TASK DEPENDENT LATERALIZATION OF THE 40 HERTZ EEG RHYTHM

A Thesis

Presented to

the Faculty of the Department of Psychology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

John D. Spydell

December, 1977

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ABSTRACT

Task dependent lateralization of the 40 Hz. EEG rhythm was investigated in 24 right handed subjects. Each subject was administered four tests: verbal, mathematical, geometric figure recognition and facial recognition. Subjects' EEGs were recorded during each of the tests and amounts of 40 Hz. EEG activity present over each hemisphere during each test were compared to baseline, resting levels. Forty Hz. EMG activity was also recorded bilaterally from the neck and temporal muscles. On-line comparators prevented 40 Hz. EMG from being counted as 40 Hz. EEG.

Significant increases in 40 Hz. EEG activity were found over the left hemisphere during performance of the verbal test, and over the right hemisphere during performance of the geometric figure recognition test. Forty Hertz EEG activity was found to be uncorrelated with 40 Hz. EMG activity. Further, decreases in alpha and beta activity were found in all leads for all tests except the facial recognition test which failed to show any significant change in beta activity.

The failure of the mathematical and facial recognition tests to show any pattern of lateralization of 40 Hz. EEG activity is discussed, and behavioral and cortical models of the 40 Hz. EEG rhythm as focused arousal are presented.

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CHAPTER I

INTRODUCTION

Statement of the Problem

A series of studies has been presented recently concerning a high-frequency, low-amplitude EEG signal centered at a frequency of 40 Hertz (Hz.). These studies have shown that the 40 Hz. EEG rhythm is highly correlated with concentration, attention, and the consolidation of newly learned tasks. These diverse cognitive terms all involve a state which can be referred to as "focused arousal." It has also been shown that subjects who have been trained to suppress the amount of 40 Hz. activity present in their total EEG were unable to maintain that suppression while problem solving. Thus it would appear that suppression of the 40 Hz. EEG signal and problem solving are incompatible tasks. Likewise, it has been shown that the total amount of 40 Hz. activity in the EEG increases during problem solving, relative to a non-problem solving baseline period.

These findings are in agreement with the presently accepted view of cerebral activation which holds that the EEG activity present during arousal should be of a higher frequency than that present during a non-aroused, resting state. Thus, the 40 Hz. EEG signal can be viewed as representing a level of arousal which is more intense than that which typically accompanies the lower frequency beta EEG signal, a state which has been described as "general arousal."

Since the research to date would seem to indicate that the 40 Hz. EEG signal is associated with "focused arousal," the question is, just how "focal" is the 40 Hz. EEG signal itself? Will it be more predominant in the cerebral hemisphere maximally engaged in the task to be performed, or is the 40 Hz. EEG signal present diffusely all over cortex during the performance of a task? The answer to this question can be of significant importance to the understanding of the 40 Hz. EEG signal and its relationship to problem solving behavior. Additionally, the present research will replicate several previous studies which have shown a consistent increase in the amount of 40 Hz. activity present during problem solving relative to a non-problem solving base. Finally, this study will replicate previous studies which have found a marked decrease in alpha rhythm amplitude during problem solving.

Hemispheric Differences

Before discussing the 40 Hz. EEG rhythm, it is necessary to show that the two cerebral hemispheres are differentially engaged in the solving of tasks. Evidence for the task dependent, differential operation of the two cerebral hemispheres comes from a variety of investigative areas. Chief among these areas are studies which infer brain function from deficits which follow brain injury, studies of the differential performance of the two hemispheres during task performance in normal subjects, studies of EEG activity underlying task performance, and studies of the anatomical differences which exist between the two hemispheres. The results from studies in these diverse areas indicate that indeed, the two cerebral hemispheres do operate in a consistent, differential manner which is dependent upon the task to be performed. Each of these three areas of study will be discussed in the following sections.

Before reviewing these findings another consistent finding should be presented, this is that lateralization of hemispheric functioning is interactive with handedness. This topic will not be discussed fully here; the interested reader is referred to Beaumont (1974). The general finding is that dextral individuals are more clearly and consistently lateralized with regard to cerebral function that are either sinistral or ambidextrous individuals. For this reason almost all work on hemispheric differences has been done with dextrals. Accordingly, all references to lateralization presented in this paper, unless specifically stated otherwise, will be for dextrals.

Function. Study in the area of functional differences between the two cerebral hemispheres originally focused on impairments of function which followed unilateral brain damage. The reasoning behind this type of research was that any deficits which appear following a brain injury must be a result of the neurological tissue damaged.

More recently, techniques which employ perceptual asymmetry, in both the auditory and visual modes, have been developed and have allowed the study of hemisphere functioning in non-brain damaged individuals. The rationale underlying this area of research is less straight forward than that which characterizes the lesion studies and may require some explanation.

The basis for these studies is anatomical. The nerve tracts which arise from receptor organs project predominantly to the appropriate primary cortical areas on the contralateral cerebral hemisphere. Thus, if two different objects are viewed simultaneously, one in the left visual field and the other in the right visual field, nerve impulses representing the object in the left visual field will go to the visual cortex of the right hemisphere. The object in the right visual field will be represented in a corresponding cortical area on the left hemisphere. If the subject is then asked to identify one of the objects as quickly as possible, it is assumed that the one identified first has been processed most efficiently because it has been represented to the hemisphere which is most adept at processing that type of information.

A similar situation exists with regard to aural stimulation. Here a technique known as dichotic listening has been used. The anatomy underlying the process is similar and the logic involved in interpreting the results is identical. In summarizing this logic Kimura (1966) has pointed out that, for both the auditory and visual mode, functional differences between the right and left hemispheres are probably responsible for the majority of performance asymmetry seen.

As a general overview of functional differences, the results found by Anderson (1951) are most typical. In assessing the performance of a group of brain damaged individuals on the Wechsler-Bellevue Intelligence Scale he found significantly lower performance on the verbal subtest by individuals with left, dominant hemisphere damage, while damage to the right non-dominant hemisphere resulted in significant decreases in performance sub-test scores.

Likewise, Luria (1973) reports that lesions of the dominant left hemisphere result in impairment of processes dependent upon coding. These processes include mathematical operations, the understanding of logical-grammatical structures, and the use and understanding of speech. Luria (1973) has also noted that lesions of the right parietal-occipital region do not disturb higher symbolic processes, and that complex logical-grammatical and mathematical operations are unimpaired. However, processes involving spatial perception and relationships in space which are unconnected with the speech system are severely impaired following right parietal-occipital lesions.

Similarly, Berlucchi (1974) has reported that:

> The clinical evidence indicates that left hemisphere lesions interfere with verbal abilities leading in general to various forms of aphasia, and right hemisphere lesions interfere with the apprehension of complex configurational properties of visual stimuli, leading sometimes to the inability to recognize faces.

Taken together these separate reports indicate that the general characteristics of tasks which maximally engage the left, dominant hemisphere are that they are of a verbal, logical, sequential nature. These tasks all involve a one to one coding/ de-coding process. On the other hand tasks which engage the right hemisphere involve three-dimensional spatial relationships and the perception of shapes which are not verbally-identifiable. These right hemisphere tasks involve a more wholistic process which is not amenable to analytical, coding/ de-coding processes like those which typify left hemisphere tasks.

A number of different tasks have been used in investigations of left hemisphere function. Among these are: letters tachistoscopically presented in the right visual field (Bryden, 1964; Berlucchi, 1974; Hilliard, 1973; Kimura, 1966; Mangan, 1973); words presented in the right visual field by a tachistoscope (Ellis and Young, in press; Milner, 1974; Mishkin and Forgays, 1952); and dichotically presenting digits to the right ear (Kimura, 1961a; b; 1964).

Using a tachistoscope to present letters in either the left or the right visual field, Bryden (1964) and Kimura (1966) both found that letters presented in the right visual field, which serves the left hemisphere, were recognized and correctly reported more frequently than letters presented in the left visual field, which serves the right hemisphere. Using the same presentation technique for letters, but with reaction time as the dependent measure, Rizzolatti, et al. (cited by

Berlucchi, 1974) found significantly faster reaction times for letter discriminations presented in the right visual field.

Tachistoscopically presenting letters in the form of consonant-vowel-consonant (CVC) trigrams, Hilliard (1973) found a significantly greater number of trigrams correctly reproduced when presented in the right visual field than when presented in the left visual field. Similarly, Mangan (1973) found superior right visual field recognition of tachistoscopically presented CVC trigrams.

When the stimuli presented are words instead of letters similar results are found. In two noun identification tasks, Ellis and Young (in press) found that nouns tachistoscopically presented in the right visual field were more easily identified than nouns presented in the left visual field. Similarly, Mishkin and Forgays (1952) found that English words presented in the right visual field were recognized more frequently than the same words presented in the left visual field.

Corsi(cited by Milner, 1974) states that a similar pattern holds for recency tasks. In this task the subject goes through a stack of cards, each card having two spondaic words on it, until he comes to a card bearing a question mark between the two words. Upon encountering such a card the subject must indicate which of the two words was seen most recently. Performance on this task was impaired by left frontal lobectomy but not by left temporal lesions. However, when the task is changed to a simple recognition one (only one of the two words on the test card has been previously seen) a slight deficit is shown by subjects with left temporal lobe lesions, but none is shown by left frontal lobe lesion patients.

Presenting stimuli aurally rather than visually results in similar findings. Kimura (1961a; b; 1964) dichotically presented digits to a number of subjects. Digits presented to the right ear, which serves the left hemisphere, were recalled with greater accuracy than digits presented to the left ear.

The range of tasks used to assess right hemisphere function is no less broad than those used to assess left hemisphere function. These tasks include the recognition of tachistoscopically presented unfamiliar faces (Benton and Van Allen, 1968; Berlucchi, 1974; DeRenzi, Faglioni and Spinnler, 1968; Hilliard, 1973; Young and Ellis, 1976), recognition and naming of familiar faces (Warrington and James, 1967), enumeration and recognition of geometric figures (Kimura, 1966); abstract pictures (Milner, 1974); familiar objects (DeRenzi and Spinnler, 1966); and dot patterns (Kimura, 1966). Visual location tasks (Milner, 1974); tactile pattern recognition tasks (Milner, 1974); and dichotic listening tasks (Kimura, 1964; 1967; Shankweiler, 1966) have also been used to assess right hemisphere functioning.

Using a group of patients with unilateral brain damage as subjects, Benton and Van Allen (1968) found significantly impaired performance by subjects with right hemisphere lesions on a test of recognition for unfamiliar faces. Further, the impaired performance by the right hemisphere lesion group could not be attributed to visual field defects. Benton and Van Allen concluded that impaired facial recognition was not the result of simple visual impairment, but rather reflected a deficit involving the faulty integration and discrimination of sensory data. Using a similar group of subjects and a comparable facial recognition task, DeRenzi, Faglioni and Spinnler (1968) found results similar to those obtained by Benton and Van Allen.

Using non-brain damaged individuals as subjects, and tachistoscopically presenting a facial discrimination task, Hilliard (1973) and Rizzolatti, et al. (cited by Berlucchi, 1974) found superior recognition scores and reaction times respectively for discriminations presented in the left visual field as compared to those presented in the right visual field. Interesting enough, this right hemisphere advantage for facial recognition is also present in children. Young and Ellis (1976) tachistoscopically presented a series of facial discrimination tasks in the left and right visual fields to three groups of neurologically normal children, aged five, seven, and eleven years. Their results also show a right hemisphere or left visual field advantage.

