a tendency to treat the hypnotic experience as a uniform condition (Tart, 1965), wide individual differences in hypnotic susceptibility (Hilgard, 1967), and inadequate methods of EEG analysis (Ulett et al., 1972).

However, several recent studies present a more consistent picture as regards hypnotic *susceptibility* and EEG patterns. Galbraith, London, Leibovitz, Cooper, and Hart (1970) used spectral analysis to analyze the EEGs of 59 subjects who had

completed the Harvard Group Susceptibility Scale (HGS). EEG was recorded for 3 min with eyes open (subject views a dim fixation light) and for 3 min with eyes closed. EEG was recorded monopolarly from OZ, CZ, FZ, and T3 leads. Autospectra were computed for each of the leads, and cross spectra were computed for each of the 6 pair-wise combinations of these leads. EEG spectral values and HGS scores were subjected to a multiple regression analysis. Five EEG variables were selected by the multiple regression analysis as significant predictors of HGS scores; four of these were frequencies in the theta range. Specifically, the best predictor of HGS scores was the 5 Hz component of the OZ autospectrum with eyes open, followed in order by the 5 Hz component of the OZ–CZ cross spectrum with eyes open, the 7 Hz component of the OZ autospectrum with eyes closed, the 6 Hz component of the OZ autospectrum with eyes open, and the 8 Hz component of the OZ–CZ cross spectrum with eyes open. The authors, noting some of the studies linking theta with problem-solving that were discussed earlier, invoked the concept of Class II inhibition (Vogel et al., 1968, p. 129) in their interpretation of these results: ‘Hypnosis has been frequently interpreted as a state of narrowly focused attention in which the subject must inhibit other responses that may be of a competing nature. The concept of Class II inhibition may thus provide a model of hypnotic susceptibility’.

Tebēcis, Provins, Farnbach, and Pentony (1975) studied the EEGs of 19 subjects who had been practising self-hypnosis for several months, and of 14 control subjects. EEG was recorded from the experimental subjects in one session during periods of relaxation, eyes open and eyes closed, and during hypnosis, also with eyes open and eyes closed. The Barber Suggestibility Scale (BSS) was administered during hypnosis. The experimental subjects also completed a separate session in which they were instructed not to go into hypnosis, but to relax and use their imagination in the execution of the various BSS tasks. Both eyes open and eyes closed conditions were used. EEG of the control subjects was recorded under the same conditions as the imagination session of the experimental subjects. The output of a frequency analyzer was used for statistical evaluation of EEG alpha, beta, delta, and theta abundance in the left parietal area (bipolar recording). Results showed a trend toward increased theta density during hypnosis compared to the relaxation condition within the experimental subjects; however, this trend was inconsistent and varied from subject to subject. The major finding of the study was that theta density is significantly greater in the experimental than the control subjects in both eyes open and eyes closed resting conditions. The BSS scores of the experimental subjects during the imagination session were significantly higher than those obtained from the control subjects during imagination. No differences between the two groups were observed in alpha, beta or delta frequency bands.

Akpınar, Ulett, and Itil (1971) analyzed right occipital EEG recorded monopolarly in 44 subjects during 10 min of eyes closed resting, and 10 min of eyes closed performance on a reaction time task. Hypnosis was then induced and suggestibility assessed by the BSS. Analog frequency analysis disclosed a significant

positive correlation between theta activity during the reaction time task and BSS scores. A non-significantly positive correlation was found between theta during the reaction time task and BSS scores using digital computer period analysis. The resting EEG of the 10 highest and 10 lowest scoring subjects on the BSS were then analyzed by the digital period analysis. Results indicated a significantly positive correlation between amount of resting theta and BSS scores in the 10 most hypnotizable subjects, but not in the 10 least hypnotizable subjects.