The above facial discrimination tasks all used pairs of unfamiliar faces as stimuli. However, Warrington and James (1967) used familiar faces as stimuli and obtained results consistent with these previously mentioned studies. The Warrington and James study utilized patients with unilateral brain lesions and presented them with pictures of well known individuals. In one condition subjects were then required to identify the same face in a second set of photographs. In the other condition subjects were asked to name the individual in the picture. In both the recognition and naming conditions subjects with right hemisphere lesions were impaired in performance relative to the left hemisphere lesion group.

From the above group of studies it can be seen that facial discrimination and recognition are clearly right hemisphere tasks. The following studies should make it clear that facial recognition is merely a member of a group of tasks which are handled most efficiently by the right hemisphere.

Kimura (1966) tachistoscopically presented normal subjects with from three to eight geometric figures at a time and asked them to report either how many forms or how many different forms were presented. Enumeration of forms was significantly better in the left visual field, while no visual field advantage was found for enumeration of different forms.

Similar results have been found with brain damaged subjects by Corsi (cited in Milner, 1974) using a non-verbal form of a recency task. This task was identical to the one previously described in this section as used by Corsi, except that abstract pictures were substituted for the words. Subjects with right frontal lobe damage were impaired in performing the recency task. However, when the task was changed to a recognition test, subjects with right temporal lobe lesions showed deficits while those with frontal lobe lesions were unimpaired.

The findings of DeRenzi and Spinnler (1966) point out that differentiation between left and right hemisphere function can not be made merely on the basis of a verbal-nonverbal distinction, but rather must also consider the potential ease with which the nonverbal stimulus can be encoded into a verbal form. They employed three groups of subjects: those with right hemisphere damage; those with left hemisphere damage; and a control group with no known cerebral damage. These subjects were administered four visual recognition tests: an object recognition test (identify a comb, toothbrush, spoon, etc.); a realistic figures test (colored designs depicting a shoe, comb, trumpet, etc.); eleven photographs selected from the Street's Completion Test; and the Ghent Overlapping Figures Test. The object recognition test failed to discriminate between the damaged and undamaged subjects, while the realistic figures test did differentiate between these two groups but failed to discriminate between the location of the damage. Both the Street's Completion Test and the Ghent Overlapping Figures Test discriminated between damaged and undamaged subjects and differentiated between the location of the damage, with the right hemisphere group significantly inferior to the left hemisphere group in both cases. Since, as DeRenzi and Spinnler point out, both the Street's Completion Test and the Ghent Overlapping Figures Test require the more complex and demanding activities of integration and discrimination, and are less readily verbalizable, their results indicate the importance of the potential verbalizability of a stimulus in differentiating between left and right hemisphere function.

Kimura (1966), using normal subjects, found a left visual field superiority for a tachistoscopically presented dot enumeration task, with the dots presented in a random pattern.

Milner (1974) found that when a tactile pattern recognition task is used with commissurotomy patients a marked right hemisphere superiority appears. She ascribes the right hemisphere advantage for this task to the fact that tactile patterns are less amenable to verbal coding and are thus less confounded with the left hemisphere.

Kimura (1964), working with normal subjects, found a left ear, and thus right hemisphere advantage for recognition of dichotically presented melodies, while a right ear, left hemisphere advantage was found for dichotically presented digits. In comparing these two stimuli it can again be seen that melodies are less readily encoded as a single input and require a more wholistic integration in order to retain any meaningfulness. As she has suggested earlier (Kimura, 1964) the right hemisphere may be especially critical in mediating the perception of melodic patterns. Both Shankweiler (1966) and Kimura (1964) have observed impaired recognition of dichotically presented melodies with right temporal lobectomy.

The results presented above support the idea of differential function of the two cerebral hemispheres and further indicate that this differentiation occurs along a continuum ranging from readily verbally identifiable to non-verbally identifiable. As Kimura (1966) has suggested, left visual field superiority occurs when nonverbal stimuli are presented and the perceived shape is not readily verbalizable. At the same time, a right visual field effect has been found only for verbally identifiable forms such as letters, words, and familiar objects.

Milner (1974), commenting on work done with temporal lobectomy patients, has stated that left temporal lobectomies, in the dominant hemisphere for speech, selectively impair the learning and retention of verbal material, regardless of whether the material is heard or read. On the other hand, excising the right, non-dominant, temporal lobe leads to impaired recognition and recall of visual and auditory patterns which are not easily coded verbally.

<u>EEG</u>. As the previous section has shown, functional differences between the left and right cerebral hemispheres do exist. Since differences in function have been shown, it is natural to wonder about differences in the brain electrical activity which underlies this functional asymmetry.

A number of studies investigating EEG asymmetry as a function of task have been carried out (Bennett and Trinder, 1977; Butler and

Glass, 1974; Doyle, Ornstein and Galin, 1974; Dumas and Morgan, 1975; Galin and Ornstein, 1972; Morgan, MacDonald and Hilgard, 1974; McLeod and Peacock, 1977). These studies have all shown significant task dependent EEG symmetries in the alpha rhythm (9-12 Hz.), with the asymmetries consistent with those to be expected from the investigations of lateralization of function. That is, the hemisphere maximally engaged by a task showed a significant decrease in the amount of alpha rhythm present during performance of the task.

The datum used in these studies has been the change in amounts of activity in certain specified EEG frequency bands. The spectrum which is made up of these frequency bands has been related to behavior. In the awake human the lower frequency alpha rhythms are indicative of an unaroused state. Changes in the direction of higher frequencies, the beta range, show an increase in arousal level.

At the cellular level these changes in EEG frequency are related to the temporal pattern of cell firings. The alpha rhythm results from the concerted, regular firing of large groups of cortical cells. As this large group of cells is broken down into smaller functional units by the requirements of input processing, these smaller units begin to fire on their own temporal pattern. This combination of a greater number of functional units firing on independent temporal patterns results in an increase in the mean EEG frequency.

These changes in EEG frequency, which are functionally related to arousal level, have been used as an indicator of the relative engagement of the two cerebral hemispheres in the performance of a task.

Butler and Glass (1974) investigated left hemisphere function by recording EEG while subjects performed mental mathematical problems.

They found an overall attenuation of both the alpha rhythm and "total EEG" (half amplitude high frequency filter set at 40 Hz.) during problem solving. Additionally, significant suppression of the alpha rhythm over the left hemisphere, relative to the right, was found during the solving of mental mathematical problems. Finally, when subjects were considered with regard to handedness the alpha rhythm asymmetry during calculations over the left hemisphere was found to be significant for dextrals but not for sinstrals.

Dumas and Morgan (1975) presented a group of dextrals from two occupation groups, artists and engineers, with two spatial tasks: facial recall, and a modified Nebe's Ring Test; and two verbal tasks: mental addition, and listening to verbal material. Each task contained three sub-tests graded for difficulty. Their results show an alpha asymmetry which is task dependent. The spatial tasks suppressed alpha over the right hemisphere while the verbal tasks suppressed alpha over the left hemisphere. Further, the difficulty of the items within a task and the occupation of the subject had no effect on lateralization of the alpha rhythm.

A number of studies have used a similar collection of these items. These items include letter writing (Bennett and Trinder, 1977; Doyle, Ornstein and Galin, 1974; Galin and Ornstein, 1972), mentally composing a letter with eyes open (Doyle, Ornstein and Galin, 1974; Galin and Ornstein, 1972; McLeod and Peacock, 1977), serial arithmetic, and listening to verbal material (Doyle, Ornstein and Galin, 1974) as verbal tasks. Spatial tasks included Koh's Block Designs (Bennett and Trinder, 1977; Doyle, Ornstein and Galin, 1974; Galin and Ornstein, 1972), a modified Minnesota Paper Form Board Test (Doyle, Ornstein and Galin, 1974; Galin and Ornstein, 1972; McLeod and Peacock, 1977), a tonal memory test (Bennett and Trinder, 1977; Doyle, Ornstein and Galin, 1974), and a "magic etch-a-sketch" task (Doyle, Ornstein and Galin, 1974).

These studies all found significant decreases in alpha over the left hemisphere during the performance of the verbal tasks and decreases over the right hemisphere during the performance of the spatial tasks. These decreases in alpha activity appear to be independent of the site recorded from. Bennett and Trinder (1977) recorded from the temporal area (T_3 and T_4), while McLeod and Peacock (1977) recorded from the parietal area (P_3 and P_4). Doyle, Ornstein and Galin (1974) and Galin and Ornstein (1972) recorded bilaterally from both the parietal and temporal areas.

Taken as a whole, the above cited studies all point to the existance of task dependent EEG asymmetries. Further, these asymmetries in the EEG are consistent with those that would be predicted from the studies of hemispheric functioning. However, it remains open to question whether these decreases in alpha activity are accompanied by increases in higher frequency EEG rhythms, a more definite indicator of increased cerebral activation. The findings of Doyle, Ornstein and Galin (1974) in particular point to this question. They found no corresponding increases in beta (13-35 Hz.) in the same hemisphere as alpha decreased. Likewise, increases in alpha did not appear correlated to decreases in beta, rather the two seemed to increase and decrease in the same hemisphere in a parallel fashion.

Anatomy. Since it has been shown that task dependent differences in function and brain electrical activity do exist between the two cerebral hemispheres it is natural to wonder if any differences exist in the structure which underlies these activities. Until recently it had been thought that anatomically the two hemispheres were mirror images of each other. However, led on by the thinking that as function varies so must structure, researchers have recently begun to uncover a number of anatomical differences between the two hemispheres.

Geschwind and Levitsky (1968), based on a study of 100 adult brains, found that the posterior margin of the Sylvian fissure was angled backward more sharply on the left in 57% of the cases, and on the right in 18%, with approximately 25% being equal. These investigators also found that the anterior margin of the temporal plane, an area known as Heschl's gyrus, was angled forward more sharply on the left in 40% of the brains studied, and on the right in 24%, with about 36% being equal.

Geschwind and Levitsky (1968) also found that on the average the left temporal lobe is one third longer than the right temporal lobe. The average difference was found to be 0.9 centimeters, with the left temporal lobe averaging 3.6 centimeters and the right temporal lobe averaging 2.7 centimeters.

As Geschwind and Levitsky point out the left temporal lobe contains Wernicke's area, a major region involved in speech, and they claim that these anatomical differences are of sufficient magnitude to be compatible with the known functional asymmetries of the two hemispheres in mediating language.

A later study by Wada (1969) has confirmed the findings of Geschwind and Levitsky (1968) and has also found similar asymmetries in the brains of fetuses and newborns.

In reporting on a more recent series of studies Geschwind (1974) has stated that in addition to the temporal plane, the following areas are larger on the left hemisphere: the portion of Wernicke's area lying on the convexity of the temporal lobe, and the cortex in the parietal operculum. Geschwind credits both these anatomical differences as resulting from the greater length of the left Sylvian fissure. In the case of Wernicke's area he states that, "the greater length of the left Sylvian fissure necessarily means a prolongation of the posterior part of the superior temporal gyrus." Likewise, the lengthening of the left Sylvian fissure results in an enlargement of the cortical area lying above it.

Similarly, it follows that:

> ...if the right Sylvian fissure is shorter, then the cortical area extending from the posterior end of the Sylvian fissure to the occipital pole must be longer on the right.

This line of reasoning receives support from another study. McRae, Branch and Milner (1968), using pneumoencephalography to study asymmetries of the ventricular system in life, found the left occipital horn of the lateral ventricle to be longer in 57% of the cases. A longer right occipital horn was found in 13% of the cases, with equality of the occipital horns present in 30% of those examined. This finding of a longer left occipital horn in 57% of those examined suggests a morphological difference between the two cerebral hemispheres. This morphological difference would appear to be a slightly smaller, at least posteriorly, left cerebral hemisphere in comparison to the right hemisphere.

Since the source of all energy for cerebral activity is oxygen and free glucose transported to the neural tissue by blood, the circulatory system would appear to be another area worthy of investigation.

It is well known that in man the right cerebral hemisphere is supplied blood from a vascular trunk which it shares with the right upper extremity, while the left cerebral hemisphere is supplied with blood directly from the aortic arch. Osman-Hill (1953, Vol. 3, p. 52) has stated that this same degree of asymmetry is seen only in the anthropoid monkeys, gorilla and chimpanzee.

Carmon and Gombos (1970) investigated the consequences of this anatomical asymmetry. They used Opthalmodynamometry, an indirect method of measuring the blood pressures in both carotid arteries by measuring the blood pressure in the opthalmic arteries. They found a significant correlation between opthalmic systolic blood pressure differences and rated handedness. This correlation indicates that right handed subjects have higher systolic pressure in the right opthalmic artery than in the left, and that left handed subjects have a reversed pattern of systolic pressure. Since opthalmic artery pressure is considered to be a function of internal carotid artery pressure, the results indicate differential pressures within the right and left internal carotid arteries which vary in a consistent manner with handedness. The more strongly right handed the subject, the better his chances are of having a higher carotid artery pressure on the right than on the left.

In another study of the brain's circulatory system, LeMay and Culebras (1972) investigated arteriographic asymmetries of the middle cerebral artery within the Sylvian fissure. They found that it angled more sharply under the left parietal operculum as it came out to the surface than it did on the right. They also found the right middle cerebral artery to be angled upward more than the left middle cerebral artery as it ran within the Sylvian fossa. In studying whole brains and coronal brain sections in an attempt to find the anatomical differences underlying the arteriographic asymmetries in the two hemispheres, LeMay and Culebras discovered a more highly developed parietal operculum on the left in right handed individuals, with left handed individuals showing equal opercular development or a more highly developed right operculum. In addition they found the right Sylvian fissure to be angled upward more sharply on the left. This finding is in agreement with the earlier findings of Geschwind and Levitsky (1968), and Wada (1969). LeMay and Culebras state that a similar pattern of anatomical differences has been found in fetal brains and in the endocranial cast of La Chapelle-Aux-Saints skull, the skull of a neanderthal man who lived over 40,000 years ago.

Dichiro (1972) studied the venous patterns of the brain and found that when comparing the three major superficial venous channels: Trolard, superficial Sylvian, and Labbe, that the vein of Labbe predominates by its larger size in the left hemisphere of right handed individuals, while the vein of Trolard predominates in the right hemisphere. Left handed individuals show a reversed asymmetry.

These findings show that structural differences do exist between the two hemispheres of the brain. Further, they point up the possibility that the asymmetries seen in function and brain electrical activity are underlain by anatomical asymmetries.

As an overview, it can be seen from the above studies that asymmetries do exist between the two cerebral hemispheres. Functionally the two hemispheres differ along a continuum of verbalizability. In right handed people the left hemisphere tends to predominate in processing stimuli which can be characterized as easily verbalizable. Such tasks include letter, word, and digit recognition and identification regardless of whether the stimuli are presented visually or aurally. Conversely, the right hemisphere predominates in processing stimuli which are not readily verbalizable, or which are poorly or incompletely characterized by a verbal representation. Tasks in this category include facial recognition, the enumeration of geometric figures and dots in a random dot pattern, tactile pattern recognition, and recognition of aurally presented melodies.

It has also been shown that the brain electrical activity which underlies neural functioning varies in a task dependent manner between the two hemispheres. Further, the asymmetries in electrical activity between the two hemispheres are appropriate to the functional asymmetries found. There is a greater decrease in the EEG pattern which characterizes a non-aroused state in the hemisphere which is maximally involved in the task presented. Again, the appropriate hemisphere can be predicted on the basis of the verbalizability of the stimulus involved.

Finally, a structural asymmetry which may be of sufficient magnitude to account for at least some of the functional and electrical asymmetries seen has been shown to exist. These structural asymmetries can be characterized as an enlargement of those areas involved predominantly in verbal activities in the left hemisphere. In the right hemisphere structural differentiation is predominantly in the area of the parietal-occipital-temporal (PCT) junction. Since the P-O-T junction is known to be an association area involved in the integration and synthesis of input from multiple brain areas and multiple input modalities, increased development in the right hemisphere would be adaptive for the processing of information which is not easily typified by a verbal code.

Thus, it can be seen that hemispheric asymmetries do exist in the brain, and that evidence for these asymmetries can be found in brain function, electrical activity, and structure. Further, evidence from these three areas can be united into a cohesive whole along the dimension of meaningful verbalizability of the stimuli within the task to be performed.

However, a word of caution should be stated. The findings presented do not support the idea of certain tasks being processed exclusively within one hemisphere. The left hemisphere doesn't exclusively process easily verbalizable stimuli, while the right hemisphere is limited to dealing with stimuli which are not easily verbalized. Rather, there is a dynamic balance between the two hemispheres with the left hemisphere more involved than the right in easily verbalizable tasks and a reversed pattern of involvement present during tasks which are not easily verbalizable. This dynamic relationship can be most easily seen in the EEG studies of hemispheric differences. In these studies, those tasks which maximally suppress the alpha rhythm over the left hemisphere also cause a decrease in alpha rhythm activity over the right hemisphere. The balance of this alpha rhythm suppression is heavily weighted toward the left hemisphere. The result is an overall reduction in alpha rhythm activity with significantly less activity over the left hemisphere than over the right. Tasks which maximally engage the right hemisphere show a reversed pattern of alpha rhythm activity.

This dynamic balance between the two cerebral hemispheres shows that neither of the two hemispheres is specialized to the point of excluding the other. Rather, both hemispheres are involved in the solution of any task. What varies from task to task is the degree of involvement of the two hemispheres.

<u>40 Hz. EEG</u>

As previously stated the frequency of the EEG signal is directly related to the arousal level of the organism. The alpha rhythm (9-12 Hz.) is indicative of an awake organism at a low level of arousal. Shifts in the EEG spectrum to frequencies below the alpha rhythm band usually indicate a behavioral shift toward a sleep state. Increases in EEG frequency to bands above the alpha rhythm are correlated with increased arousal. Increases in the EEG frequency are also marked by a progressive reduction in the amplitude of the signal.

Because of the marked decrease in amplitude which accompanies the high frequency EEG rhythms and because of the slow paper speeds which are traditionally used in EEG recording, the high frequency spectrum above 30 Hz., when not specifically filtered out of the total EEG signal, has been ignored as an uninteresting thick black line. Several investigators have, however, looked into this thick black line of high frequency beta activity and have found changes in it which can be related to behavior.

Sakhialina and Mukhamedova (1958) have recorded a band of 30-40 Hz. EEG activity from the occipital, parietal, and temporal regions of subjects engaged in the initial phases of an unfamiliar muscular activity, in this case pedaling a bicycle ergometer. With further training this band of EEG activity became localized in specific sensory motor areas. Continued practice led to a reduction in the 30-40 Hz. EEG activity with an eventual return of the alpha rhythm.

Using depth recording techniques with humans, Perez-Borja, et al. (1961a; b) bilaterally implanted electrodes deep in the posterior temporal or the parietal lobes. The electrodes were located just posterior to the pulvinar and anterior to the ventral portion of the calcarine region, about 25 millimeters from midline. They found a fast focal response in the 40-45 Hz. band which was nonspecifically responsive to stimulation in all sensory modalities.

Using period analysis techniques, Giannitripani (1966) found a significant change in the average frequency of the EEG signal from a resting condition to a "thinking" condition. During the resting condition the mean frequency was found to be 32.8 Hz., but during the "thinking" condition, which required mental arithmetic, the mean EEG frequency increased to 38.9 Hz.

Recently a series of studies by Sheer and his associates (Bird, 1975; Ford, 1976; Hix, 1971; Johnson, 1975; Laxton, 1976; Newton, 1975; Peters, 1970; Sheer, 1970, 1972, 1975, 1976; Sheer and Grandstaff, 1970) have focused on a particular high frequency, low amplitude EEG signal centered at 40 Hz. This signal has been interpreted by Sheer (1972) as reflecting a state of "focused arousal" which occurs during the consolidation of short term memory.

Exhaustive reviews of both the animal literature (Hix, 1969) and the human literature (Hix, 1971; Peters, 1970) relevant to 40 Hz. EEG activity have already been made, so only the highlights will be handled here.

Using college students as subjects, Bird (1975), Laxton (1976), and

Newton (1975) have all noted significant increases in 40 Hz. EEG activity during problem solving. Similarly, Peters (1970), recording from the occipital area in adults, has found consistent increases in 40 Hz. EEG activity during the stimulus periods of a visual discrimination task. These increases in 40 Hz. activity were accompanied by decreases in 20 Hz. EEG activity.

Johnson (1975) has also found an increase in 40 Hz. EEG activity during problem solving in children. Hix (1971) has noted a similar increase in the 40 Hz. EEG band during problem solving in normal children, but failed to find a corresponding increase in a matched group of minimal brain damaged children.

In an analysis of the subjective states of subjects involved in a 40 Hz. EEG biofeedback study, Bird (1975) found that high arousal and mental concentration were associated with increased 40 Hz. activity while low arousal and little mental effort were associated with suppression of 40 Hz. activity.

In another study, which offers some support to the findings of Bird, Ford (1976) trained subjects to suppress 40 Hz. EEG activity. After they had gained voluntary control over 40 Hz. suppression, they were presented with a problem and told to attempt to solve it while maintaining a suppressed level of 40 Hz. EEG activity. Subjects were unable to simultaneously solve problems and maintain 40 Hz. suppression. This finding indicates that problem solving and suppression of 40 Hz. EEG activity may be incompatible tasks.

In recording from the amygdala in cats, Sheer (1970) has noted that this higher order olfaction area in the limbic system shows 40 Hz. activity. The 40 Hz. activity recorded from this structure occurs concomitant with inhalation, but is not solely dependent upon it. Rather 40 Hz. activity in the amygdala is related to the novelty of the olfactory stimulus and always occurs simultaneous with orienting behaviors indicated by a sniffing response, an aroused EEG pattern, and high alertness.

A commonality through all these research findings is that 40 Hz. EEG activity is observed as a consequence of meaningful or arousing stimuli. In humans the state of the organism appears to be a constant. In all cases increases in 40 Hz. EEG activity accompany periods of concentration, such as during problem solving. In such situations the individual is highly aroused and his attention is focused on the stimulus. The EEG activity is highly desynchronized. It is during periods such as this that 40 Hz. EEG activity is most prominent.