These studies uniformly indicate that persons who are ranked high in hypnotic susceptibility by standardized criteria are characterized by large amounts of theta in various non-hypnotic conditions. Given the link between theta and selective processing found in studies reviewed earlier, the findings considered in this section fit well with recent conceptualizations that have emphasized the important role of selective, focused attention in hypnotic susceptibility and induction (As, 1962; Beck and Barolin, 1965; Galbraith, Cooper, and London, 1972; London, 1967; Mitchell, 1970; O'Connell and Orne, 1962). A potentially fruitful area for study concerns the amount of theta activity observed in high vs. low susceptible subjects during performance of cognitive tasks known to elicit theta. Do subjects high in hypnotic susceptibility show more theta than low susceptible subjects on tasks which require selective, focused attention? Are there differences between these two groups in the scalp topographical distribution of theta observed during these activities? Answers to such questions might provide data on which to evaluate the possibility that theta increments seen in problem-solving and perceptual processing tasks and theta observed in high susceptible subjects reflect similar underlying mechanisms.

However, we must also consider an alternative explanation for the large amounts of theta observed in high susceptible subjects – namely, that these subjects become more drowsy than low susceptible subjects during the experimental situation. In light of the consistent relation found between theta activity and drowsiness, this possibility clearly merits investigation. Unfortunately, existing studies have not provided enough information about the relevant wave characteristics of theta found in high susceptible subjects to permit evaluation of this possibility. That is, we cannot know if theta activity observed in high susceptible subjects more closely resembles theta seen in drowsy states or theta seen in attentive states. Future research must analyze the *properties* of observed theta activity before offering psychological interpretations of this activity. This problem will be encountered again in the next section.

## 5.2. *Meditation*

The literature on psychophysiological correlates of meditation has recently been reviewed by Woolfolk (1975), who notes that psychophysiological data exist primarily on three meditational groups: yogis and students of Yoga in India, practitioners of Zen Buddhism in Japan, and students of Transcendental Meditation (TM) in the United States. An investigation of the literature on each of these groups indi-

cates that theta activity is found primarily in the Zen and TM practitioners, and it is literature concerned with these groups that will be reviewed here.

### 5.2.1. *Zen meditation*

*Zazen* is the major form of Zen Buddhist meditation. When practicing *zazen*, the meditator is seated in the lotus or half-lotus position with eyes open. Shimano and Douglas (1975) have identified three main features of *zazen*: '1) the use of selective attention to breathing, 2) concentration on the resolution of purposely paradoxical counterconceptual problems, and 3) sustained efforts to continually refine a choiceless concentration without subjects or object' (1975, p. 1300). Maupin (1962, p. 364), in a lucid review of the psychological literature on Zen, depicts the practice of *zazen* in the following manner:

... the student spends a portion of the day sitting motionless and engaging in concentration. The object of concentration varies considerably and may be changed as the student progresses. The aim is to suspend the ordinary flow of thoughts without falling into a stupor. The achievement of undistracted attention is the first means of coming to grips with the egoistic, conceptual mode of existence.

The major studies on EEG correlates of *zazen* have been summarized in a recent book by Hirai (1974), whose presentation will be reviewed here. Subjects in these experiments were 48 monks of the Soto and Rinzai Zen sects, whose experience with *zazen* ranged from 22 to 55 yr and whose average age was 52 yr; 15 control subjects aged 50–55 yr; 98 Zen disciples whose experience with *zazen* ranged from 1 to 15 yr and whose average age was in the mid-twenties; and 18 control subjects whose age approximated that of the disciples. EEG was recorded from occipital, vertex, and frontal leads along the midline. The experimental subjects engaged in *zazen* (with eyes open) while EEG was recorded. The control subjects were instructed to relax with eyes open. Analysis of the EEG was achieved in most cases through visual inspection of EEG records. (Data from the output of a frequency analyzer is presented, but no statistical analyses are offered.)

Hirai (1974) has classified the EEG changes seen during *zazen* into four stages. First there is the appearance of alpha waves at the beginning of meditation. In Stage II there is an increase of alpha amplitude, followed by a decrease of alpha frequency in Stage III. Stage IV is achieved only by the most advanced monks, and is signaled by the appearance of high voltage (70–100  $\mu$ V) rhythmical theta waves. Little EEG change is seen in any of the control subjects: desynchronized beta frequencies dominated the record, and no increase in alpha or theta was observed.