CHAPTER II

METHOD

Subjects

Twenty-four subjects, 12 male and 12 female, between the ages of 18 and 30 were used. Six additional subjects were run, but their data was excluded from the analysis due to either EEG activity of insufficient amplitude, or an EEG record that was confounded by muscle activity. All subjects were administered a modified form of the Harris Tests of Lateral Dominance (see Appendix A) and were judged to be right hand dominant. A judgment of right hand dominance was based on all motor tasks being reported as performed by the right hand or foot.

Apparatus and Materials

The apparatus used in this study was essentially the same as that used in previous studies of 40 Hz. EEG activity carried out at this laboratory. Stimulus materials were presented on a rear projection screen by a slide projector. The distance between the projection screen and subject was approximately 6 feet. The presentation intervals for each stimulus item, inter-stimulus-intervals, and response intervals were automatically controlled by external electromechanical programming equipment. This programming equipment also inhibited output pulses from the filters and comparators to the digital counters during the response interval. Subjects' EEGs were recorded while seated in a reclining chair in a dimly lit, sound attenuated, and electronically shielded room.

EEGs were recorded using grass silver disc electrodes filled with conductive paste. The electrodes were attached to skin areas which had first been cleansed with acetone and then mildly abraded with redux paste. Electrodes were held in place by cotton gauze squares that had been soaked in collodion, placed over the electrode, and dried in place using a stream of compressed air. Resistances for all electrodes were below 5,000 ohms.

The EEG electrodes were placed according to the following scheme: the inion to nasion distance along the midline was measured and 20% of this distance above the inion was marked. The distance from this point to a midline point on the forehead was measured in a horizontal plane. This measurement was made on both sides of the head. Twenty percent of this unilateral distance was marked from the previously calculated midline point. This places an electrode approximately in the middle of the triangle formed by placements O_1-P_3-T_5 of the International Ten-Twenty System (Jasper, 1958) on the left side and in a corresponding position relative to O_2-P_4-T_6 on the right side. In addition to these two electrode placements a third EEG electrode was located at C_z of the international ten-twenty system.

Electrodes for recording muscle activity were located on the neck muscle (splenius) and ipsilateral temporal muscle. Coordinates for the placement of muscle electrodes were:

Neck: 13 cm. ventral and 3 cm. lateral from the inion,

Temporal: Approximately 3 cm. directly anterior from the external auditory meatus.

Muscle electrodes located ipsilaterally were referenced to each other.

Grass EEG amplifiers (Model 7P511) were used to amplify the electrical signal from the electrodes. The amplifiers were adjusted to a high pass filter setting of 10 Hz., 3 Hz. for the channel monitoring alpha rhythm activity, and to a low-pass filter setting of 90 Hz. All amplifiers were set at maximum sensitivity, and the 60 Hz. filters were switched out. Chart speed varied from 5 mm/second during the response interval, to between 50 and 100 mm/second during the problem solving interval. The higher chart speeds were used to allow visual inspection of the high frequency, low amplitude activity.

Comparators and Filters

The amplified EEG and muscle outputs were connected to four coincidence detection units, which served to control for muscle confounds (Appendices B and C). Each unit contained two high Q, narrow band, twin-T analog filters (Model 3385, White Instrument Co., Austin, Texas). Each filter had a 23% roll-off curve. One filter in each comparator was centered at 40 Hz., with a range of from 37.5 to 42.5 Hz., and the other was centered at 70 Hz., with a range of from 68 to 72 Hz. The outputs from these filters were rectified to DC, then integrated and fed to digital counters. The filter output required to trigger the counter could be regulated both in terms of time constants and amplitude threshold levels.

Each unit also contained an anion gate which only allowed the 40 Hz. output to trigger a digital counter when it occurred in the absence of the 70 Hz. output. The 70 Hz. output, based on the finding that 40 Hz. muscle is polyphasic with 70 Hz. activity, while 40 Hz. EEG is not (Hix, 1971), was used to represent high frequency muscle activity. The time constant criteria for an output from both the 40 Hz. and 70 Hz. circuits was set at 75 msec., this duration representing three cycles of

40 Hz. activity and five cycles of 70 Hz. activity. The occurrance of any overlap, time wise, between a 40 Hz. output and a 70 Hz. output inhibited the pulse to the digital counter. Amplitude levels for 40 Hz. varied from 5 to 10 microvolts (μv), while amplitude levels for 70 Hz. were adjusted to reflect high frequency muscle activity seen in the record.

The other control for muscle confounds consisted of a comparator and a 200 msec. contingency window circuit. This circuit had the effect of inhibiting all digital outputs that were a consequence of 40 Hz. EEG activity if the output occurred within 200 msec. of a 40 Hz. muscle output. The distinction between EEG and muscle was determined by electrode placement

The muscle control circuits, in simplest terms, worked as follows: No digital counts were registered for any 40 Hz. activity, of either muscle or EEG origin, that was coincident with 70 Hz. activity from the same lead. Also, no digital counts were registered for any 40 Hz. EEG activity from an EEG lead that occurred within 200 msec. of any 40 Hz. muscle activity from a muscle lead. These two controls greatly reduced the possibility of misinterpreting muscle activity as 40 Hz. EEG.

Two other filters were also used on the raw EEG signal. One was centered at 10.5 Hz., with a range of from 8 to 13 Hz., and was used to filter the alpha rhythm. The other was centered at 24.5 Hz., with a range of from 21 to 30 Hz., and was used to filter the high beta frequencies currently known as Beta II. Time constants were set to coincide with three cycles of alpha and three cycles of beta respectively. Amplitude levels were adjusted to minimum of 15 to 20 μv. Separate digital counters recorded alpha and beta wave activity. Half of the subjects had alpha and beta activity recorded from the left EEG lead, the remainder of the subjects had this activity recorded from the right EEG lead. Since muscle activity doesn't range down to these lower frequencies, no muscle comparator circuits were required.

EEG and muscle leads were recorded on chart paper along with event markers for 40 Hz. EEG, and 40 Hz. muscle.

Procedure

Subjects were required to participate a total of two days. The first day served as a screening session for prospective subjects. The second day consisted of the actual EEG recording session. Procedures for each day were as follows.

Procedure for Day 1. Prospective subjects reported to the laboratory where they were given a general description of the goals of the study and the procedures to be used. Those who agreed to participate were then administered a modified form of the Harris Tests of Lateral Dominance (Appendix A), and questioned about any medications they might currently be taking. Subjects who met the criteria of all motor tasks lateralized on the right side and who were not taking, or had not recently taken, any medication, were scheduled to return for the second day.

Procedure for Day 2. While electrodes were being applied subjects were again briefed on the procedures to be carried out and were encouraged to ask any questions they might have. After the electrodes had been applied and resistances checked, the subject was taken to the previously mentioned sound attenuated, electronically shielded room and seated in a reclining chair. The chair was adjusted so that the subject could see the rear projection screen easily without lifting his head or tensing his neck muscles. The amplitude criteria on all the filters and comparators were adjusted to suit the individual subject and a 5 minute pre-test baseline was recorded with the subject relaxed, but awake with eyes open.

Following the pre-test baseline the four tests were administered and the subject's EEG recorded. Digital counts were recording only during the presentation of the test items and during any time allowed for solution of the problem. During the answer interval the counters were turned off. The order of presentation for the four tests was completely randomized across all subjects. Before the beginning of each test the general type of problem to be seen was explained to each subject and an example was shown.

After the testing phase a 5 minute post-test baseline was recorded under the same conditions used during the pre-test baseline.

This concluded the procedures to be carried out on day two. The electrodes were removed and the subject was given an opportunity to ask any questions he might have.

Test Items. As previously stated, four tests were administered (See Appendix D). Two of the tests were judged to primarily involve left hemisphere processes while the other two were judged to rely primarily on right hemisphere processes. The two left hemisphere tests were verbal and mathematical tests adapted from the verbal and mathematical sections of a Graduate Record Examination preparation book (Gruber, 1965). Each of the two tests contained six items. The two right hemisphere tests were facial recognition and geometric shape recognition tests. The facial recognition test items were adapted from a standard clinical test of right hemisphere function (Benton, Van Allen, Hamsuer and Levin, 1975). The items in the three dimensional geometric figure recognition test were adapted from a test developed by Metzler (cited by Metzler and Shepard, 1974). Each test contained 20 items, with each item consisting of two slides, a standard and a match. The items in all four tests were selected from a larger group of items which had previously been presented to a large group of college students. A probability-of-correct-response figure had been calculated for each item in these larger groups and the items used were picked to insure a constant difficulty, or probability-of-correct-response, level for all four tests. The mean difficulty level of each test was about .50, with difficulty for each item ranging from .30 to .70.

Presentation of Test Items. All problems were made into slides and projected onto a rear projection screen in the subject room. The order of presentation for the four tests was counterbalanced across all individuals. The presentation format differed between the math and verbal problems and the facial and geometric figure recognition problems. The math and verbal problems were each presented for 45 seconds. At the end of the 45 second interval the problem was replaced by a blank, opaque slide. The blank slide remained on the screen for 5 seconds during which the subject gave his answer. The facial recognition and three-dimensional geometric figure recognition items each contained two slides. The first slide was the standard and the second the match. The subject was to indicate whether or not the standard and match were of the same person or object. For the facial recognition test the standard was presented for 1 second, a blank slide came on for 3 seconds followed by the match which was also presented for 1 second. After the match slide another blank slide came on for 5 seconds during which the subject gave his answer. Presentation of the three-dimensional geometric figure recognition items was essentially the same as the facial recognition items except that the standard and match were presented for 3 seconds each.

CHAPTER III

RESULTS

Tables 1 and 2 show the mean change in rate from baseline in the EEG bands of interest over each hemisphere, during the various tests. These changes in amount of EEG activity were analyzed using a two-tailed Wilcoxen Signed-Ranks Test (Bruning and Kintz, 1968). This test revealed significant decreases in the amount of alpha rhythm activity in both hemispheres during all four tests as shown in Table 1 (left hemisphere: Math, $T=2$, $n^1=12$, $p \leq .01$; Verbal, $T=12$, $n^1=12$, $p \leq .05$; Facial Recognition, $T=12$, $n^1=12$, $p \leq .05$; Figure Recognition, $T=8$, $n^1=12$, $p \leq .02$. Right hemisphere: Math, $T=4$, $n^1=12$, $p \leq .01$; Verbal, $T=1$, $n^1=12$, $p \leq .01$; Facial Recognition, $T=2$, $n^1=12$, $p \leq .01$; Figure Recognition, $T=3$, $n^1=12$, $p \leq .01$). Significant decreases in beta activity, again shown in Table 1, were also found in both hemispheres for three tests: Math (left: $T=7$, $n^1=12$, $p \leq .01$; right: $T=8$, $n^1=12$, $p \leq .02$), Verbal (left: $T=12$, $n^1=12$, $p \leq .05$; right: $T=6$, $n^1=12$, $p \leq .01$), and Geometric Figure Recognition (left: $T=12$, $n^1=12$, $p \leq .05$, right: $T=14$, $n^1=12$, $p \leq .05$). No significant changes in beta activity were found in either hemisphere during the facial recognition test.

In the 40 Hz. frequency band, as shown in Table 2, a significant increase in activity was found over the left hemisphere during the verbal test ($T=28.5$, $n^1=22$, $p \leq .01$). Over the right hemisphere a significant increase in 40 Hz. activity was found during the geometric figure recognition test ($T=33$, $n^1=23$, $p \leq .01$).

An analysis of muscle activity, also shown in Table 2, revealed that

TABLE 1

Change in Mean Rate of Activity From Baseline to Problem Solving Conditions in Alpha and Beta EEG Bands

			Math	Verbal	Faces	Figures
Alpha	Left N=12	Mean	46.45***	64.08*	71.64*	65.22**
		% change from baseline	-55	-38	-31	-37
		Proportion of S's changing	11/12	9/12	10/12	9/12
		Range	0-132.1	0.9-169.0	2.4-188.5	0-135.8
	Right N=12	Mean	52.25***	61.43***	78.31***	69.96***
		% change from baseline	-58	-51	-38	-44
		Proportion of S's changing	11/12	11/12	11/12	11/12
		Range	1.5-158.2	2.2-134.8	24.2-141.6	12.2-142.5
Beta	Left N=12	Mean	62.9***	64.55*	93.86	71.43*
		% change from baseline	-23	-21	+14	-13
		Proportion of S's changing	10/12	10/12	8/12	9/12
		Range	9.3-121.5	12.8-135.4	11.3-226.2	10.0-137.3
	Right N=12	Mean	38.31**	38.58***	49.15	44.58*
		% change from baseline	-37	-37	-19	-27
		Proportion of S's changing	9/12	10/12	8/12	9/12
		Range	0.2-139.0	2.2-135.1	6.1-151.6	3.0-140.5

*$p \leq .05$ (2-tailed) **$p \leq .02$ (2-tailed) ***$p \leq .01$ (2-tailed)

TABLE 2

Change in Mean Rate of Activity From Baseline to Problem Solving Conditions in 40 Hz. EEG and 40 Hz. EMG Bands

			Math	Verbal	Faces	Figures
40 Hz. EEG	Left N=24	Mean	4.59	6.20*	6.70	6.19
		% change from baseline	+12	+51	+63	+51
		Proportion of S's changing	10/24	19/24	15/24	16/24
		Range	0-13.3	0.4-30.6	0-32.7	0-25.9
	Right N=24	Mean	2.54	2.86	1.94	3.11*
		% change from baseline	+77	+99	+35	+117
		Proportion of S's changing	9/24	14/24	12/24	18/24
		Range	0-12.2	0-15.9	0-6.7	0-12.4
40 Hz. EMG	Left N=24	Mean	54.68*	39.38*	42.48*	45.63*
		% change from baseline	+121	+59	+72	+84
		Proportion of S's changing	21/24	18/24	17/24	21/24
		Range	7.5-174.7	0.9-218.1	1.4-200.4	1.7-181.6
	Right N=24	Mean	37.54*	27.86*	34.37*	28.38*
		% change from baseline	+137	+76	+117	+79
		Proportion of S's changing	22/24	20/24	20/24	23/24
		Range	12.1-91.7	1.5-102.0	1.0-121.6	3.9-98.8

*$p \leq .01$ (2-tailed)

it increased significantly on both sides during all tests (Math: left, $T=30$, $n^1=24$, $p \leq .01$, right, $T=22$, $n^1=24$, $p \leq .01$; Verbal: left, $T=28$, $n^1=24$, $p \leq .01$, right, $T=23$, $n^1=24$, $p \leq .01$; Faces: left, $T=53$, $n^1=24$, $p \leq .01$, right, $T=28$, $n^1=24$, $p \leq .01$; Rotations: left, $T=12$, $n^1=24$, $p \leq .01$, right, $T=4.5$, $n^1=24$, $p \leq .01$).

Since the 40 Hz. EEG frequency band is completely overlain by muscle activity, a series of Spearman Rho correlations (Bruning and Kintz, 1968) were performed between 40 Hz. EEG activity and ipsolateral muscle activity during each test. Since the base rates for both muscle and 40 Hz. EEG activity varied from subject to subject, the data used in performing the correlations was a ratio of problem solving rate to baseline rate. No significant correlations were found between 40 Hz. EMG activity and 40 Hz. EEG activity during any test on either the left or the right side.

Finally, a series of Spearman Rho correlations were performed between the amount of 40 Hz. EEG activity (problem solving rate/baseline rate) and the number of items answered correctly on each test. Again, no significant correlations were found regardless of the test or the hemisphere over which the 40 Hz. EEG was recorded. These correlations are presented in Table 3.

TABLE 3

Spearman Rho Correlations for Selected Measures

Correlated Measures		Test: Math	Verbal	Faces	Rotation
40 Hz. EMG and 40 Hz. EEG	Left	-.045	+.188	-.231	+.358
	Right	+.349	+.277	-.349	+.232
40 Hz. EEG and # Correct	Left	+.176	+.158	+.132	-.032
	Right	+.067	-.006	-.178	-.225
40 Hz. EMG and # Correct	Left	+.403	-.052	-.253	-.378
	Right	+.333	+.191	+.043	+.083
40 Hz. EEG on Left and Right		+.699*	+.393	+.396	+.710*
40 Hz. EMG on Left and Right		+.663*	+.564*	+.534*	+.362

*$p \leq .001$ (2-tailed)

CHAPTER IV

DISCUSSION

The failure to obtain alpha asymmetry in the present study is not unexpected, and can be attributed to several factors. First the method used to measure alpha in this study is different from that used in studies specifically interested in alpha activity. Those studies have generally measured changes in total "power" over a specific frequency band while the present study only looked at number of bursts of activity exceeding a pre-set amplitude criteria. Second, due to a limitation in filters available, alpha levels over the left and right hemispheres were not recorded in the same individual. Half of the subjects had alpha recorded over the left hemisphere during all tasks, while alpha activity over the right hemisphere was recorded in the remaining subjects. Although these two factors excluded the finding of alpha asymmetry, a general decrease in the alpha rhythm was found which paralleled changes in beta activity, a relationship which has previously been observed (Butler and Glass, 1974; Doyle, Ornstein and Galin, 1974).

However, concomitant with this decrease in both the alpha and beta rhythms, is an increase in the amount of 40 Hz. activity present in the EEG. These findings have been presented individually in previous studies and the finding of their joint occurrence is not particularly surprising. It does lend additional support to the presently held view of the relationship between EEG and behavior which was cited earlier.

In addition, the lack of correlation between 40 Hz. EEG and 40 Hz. EMG activity indicates that the increased 40 Hz. activity recorded from the EEG electrodes was not associated with increased 40 Hz. activity at the EMG electrodes. This finding increases the likelihood that 40 Hz. activity recorded at the EEG electrode sites is of neurological origin and not related to muscle activity.

Of greater interest is the asymmetry shown in the increases of 40 Hz. activity. It should be noted that those asymmetries found are consistent with what would be expected from previous studies as developed in earlier sections of this paper. Specifically, the increases are greatest in the hemisphere maximally engaged by the task. The failure to find an asymmetry in the 40 Hz. band during the performance of both the math and the facial recognition tasks may not be as surprising as it initially seems. The mathematics test may not be as strongly lateralized to the left hemisphere as the verbal test. This incomplete lateralization can be predicted by returning to the concept of the degree of meaningful verbalizability of the stimulus. Any mathematical problem contains two elementary parts; first there are the mathematical operations to be carried out within the problem. These operations include add, subtract, multiply, divide and equals. These operations, and the symbols which represent them are easily verbalizable in a meaningful way, almost anyone can readily explain the concept of these operations. However, the second part of any mathematical problem is the numbers that the operations are performed on. Here, the symbols that represent the numbers are readily verbalizable, but the concept of the number is not. The concept, or spatial area which the numerical symbol represents can not be readily verbalized in any meaningful way. As an example try to verbalize the concept or amount of "numerical space" represented by the symbol "9." When this is extended to include the results of the operations carried out, the final outcome is particularly difficult to meaningfully verbalize.

This analysis of mathematics as being poorly lateralized is also supported by clinical observations. In patients suffering from cerebral trauma and displaying a difficulty with mathematics, a problem known clinically as acalcula, those whose trauma is to the left hemisphere principally have difficulty in carrying out the operations required by the problem. Conversely, those patients with acalcula whose damage is to the right hemisphere typically have trouble representing the "number space" expressed by the numerical symbols; but have a perfectly adequate understanding of the operations to be performed. From this analysis an increase in activity in both hemispheres would be expected. Referring to Table 2 it can be seen that this is exactly what occurred.

In discussing the failure of the facial recognition test to reveal any asymmetry in the distribution of 40 Hz. EEG activity, no such clear cut analysis is forthcoming. Facial recognition is not a task that can be easily verbalized in any meaningful way. Additionally, research previously presented (Dumas and Morgan, 1975) has shown asymmetrical suppression of the alpha rhythm, with greatest suppression over the right hemisphere, during performance of a facial recall task. Clinically, facial recognition has long been recognized as a right hemisphere task (Benton _et al_., 1975; Benton and Van Allen, 1968; DeRenzi _et al_., 1968; Warrington and James, 1967). Thus, the failure to obtain an asymmetry in the distribution of 40 Hz. activity remains as a surprise and indicates that further research in this area is needed.

However, by far the most interesting result of the present study is the finding of clearly lateralized patterns of 40 Hz. EEG activity during the verbal and the geometric figure recognition tasks. This finding indicates that the 40 Hz. EEG is an indicator of focused arousal not just behaviorally, but also neocortically.

At the behavioral level Sheer (personal communication) has recently developed a model for focused arousal and its resultant, selective attention. This model presents focused arousal as resulting from the interaction of three functional components-- facilitory, inhibitory, and corticifugal processing. These three functional components are defined behaviorally by the momentary situation. For example, facilitory processing can be defined by the state of the organism: number of hours of food deprivation, peripheral autonomic measures of arousal level, etc.; and by the contingencies of reinforcement operating within the momentary situation. Inhibitory processing can be defined by the effects of distractors vs non-distractors, and by response bias, like that seen in discrimination reversal tasks. Finally, corticifugal processing can be defined by expectancies: the effect of instructional sets, past experiences, etc.; and by stimulus attributes, like the meaningfulness or non-meaningfulness of sounds.

According to this model, corticifugal and facilitory processing interact to effect focused arousal, the 40 Hz. EEG signal, at the cortex. Focused arousal then interacts with inhibitory processing to bring about selective attention, which, behaviorally, is multi-faceted in its expression.

At neocortex, focused arousal is undoubtedly a result of recurrent inhibition. Recurrent inhibition is essentially negative feedback that has been triggered by a train of excitation. This function, which allows a cell to "turn itself off" following excitation, contributes to the phasing of rhythmic discharges.

A very detailed analysis of the process of recurrent inhibition at the level of the olfactory bulb, a laminar structure of simpler form than the neocortex, has been presented by Rall and Shepherd (1968) and Shepherd (1970). In this analysis granule cells are excited by mitral cells, which in turn have been activated by bipolar cells reacting to olfactory stimulation. The excited granule cells deliver a graded inhibition to the mitral cells which removes the source of excitatory input to the granule cells. As the activity of the granule cells decreases, the amount of inhibition to the mitral cells decreases, which allows the mitral cells to again respond to excitatory input from bipolar cells. As can be seen, this system allows the constant excitation arising from olfactory stimulation to be converted to a pulsed, rhymical train of excitation. At the level of neocortex the effect of recurrent inhibition is functionally similar, but the analysis is much more complex due to the more complex laminar structure involved.