Hirai (1974) argues that the theta waves observed in Stage IV are functionally different from those found in drowsiness. Stage IV theta waves are of much larger amplitude than those seen in drowsiness, and further are more rhythmic and less contaminated by superimposed high frequency activity. The most compelling evidence is found in the results of auditory stimulation experiments. In the case of

drowsy subjects whose EEG is dominated by diffuse theta activity, auditory stimulation will elicit alpha, as discussed earlier. However, when click stimuli are presented to a subject engaged in zazen whose EEG consists of the rhythmical theta waves, a *blocking* response similar to classic alpha blocking is observed: the EEG is briefly desynchronized upon stimulus presentation, but the rhythmical theta train re-appears after an interval of 2–3 sec. Hirai further points out that in the younger disciples, periods of drowsiness are often seen in the early stages of practice. These periods are accompanied by low-voltage theta activity. Upon presentation of the click stimulus, the classical alpha enhancement response is seen. Hirai notes that these periods of drowsiness (called 'konchin') are strictly prohibited in zazen training, and can be introspectively distinguished from the desired meditational state.

Three problems with this work are that within subject control click experiments (in the non-meditational waking state) are not reported, statistical analyses of results are not presented, and that only a few meditators exhibit the high voltage, sinusoidal theta activity. The implications of this work will be discussed shortly.

### 5.2.2. *Transcendental Meditation (TM)*

TM is a relatively simple meditational technique which requires mental repetition of specific syllables known as the mantra for 15–20 min periods twice per day. Wallace (1970), in one of the first studies on the psychophysiology of TM, reported that theta activity was observed in the EEG of 4 of his 15 subjects. Unfortunately, little information is provided concerning the structure and topography of the observed theta activity, except for the observation that it resembles the low-voltage theta of drowsiness. Wallace, Benson, and Wilson (1971) reported the occurrence of theta activity in 5 of their 36 subjects. They found that in these subjects theta appeared in the frontal area simultaneous with alpha dominance in other cortical areas. Though no analysis of wave structure is made, the authors present a sample EEG record in which the frontal theta is of relatively high amplitude, and fairly rhythmic. The authors do not indicate how long the subjects who manifested theta activity had been practising TM in either study. In view of the widely varying amounts of experience of the subjects in both studies (6 months to 3 yr in Wallace, 1970; less than a month to 9 yr in Wallace et al., 1971), and the possible interaction between meditational experience and theta occurrence suggested by the Hirai (1974) work, such information would be desirable. Also, interpretation of both Wallace studies is constrained by the absence of control groups, and by the absence of within-subject statistical analysis of the EEG.

Banquet (1973) used spectral analysis to evaluate the EEGs of 12 meditators (9 mo to 5 yr experience with TM) during 30 min of TM practice, and of 12 matched controls during 30 min of eyes closed relaxation. Banquet observed three EEG stages during the course of TM. First, alpha amplitude increased and frequency decreased compared to the resting record. In the second stage, bursts of high-voltage (up to 100  $\mu$ V) theta were seen primarily in the frontal areas and then diffused posteriorly. Banquet points out that spectral analysis showed EEG power to be

largely concentrated in the 5 Hz region of the frequency spectrum. In contrast, theta observed in four of the control subjects showed power distributed between theta and other frequencies, indicating drowsiness. The third stage was reached by only four meditators, and consisted of large amplitude (30–60  $\mu$ V) beta waves with dominant frequencies at 20 and 40 Hz, which were prominent over the whole scalp. Results of auditory stimulation experiments performed on seven meditators are similar to those reported by Hirai (1974). Click stimulation blocked rhythmic theta activity seen in the meditators; theta activity returned after 1–3 sec of depression. These results are contrasted to those obtained when the low-voltage mixed frequency theta activity of drowsiness was present. In these cases, the alpha enhancement response was seen. Methodologically, this study could have been improved by providing statistical analysis of EEG spectra, as well as by including control click experiments in the non-meditational waking state (for the TM subjects).

Some recent studies suggest that theta activity occurring during TM is quite similar to theta found in the drowsy period. Fenwick, Donaldson, Bushman, Gillis, and Fenton (1975), in a short report, state that the EEG characteristics of drowsiness were found in their TM group during meditation. They also noted the presence of slow eye movements characteristic of the hypnagogic period (see Schacter, 1976) and suggested that TM is ‘... a technique for holding the level of consciousness constantly in the hypnagogic state’ (1975, p. 221). Younger, Adriance, and Berger (1975) studied 8 meditators whose experience with TM ranged from 14–44 mo. They found that on the average almost half of meditation was accompanied by waking alpha and about half was spent in drowsiness or Stage II sleep. Pagano, Rose, Stivers, and Warrenburg (1976) studied 5 TM practitioners with 2.5 yr or more experience. Results from 10 sessions with each meditator indicate that 39% of meditation was accompanied by wakeful EEG, 19% by drowsy EEG, and 40% by sleep stages II, III, and IV. They further noted that EEG ratings of drowsiness and sleep covaried well with the meditators introspective accounts of drowsy and sleep periods. It is worth noting that visual EEG inspection is the only method of EEG analysis reported in these three studies. Thus it is difficult to compare the properties of theta observed in these studies with the features of meditational theta reported by Banquet (1973).

The studies reviewed in this section concerning Zen and TM pose interpretational difficulties similar to those discussed earlier in this paper. On the one hand, theta activity observed in Zen and TM might be expected on the basis of characterizations of these processes which emphasize the role of focused attention and concentration during meditation. This proposition receives support from the click stimulation experiments of Banquet and of Hirai, which suggest that theta observed in these meditating subjects possesses functional characteristics which are more consistent with interpretations of enhanced attentiveness than with interpretations of drowsiness. Also, the large amplitude and rhythmicity of theta observed in some Zen and TM subjects, and the unimodal 5 Hz spectral peak observed during TM by Banquet are not consistent with the known characteristics of theta waves which

accompany drowsiness. Finally, the observation by Wallace et al. (1971) and Banquet that theta activity may be maximal over frontal areas during TM is similar to the findings of Ishihara and Yoshii (1972) and Legewie et al. (1969) in problem-solving studies. On the other hand, theta activity in meditation might be expected on the basis of the similar conditions which encourage entry into meditational and hypnagogic states (Stoyva, 1973). Similarly, it could be argued that monotonous repetition of the mantra induces a sleep-like state through processes of Pavlovian inhibition (Bohlin, 1971), thus accounting for observed theta activity. This interpretation is supported by the findings in several studies that theta in TM is structurally similar to theta in drowsiness, and is often followed by unambiguous sleep.

These considerations reinforce the point made earlier: it is dangerous to extrapolate about psychological events based solely on the observation that there is an increase of theta activity in the EEG. In the case of the Zen data, however, the properties of the observed theta activity are generally consistent with psychological characterizations of Zen which emphasize the role of selective attention in the practice of zazen. Future research can explore the extent to which features of theta observed during zazen are similar to those found in 'normal' subjects during tasks which elicit theta activity. The TM data is more confusing: when one begins to explore properties of the observed theta, support is found for two rather different psychological interpretations, one being selective attention to the mantra, and the other, periods of drowsiness and sleep. The observation made by Pagano et al. (1976) that there is great inter-subject and intra-subject variability in the type of meditational state seen from day-to-day, might account for some of this confusion. It could be hypothesized that in some subjects (some of the time), selective attention to the mantra is achieved without falling into drowsiness or sleep; theta activity of the sort reported by Banquet (1973) might be expected in these subjects. Other subjects may more easily pass into hypnagogic and sleep states, and produce the kind of theta activity observed by Fenwick et al. (1976), Pagano et al. (1976), and Younger et al. (1975). These tentative suggestions are made to emphasize two points: (1) inter-subject and intra-subject variability must be accounted for in future EEG studies of TM; (2) in studies which make psychological extrapolations based on the observation of increased theta activity during TM, consideration must be given to the various properties of the theta waves if that extrapolation is to be meaningful.