It is known that repetitive synchronous excitation of cortical cells is dependent upon cholinergic pathways which approach the pyramidal cells of cortical layer V. These cholinergic pathways represent the final stage of the ascending reticular activating system. Direct stimulation of this brain stem reticular activating formation increases the release of acetylcholine and has been correlated with activation of an aroused EEG pattern (Celesia and Jasper, 1966). In addition, Drachman (1977) has shown that interference with cholinergic function results in a strong disturbance of memory/cognitive performance.

Finally, Block (1970) has shown that stimulation of the reticular activating system facilitates learning. He found that direct reticular stimulation applied immediately after the registration of information, resulted in considerable inprovements in learning. If, however, the application of stimulation was delayed, the improvements in learning were decreased.

Since it has previously been shown (Ford, 1976) that subjects trained to suppress 40 Hz. EEG activity are unable to maintain that suppression during problem solving; and that subjects trained to increase 40 Hz. EEG activity report subjective states of high arousal and mental concentration (Bird, 1975); together with the accepted view of high frequency EEG activity representing an aroused state, it appears reasonable to associate the 40 Hz. EEG with the cholinergic system and the ascending reticular activating system.

Stimulation of the reticular activating system excites cholinergic pathways, which have been shown to be important for the performance of memory and cognitive tasks. Stimulation of these cholinergic pathways also results in recurrent inhibition at the level of neocortex. Thus, the 40 Hz. EEG activity can be seen as a special case of recurrent inhibition which, as Sheer (1976) has pointed out, "reflects repetitive stimulation at a constant frequency for a limited time over a limited circuitry."

An important consequence of the feedback loop established by recurrent inhibition is contrast, which serves to sharpen the focus of cortical excitation. This sharpening occurs because the negative feedback of recurrent inhibition has a greater inhibitory effect on synapses that are weakly excited by incoming stimuli. Thus synapses, and in turn cells and cell assemblies, that are poorly excited by incoming stimuli are maximally inhibited by recurrent inhibition. This results in a clearly defined area of cell excitation, the area being determined by the susceptibility of cortical cells to arousal by the incoming stimuli. The specialization of cortical cells for various functions has long been recognized in the sensory systems, and on a gross level, can be inferred for the rest of cortex from the anatomical differences which exist between the two hemispheres of the brain, for it is the cell, and cell assemblies, which form the basis for anatomical structure. The operation of contrast as a function of inhibition of weakly excited cells has been detailed for a number of sensory cortical areas, including the auditory (Whitfield, 1965), and somesthetic (Mountcastle, 1961) and the visual (Hubel and Wiesel, 1962).

The net result of this neocortical recurrent inhibition, which is responsible for the 40 Hz. EEG activity itself, is that it also focuses the 40 Hz. activity in the cortical cells most responsive to the stimuli being presented. This focusing of activity accounts for the lateralization of 40 Hz. EEG found in the present study. The finding of task dependent lateralization of 40 Hz. activity also ties the 40 Hz. EEG rhythm to the cholinergic pathways discussed earlier, and, in turn, to the ascending reticular activating system.

These findings are important to a more complete understanding of the 40 Hz. EEG rhythm. They indicate that it represents a state of focused arousal, not just behaviorally, but also neocortically. The findings, and the connections these findings allow with cholinergic pathways and the reticular activating system, also help to consolidate the view of 40 Hz. EEG as essential to learning and problem solving.

BIBLIOGRAPHY

Anderson, A. L. The effect of laterality localization of focal brain lesions on the Wechsler-Bellevue Subtests. Journal of Clinical Psychology, 1951, 7, 149-153.

Beaumont, J. G. Handedness and hemisphere function. In S. J. Dimond and J. G. Beaumont (Eds.) Hemisphere Function in the Human Brain. New York: John Wiley & Sons, 1974.

Bennett, J. E. and Trinder, J. Hemispheric laterality and cognitive style associated with transcendental meditation. Psychophysiology, 1977, 14, 293-296.

Benton, A. L. and Van Allen, M. W. Impairment in facial recognition in patients with cerebral disease. Cortex, 1968, 4, 344-358.

Benton, A. L. and Van Allen, M. W. Prosopagnosia and facial discrimination. Journal of the Neurological Sciences, 1972, 15, 167-172.

Benton, A. L., Van Allen, M. W., Hamsuer, K. des. and Levin, H. S. Test of Facial Recognition, Form SL. Iowa City: Department of Neurology, University of Iowa Hospitals, 1975.

Berlucchi, G. Cerebral dominance and interhemispheric communication in normal man. In Schmitt, F. O., and Worden, F. G. (Eds.) The Neurosciences: Third Study Program. Cambridge, Massachusetts: The MIT Press, 1974.

Bird, B. L. Biofeedback Training of the 40 Hz EEG: Relation to Subjective States and Other EEG Rhythms. Unpublished Doctoral Dissertation, University of Houston, 1975.

Block, V. Facts and hypotheses concerning memory consolidation processes. Brain Research, 1970, 24, 561-575.

Bruning, J. L. and Kintz, B. L. Computational Handbook of Statistics. Glenview, Illinois: Scott, Foresman and Company, 1968.

Bryden, M. P. Tachistoscopic recognition and cerebral dominance. Perceptual and Motor Skills, 1964, 19, 686.

Bryden, M. P. Tachistoscopic recognition, handedness, and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

Bryden, M. P., and Rainey, C. A. Left-right differences in tachistoscopic recognition. Journal of Experimental Psychology, 1963, 66, 568-571.

Butler, S. R., and Glass, A. Asymmetries in the electroencephalogram associated with cerebral dominance. Electroencephalography and Clinical Neurophysiology, 1974, 36, 481-491

Carmon, A. and Gombos, G. H. A physiological vascular correlate of hand preference: Possible implications with respect to hemispheric cerebral dominance. Neuropsychologia, 1970, 8, 119-128.

Celesia, G. G. and Jasper, H. H. Acetylcholine released from cerebral cortex in relation to state of activation. Neurology, 1966, 16, 1053-1083.

Corsi, P. M. Human Memory and the Medial Temporal Region of the Brain. Unpublished Ph.D. Thesis, McGill University, 1972.

DeRenzi, E., Faglioni, P., and Spinnler, H. The performance of patients with unilateral brain damage on face recognition tasks. Cortex, 1968, 4, 17-34.

DeRenzi, E. and Spinnler, H. Facial recognition in brain-damaged patients. Neurology, 1966a, 16, 145-152.

DeRenzi, E. and Spinnler, H. Visual recognition in patients with unilateral cerebral disease. Journal of Nervous and Mental Disease, 1966b, 142, 515-525.

DiChiro, G. Venous patterns of cerebral dominance. New England Journal of Medicine, 1972, 287, 933-934.

Dorff, J. E., Mirsky, A. F., and Mishkin, M. Effects of unilateral temporal lobe removals in man on tachistoscopic recognition in the left and right visual fields. Neuropsychologia, 1965, 3, 39-51.

Doyle, J. C., Ornstein, R., and Galin, D. Lateral specialization of cognitive mode: II. EEG frequency analysis. Psychophysiology, 1974, 11, 567-578.

Drachman, D. A. Memory and cognitive function in man: Does the cholinergic system have a specific role? Neurology, 1977, 27, 783-790.

Dumas, R. and Morgan, A. EEG asymmetry as a function of occupation, task, and task difficulty. Neuropsychologia, 1975, 13, 219-228.

Ellis, H. D. and Young, A. W. Age of acquisition and recognition of nouns presented in the left and right visual fields: A failed hypothesis. Neuropsychologia, in press.

Ford, M. R. Biofeedback Training of 40 Hz EEG in Humans; Follow-Up on Control, Generalization of Effect, and Maintenance of Control During Problem Solving. Unpublished Master's Thesis, University of Houston, 1976.

Galin, D. and Ornstein, R. Lateral specialization of cognitive mode: An EEG study. Psychophysiology, 1972, 9, 412-418.

Geschwind, N. The anatomical basis of hemispheric differentiation. In S. J. Dimond and J. G. Beaumont (Eds.) Hemisphere Function in the Human Brain. New York: Halstead Press, 1974.

Geschwind, N. and Levitsky, W. Human brain: Left-right asymmetries in temporal speech region. Science, 1968, 161, 186-187.

Giannitrapani, D. Attenuation of the EEG in left and right preference subjects. Proceedings of the 74th Annual Convention of the American Psychological Association, 1966, 1, 127-128.

Gruber, E. C. (Ed.), How To Pass High On The Graduate Record Examination. New York: ARCO, 1965.

Hayashi, T. and Bryden, M. P. Ocular dominance and perceptual asymmetry. Perceptual and Motor Skills, 1967, 25, 605-612.

Hilliard, R. D. Hemispheric laterality effects on a facial recognition task in normal subjects. Cortex, 1973, 9, 246-258.

Hix, L. B. 20 And 40 C/Sec Power Function in the Visual, Motor, and Auditory Corticies of the Cat During Three Levels of Performance in a Successive Visual Discrimination Task. Unpublished Master's Thesis, University of Houston, 1969.

Hix, L. B. 40 Hz. Power Functions in MBI and Normal Children During Performance of Behavioral Tasks. Unpublished Doctoral Dissertation, University of Houston, 1971.

Hubel, D. H. and Wiesel, T. N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. Journal of Physiology (London), 1962, 160, 106-154.

Jasper, H. H. Report of The Committee on Methods of Clinical Examination in Electroencephalography. Appendix: The Ten Twenty Electrode System of the International Federation. Electroencephalography and Clinical Neurophysiology, 1958, 10, 371-375.

Johnson, P. A. J. A Distribution of 40 Hz. EEG Activity in Normal Children. Unpublished Master's Thesis, University of Houston, 1975.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 1961a, 15, 166-171.

Kimura, D. Some effects of temporal-lobe damage on auditory perception. Canadian Journal of Psychology, 1961b, 15, 156-165.

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-358.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1966, 4, 275-285.

Kimura, D. Functional asymmetry of the brain in dichotic listening. Cortex, 1967, 3, 163-178.

Kinsbourne, M. The cerebral basis of lateral asymmetrics in attention. Acta Psychologica, 1970, 33, 193-201.

Laxton, G. Unpublished Doctoral Dissertation, University of Houston, 1976.

LeMay, M. and Culebras, A. Human brain: Morphological differences in the hemispheres demonstrated by carotid arteriography. New England Journal of Medicine, 1972, 287, 168-170.

Levy, J. Psychobiological implications of bilateral asymmetry. In S. J. Dimond and J. G. Beaumont (Eds.), Hemisphere Function in the Human Brain. New York: Halstead Press, 1974.

Luria, A. R. The Working Brain: An Introduction to Neuropsychology. New York: Basic Books, Inc., 1973.

Mangan, G. L. Recognition in the dominant and non-dominant visual fields. Perceptual and Motor Skills, 1963, 17, 558.