### *5.3. Autogenic training*

Autogenic training is a relaxation technique which involves 'passive concentration' (Schultz and Luthe, 1959) on verbal suggestions (known as the six standard exercises) of heaviness, warmth, etc., in various parts of the body. Detailed consideration of the numerous aspects of autogenic training can be found in Schultz and Luthe (1959) and Luthe (1970).

EEG studies reporting an increment in theta activity during autogenic relaxation have been reported by several investigators. A problem common to all of these



studies is that inadequate detail is given concerning procedures, analysis methods, and results; thus interpretation of the findings of these studies must be cautious pending the appearance of more detailed and thorough investigations. Also, as Luthe (1972) has pointed out, none of the published studies concerning EEG correlates of the autogenic state have employed a control group. The failure to do so emphasizes the tentative nature of these results.

Israel and Rohmer (1958) noted the occurrence of theta activity in a study of six subjects during autogenic training. They suggested that the autogenic state closely resembles the drowsy state. Geissman and Noel (1961) studied 14 subjects during the execution of the autogenic standard exercises. They noted two distinctly different types of theta activity appearing during the course of passive concentration. During successful concentration on the autogenic formulae, 'rare' paroxysmal theta was seen in parieto-temporal regions. However, periods of generalized theta activity also occurred, which the authors suggest was related to the development of a drowsy state. Geissman, Jus, and Luthe (1961) noted that in subjects with brief training (2–4 mo) in autogenic methods theta activity appeared first in anterior bursts followed by a tendency toward spatial generalization in the anterior–posterior direction. In subjects with longer training (6–36 mo), there appeared '... a flattening of the baseline with theta oscillations ...' (1961, p. 465), and brief paroxysmal bursts of theta in temporal-posterior areas. They noted that successful autogenic concentration was related to the maintenance of a 'pre-drowsy' state, and that a drowsy state accompanied by generalized theta activity '... tended to occur whenever a trainee did not maintain the mental activity required for passive concentration on the Autogenic Formulae' (1961, p. 467). Jus and Jus (1961, 1965) reported on the study of 15 subjects who had been observed during autogenic training at least eight times during the course of several months. They noted that theta tended to appear first in anterior leads, and then generalized over the scalp. Jus and Jus further observed that the stage of anterior theta is related to the experience of 'heaviness', while the stage of generalized theta is related to the experience of 'warmth'. They also reported the results of sensory stimulation (modality of the stimulus was not specified) conducted in the presence of '... slow activity in the EEG ...' (1965, p. 13). Alpha enhancement responses were observed in all cases.

Stojanow and Heidrich (cited in Luthe, 1970, vol. 4, p. 86) studied the EEG during 15 min of autogenic training in 14 long-term trainees. They found that brief periods of theta localized over frontal, central, and parietal regions were present toward the end of the 15 min period. Stojanow and Heidrich found no evidence that theta activity is related to the experience of 'heaviness' or 'warmth'.

As mentioned above, these studies are difficult to interpret due to lack of relevant detail and inadequate experimental rigor. Thus we will not discuss the possible theoretical implications of these studies in this paper. Hopefully, future well-controlled studies of 'passive concentration' and autogenic training will provide more details on the properties of observed theta activity, and offer more specific analyses of the cognitive operations involved in these procedures.

## 6. Theta and affective phenomena

Hoagland and his colleagues (Hoagland, Cameron, and Rubin, 1938; Hoagland, Cameron, Rubin, and Tegelburg, 1938) had reported that emotional activity and slow (<8 Hz) EEG frequencies are related. However, this work was criticized on methodological grounds by Lindsley (1950). The first investigator to link theta activity with affective phenomena was Walter (Walter and Walter, 1949; Walter, 1953). Walter and Walter (1949) reported that normal adult subjects who showed large amounts of theta in the resting EEG could be psychologically characterized as 'immature' or 'ingenuous'. They further noted that in these subjects augmented theta activity was observed during 'emotional stress'. Photic stimulation experiments indicated that when theta activity was augmented by the stimulation, subjects reported '... a feeling of irritation and vague discomfort' (1949, p. 66). Walter (1953) later observed that withdrawal of a pleasant stimulus – such as stroking – resulted in '... a sudden transient outburst of theta rhythms at 6 cycles per second' (1953, p. 207). He noted wide individual differences in the occurrence of this response, but observed it consistently in a number of subjects. Walter (1953) suggested that theta rhythms are involved in 'scanning for pleasure': 'On this basis the uniform swell of theta rhythms, as pleasure fades, would represent the renewed search for other pleasures...' (1953, p. 209).

The problem with this work is that systematic use of control groups, precise specification of stimulus attributes, and statistical analysis of results are lacking. For example, we might question whether it is the specifically 'emotional' value of the stimuli used by Walter which evoked the observed theta activity, or whether these stimuli (or withdrawal of them) elicited the sort of selective and effortful processing which was related to theta activity in studies previously reviewed. Unfortunately, most investigators who cite the Walter studies have not questioned the validity of these results, and have themselves offered largely unsystematic evidence to support Walter's hypotheses. Mundy-Castle (1951) offered as support for an affect-theta relationship the informal observation that '... certainly slight embarrassment, frustration or discomfort was reported by those subjects showing augmented theta activity during ... mental effort' (1951, p. 479). Mundy-Castle (1957) reported that subjects whose case histories contained mention of emotional disturbance or 'bad temper' showed significantly more theta in their EEGs than subjects without any such comments in their case histories. Mundy-Castle interpreted this finding as support for an affect-theta relationship. An inspection of Mundy-Castle's data, however, suggests that this finding may be an artifact of age differences in the two groups. It is known that theta is more prominent in the awake resting EEG of children and adolescents than in older persons (Pond, 1963). Mundy-Castle's 'bad temper' group contained 89 persons aged 3–14 yr; the 'no bad temper' group contained only 71 persons in this age bracket. Thus the greater incidence of theta in the 'bad temper' group may simply have reflected the larger number of young persons in this group. de Lange, van Leeuwen, and Werre (1960)

gave subjects a variety of projective tests, and noted that those subjects who '... are psychologically characterized by unfavourable reactions to feelings of frustration, little tension and little selfconfidence' (1960, p. 399) tended to produce large amounts of theta. However, no specific information is given concerning methods of analysis, and no data is presented. Maulsby (1971) recently presented evidence that theta is enhanced in one infant subject during emotional activity; however, extrapolation to adults is difficult due to confounding developmental factors.

Experimental evidence favoring a relationship between theta activity and affective phenomena is found in a subliminal perception experiment conducted by Dixon and Lear (1964). These investigators recorded occipital EEG while subjects viewed initially sub-threshold words which were gradually increased in intensity. Subjects were presented with four emotionally arousing words (as determined by previous word association tests) and with four neutral words. They were instructed to indicate when they first became aware of the stimulus, and then when they recognized it. Dixon and Lear found a greater rise and fall of theta abundance between stimulus onset and stimulus awareness on trials in which awareness threshold was either high or low (emotional words), as opposed to those trials where awareness threshold was intermediate. Similar findings were reported for the recognition data. The major criticism of this work is that to the present author's knowledge, it has not been replicated.