McLeod, S. S. and Peacock, L. J. Task related EEG asymmetry: Effects of age and ability. Psychophysiology, 1977, 14, 308-311.

McRae, D., Branch, P., and Milner, B. The occipital horns and cerebral dominance. Neurology, 1968, 18, 95-98.

Metzler, J. and Shepard, R. N. Transformational studies of the internal representation of three-dimensional objects. In Solso, R. L. (Ed.) Theories In Cognitive Psychology: The Loyola Symposium. New York: The Halsted Press, 1974.

Milner, B. Hemispheric specialization: scope and limits. In Schmitt, F. O., and Worden, F. G. (Eds.) The Neurosciences: Third Study Program. Cambridge Massachusetts: The MIT Press, 1974.

Mishkin, M. and Forgays, D. G. Word recognition as a function of retinal locus. Journal of Experimental Psychology, 1952, 43, 43-48.

Morgan, A. H., Macdonald, H., and Hilgard, E. R. EEG alpha: Lateral asymmetry related to task, and hypnotizability. Psychophysiology, 1974, 11, 275-282.

Mountcastle, V. B. Duality of function in the somatic afferent system. In M. A. Brazier (Ed.), Brain and Behavior, Vol. 1. Washington, D. C.: American Institute of Biological Sciences, 1961.

Newton, F. A. Biofeedback Training of 40 Hz EEG Activity in Humans: Relations To Cognitive Performance, Voluntary Control, Subjective States and Autonomic Activity. Unpublished Doctoral Dissertation, University of Houston, 1975.

Osman-Hill, W. C. Comparative Anatomy and Taxonomy, Primates (6 Vols.). Edinburgh, Scotland: Edinburgh University Press, 1953.

Perez-Borja, C., Bickford, R. G., Tyce, F. A. and McDonald, C. Depth electrographic studies of a focal fast response to sensory stimulation in the human. Electroencephalography and Clinical Neurophysiology, 1961(a), 13, 148.

Perez-Borja, C., Tyce, F. A., McDonald, C. and Uihlein, A. Depth electrographic studies of a focal fast response to sensory stimulation in the human. Electroencephalography and Clinical Neurophysiology, 1961(b), 13, 695-702.

Peters, J. F. Frequency analysis of the human electroencephalogram during the performance of a discrimination task. Unpublished Master's Thesis, University of Houston, 1970.

Rall, W. and Shepherd, G. W. Theoretical construction of field potentials and dendrodendritic synaptic interactions in the olfactory bulb. Journal of Neurophysiology, 1968, 31, 884-915.

Riklan, M. and Levita, E. Laterality of subcortical involvement and psychological functions. Psychological Bulletin, 1965, 64.

Sakhialina, G. R. and Mukhamedova, Ye. A. Changes in the electroencephalogram of man in the process of motor habit formation. Pavlov Journal of Higher Nervous Activity, 1958, 8, 459-466.

Semmes, J. Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Shankweiler, D. Effects of temporal lobe damage on perception of dichotically presented melodies. Journal of Comparative and Physiological Psychology, 1966, 62, 115-119.

Sheer, D. E. Electrophysiological correlates of memory consolidation. In G. Ungar (Ed.), Molecular Mechanisms in Memory and Learning. New York: Plenum Press, 1970.

Sheer, D. E. Neurobiology of Memory Storage Processes. Winter Conference on Brain Research, Vail, Colorado, 1972.

Sheer, D. E. Biofeedback training of 40 Hz EEG activity and behavior. In N. Burch and H. Altschuler (Eds.), Behavior and Brain Electrical Activity. New York: Plenum Press, 1975.

Sheer, D. E. Focused arousal and 40 Hz EEG. In R. M. Knight and D. J. Bakker (Eds.), The Neuropsychology of Learning Disorders. Baltimore: University Park Press, 1976.

Sheer, D. E. and Grandstaff, N. Computer analysis of electrical activity in the brain and its relation to behavior. In H. Wycis (Ed.), Topical Problems in Psychiatry and Neurology, Basel/New York: Karger Press, 1970.

Shepherd, G. W. The olfactory bulb as a sample cortical system: Experimental analysis and function and implications. In F. P. Schmidt (Ed.), The Neurosciences Second Study Program. New York: Rockefeller Press, 1970.

Wada, J. Interhemispheric sharing and shift of cerebral speech function. Paper presented at The 9th International Congress of Neurology, New York, September, 1969.

Warrington, E. K. and James, M. An experimental investigation of facial recognition in patients with unilateral cerebral lesions. Cortex, 1967, 3, 317-326.

White, M. J. Laterality differences in perception: A review. Psychological Bulletin, 1969, 72, 387-405.

Whitfield, J. C. "Edges" in auditory information processing. In 23rd International Congress of Physiological Sciences. Amsterdam: Excerpta Medica Foundation, 1965.

Witelson, S. and Pallie, A. Left hemisphere specialization for language in the newborn. Brain, 1973, 96, 641-646.

Young, A. W. and Ellis, H. D. An experimental investigation of developmental differences in ability to recognize faces presented to the left and right cerebral hemispheres. Neuropsychologia, 1976, 14, 495-498.

APPENDIX A

Modified Form Of The Harris Tests

Of Lateral Dominance

1. <u>Knowledge of left and right</u>

R hand _______ L ear _______ R eye _______

HAND DOMINANCE

2. <u>Hand preferences</u>

1. Throw a ball _______
2. Wind a watch _______
3. Hammer a nail _______
4. Brush teeth _______
5. Comb hair _______
6. Turn door knob _______
7. Hold eraser _______
8. Use scissors _______
9. Cut with knife _______
10. Write _______