Another area of research which was used to support the theta-affect link concerned the finding of excess amounts of theta in the EEG of psychopaths in several early studies (see Ellingson, 1954, for review). Ellingson (1954) pointed out that many of these studies suffer from the absence of statistical analysis and matched control groups, and from the presence of diagnostic variability. Since that time, both positive (Murdoch, 1972) and negative (Arthurs and Cahoon, 1964) findings have been reported. Two recent studies which employed matched control groups, automatic EEG analysis, and statistical treatment of data (Blackburn, 1975; Syndulko, Parker, Jens, Maltzman, and Ziskind, 1975) failed to find a significant correlation between psychopathy and theta activity.

In sum, it seems most appropriate to say that the relation between theta and affective phenomenon is currently an open question. The early observations of Walter have simply not been put to adequate experimental test. Studies which propose to explore this matter must be especially concerned with specifying criteria for stimulus emotionality, and with distinguishing these stimuli from other kinds of 'attention-getting' stimuli which might be expected to elicit theta on the basis of literature reviewed here. As Adey et al. (1967, pp. 357-358) observed when discussing Walter's hypothesis that theta and affect are related, 'Even where such correlates have been noted, they may not describe exclusive relationships, but rather arise in the physiological substrates of more fundamental mechanisms, such as alerting and orientation'. This is the critical issue that future research on this problem must face.

## 7. Concluding remarks

Two major issues are left unresolved by the literature reviewed in this paper: (1) the degree to which the various properties of theta waves are systematically correlated with specific psychological processes, and (2) the exact type of information about psychological processes which is provided by EEG theta activity. Future research in this area must recognize the two sides of these issues. With regard to the EEG, careful study of the frequency, amplitude, regularity, topographical distribution and reactivity of observed theta activity must be made if a meaningful picture of that activity is to be drawn. Other EEG parameters, such as the time course of theta observed, say, during a particular task, and the relation between theta occurring at two or more electrode sites (which can be quantitatively assessed through measures such as coherence spectra and phase spectra) are dimensions which have not been well-explored, and merit future consideration. Explicit study of these several parameters is critical to a meaningful analysis of the relation between theta and psychological processes; as noted earlier in this review, inferences about psychological processes based solely on the observation that there is an increase of theta activity in the EEG may be extremely misleading. There is evidence in the literature that different properties of theta activity are related to different psychological processes; but the strength, specificity and consistency of these relations are not yet certain. It is worth noting that despite differences in electrode placement, recording technique (bipolar vs. monopolar) and analysis procedures, a considerable degree of consistency has been found in the results of studies within several of the areas considered in this review. Our understanding of the nature of the information which is contained in the properties of theta activity will be aided by progress in understanding the neurophysiological genesis of the EEG (see Elul, 1972, and Uttal, 1967, for relevant discussions).

On the psychological side, the literature indicates that at least two grossly different processes are related to EEG theta activity. In hypnagogic and sleep deprivation states (and to some extent the REM state), theta activity was seen to accompany a generally low level of pre-stimulus alertness which results in impaired processing of various kinds of information. In studies of problem-solving and perceptual processing, theta was seen to accompany relatively active and efficient processing, which was discussed in terms of selective and intensive components of attention. Theta related to hypnotic susceptibility, meditation and affective phenomena was discussed in relation to these two psychological characterizations. It is not yet known whether the two 'classes' of psychological events related to theta activity are essentially different processes, or whether they are different aspects of the same process (as is implied by the Vogel et al., 1968 concept of Class II inhibition). This is a critical problem for future research. Even if the independence of these two 'classes' of psychological processes were granted, it is not clear that various phenomena which occur within each class should be considered alike. For example, we could ask whether theta observed in problem-solving and perceptual processing tasks change

in a similar way when specific aspects of the task are altered, i.e., evidence exists that increments in the difficulty of a problem-solving task yield increased theta; is the same true of theta in a perceptual processing task? Similarly, we might question whether it is plausible to accept that theta activity observed during zazen concentration in experienced meditators indexes psychological processes that are similar to those observed in college-age volunteers when concentrating on a mental arithmetic problem. Greater precision in the analysis of operations required by specific tasks is needed in order to understand which processes are fundamental to changes in theta activity.

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