3. <u>Simultaneous writing</u>

No. of reversals: R _______ L _______

Co-ordination better: R _______ L _______

4. <u>Handwriting</u>

Co-ordination better: R _______ L _______

EYE DOMINANCE

5. <u>Monocular tests</u>

1. Kaleidoscope _______
2. Telescope _______
3. Sight rifle _______

 Eye _______

 Shoulder _______

5. <u>Binocular tests</u>

1. Holes _______ _______ _______

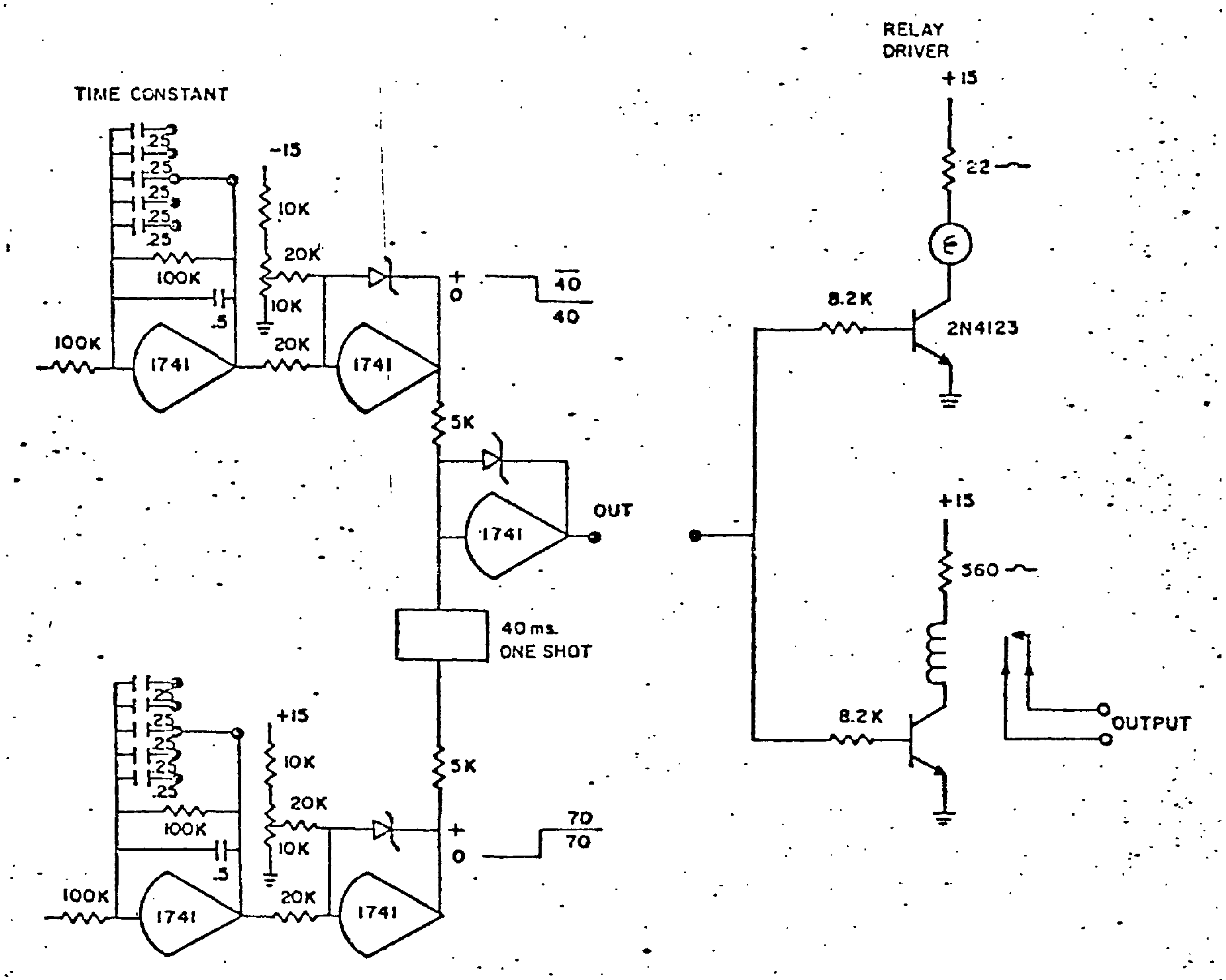
FOOT DOMINANCE

6. <u>Kick</u>: Prefered _______ Better _______

7. <u>Stamp</u>: Foot used _______

APPENDIX B

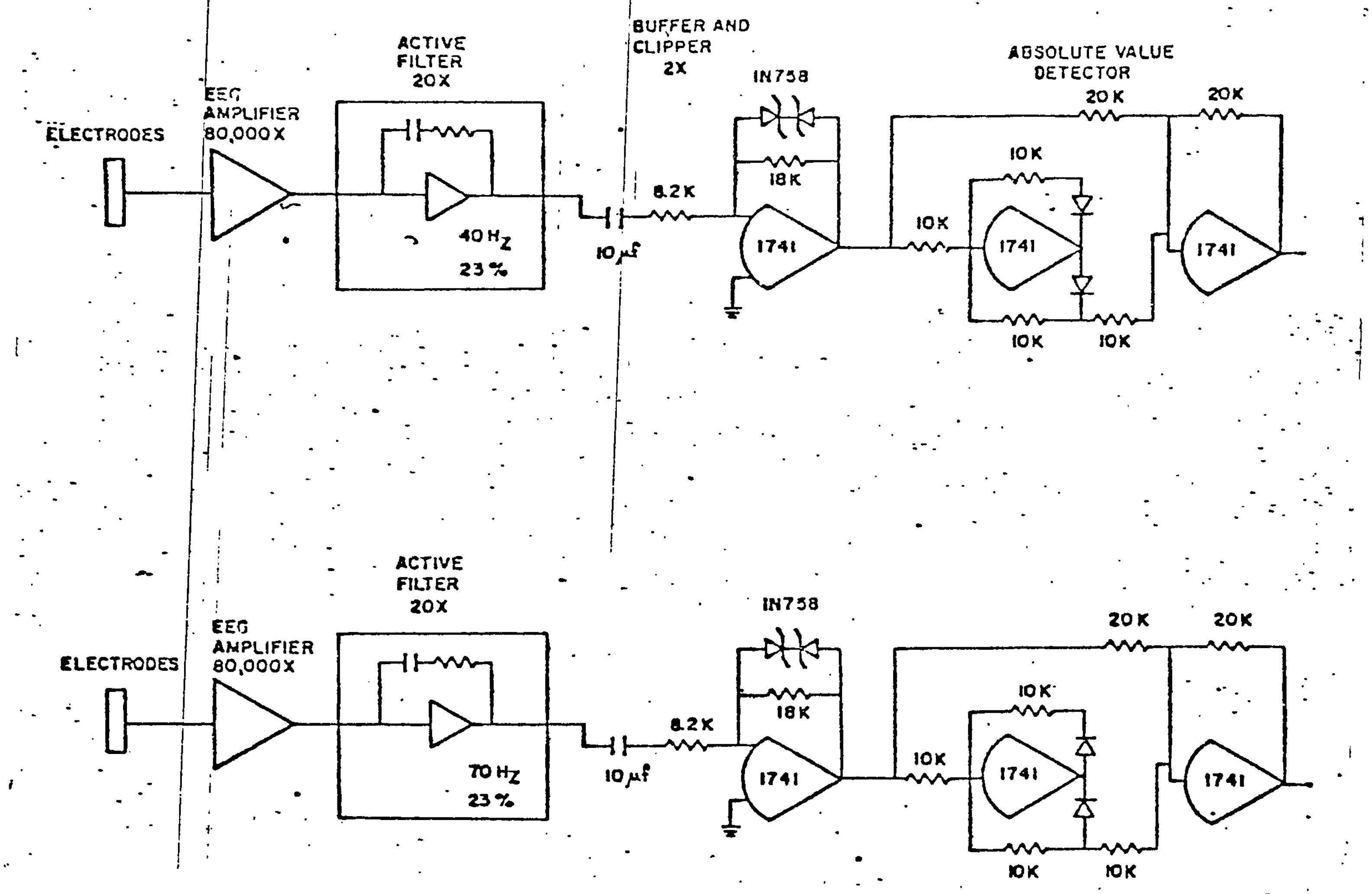
FILTER CIRCUIT



TIME CONSTANT
.25
.25
.25
.25
.25
.25
100K
.5
100K
1741
-15
10K
20K
10K
20K
1741
+
0
40
40
5K
1741
OUT
40 ms.
ONE SHOT
100K
.5
100K
1741
+15
10K
20K
10K
20K
1741
5K
+
0
70
70
RELAY
DRIVER
+15
22 ~
8.2K
2N4123
+15
560 ~
8.2K
OUTPUT

APPENDIX C

COMPARATOR CIRCUIT


ELECTRODES
EEG
AMPLIFIER
80,000X
ACTIVE
FILTER
20X
40 Hz
23 %
10 μf
BUFFER AND
CLIPPER
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IN758
18K
8.2K
1741
ABSOLUTE VALUE
DETECTOR
20K
20K
10K
10K
1741
10K
10K
1741
ELECTRODES
EEG
AMPLIFIER
80,000X
ACTIVE
FILTER
20X
70 Hz
23 %
10 μf
IN758
18K
8.2K
1741
20K
20K
10K
10K
1741
10K
10K
1741

APPENDIX D

TEST ITEMS AND ANSWERS

MATHEMATICAL PROBLEMS

Sample Item:

The distance from City A to City B is 150 miles; from City A to City C, 90 miles. Therefore it is necessarily true that:

(A) The distance from B to C is 60 miles.

(B) Six times the distance from A to B equals 10 times the distance from A to C.

(C) The distance from B to C is 240 miles.

(D) The distance from A to B exceeds by 30 miles twice the distance from A to C.

Test Items:

1. In the two fractions $\frac{a}{b}$ and $\frac{c}{d}$, b is twice as large as d, whereas a and c are the same. The two fractions will be equal in value if:

(A) a is multiplied by 2.

(B) a is divided by 2.

(C) c is multiplied by 2.

(D) d is divided by 2.

(E) a and c are both multiplied by 2.

2. If Paul can paint a fence in 2 hours and Fred can paint the same fence in 3 hours, Paul and Fred working together can paint the fence in:

(A) 2.5 hours.

(B) 1.2 hours.

(C) 5 hours.

(D) 1 hour.

3. If the result of squaring a number is less than the number, the number is:

   (A) Negative and greater than -1.

   (B) Negative and less than -1.

   (C) A positive fraction greater than 1.

   (D) Positive and less than 1.

4. When a shipment of light bulbs was received, it was found that bulbs out of the total of bulbs were broken. Which of the following expressions indicates the percentage of the bulbs that were <u>not</u> broken?

   (A) $\frac{100\ (\quad -k)}{k}$

   (B) $\frac{100\quad -k}{k}$

   (C) $\underline{100\ (\quad -k)}$

   (D) $\underline{100\ k\quad -k}$

   (E) $\frac{100\ (\quad -k)}{+\ k}$

5. It is proposed that a state income tax be set at a rate of X on the first A dollars of income and a rate of Y on the additional B dollars of income. A fixed allowance of K dollars is to be deducted from this estimated tax for each dependent to obtain the net amount due. If d is the number of dependents, the net amount due can be expressed as:

   (A) $XA + YB + Kd$

   (B) $X\ (A-Kd) + (B-Kd)$

   (C) $XA + YB - Yd$

   (D) $XY\ (A + B) - Kd$

   (E) $X\ (A + B) + Y\ (A + B) - Kd$

6. A is 15 years old. Be is one third older. The number of years ago when B was twice as old as A is:

(A) 3

(B) 5

(C) 7.5

(D) 10

VERBAL ANALOGIES

Sample:

Frame : Picture::

(A) Cup : Saucer
(B) Table : Floor
(C) Radio : Sound
(D) Cover : Book

Test Items:

Adversity : Happiness::

1. (A) Fear : Misfortune
(B) Solace : Adversity
(C) Vehemence : Serenity
(D) Troublesome : Petulance
(E) Graduation : Felicitation

2. Debate : Soliloquy::
(A) Crowd : Mob
(B) Hamlet : Macbeth
(C) Lincoln : Douglas
(D) Group : Hermit

3. Cat : Feline::
(A) Horse : Equine
(B) Tiger : Carnivorous
(C) Bird : Vulpine
(D) Chair : Furniture
(E) Sit : Recline

4. Clouds : Rain::
(A) Wind : Hurricane
(B) Thunder : Lightning
(C) Water : H_2O
(D) Sky : Universe

5. 20 : 21::
(A) 5 : 10
(B) A : B
(C) 10 : 9
(D) S : V

6. Corrugated : Striped::
(A) Box : Zebra
(B) Paint : Crayon
(C) Roughness : Smoothness
(D) Pit : Dot

FACIAL RECOGNITION ITEMS

Samples:

1.

2.

Test Items:

1.

2.

3.

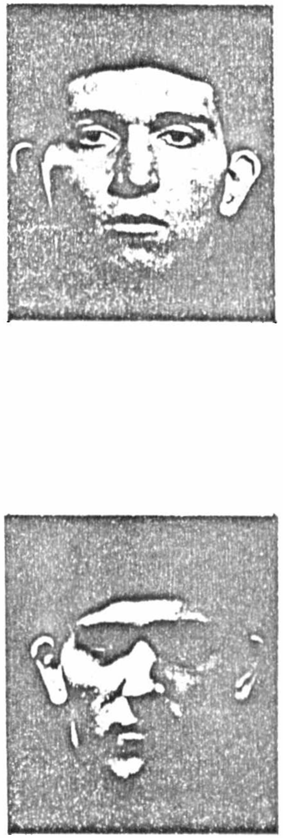
4.

5.

6.

7.

8.



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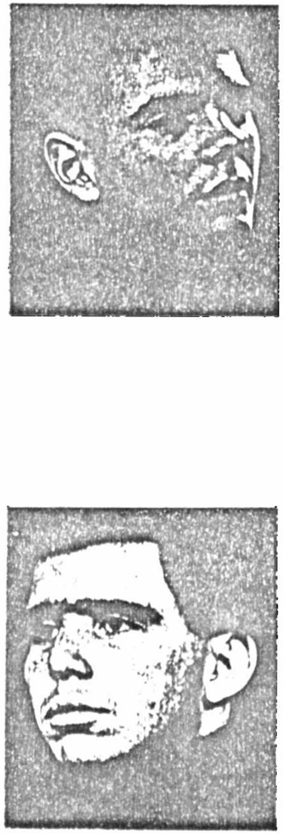

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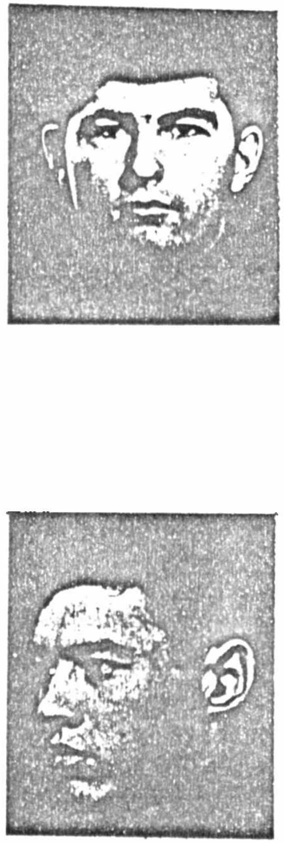

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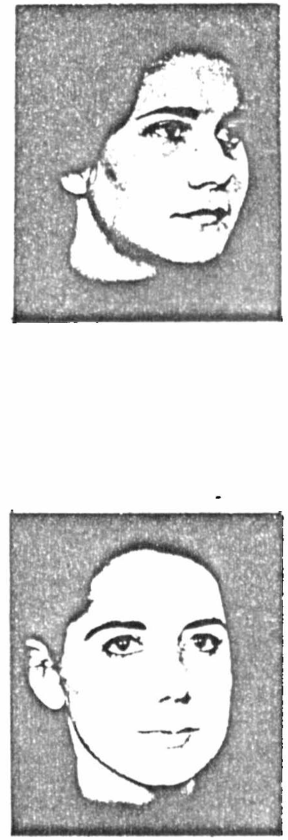
12.



13.

14.

15.

16.

17.

18.

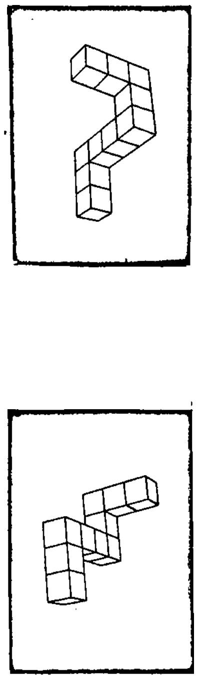
19.

20.

GEOMETRIC FIGURE RECOGNITION ITEMS

Samples:

1.



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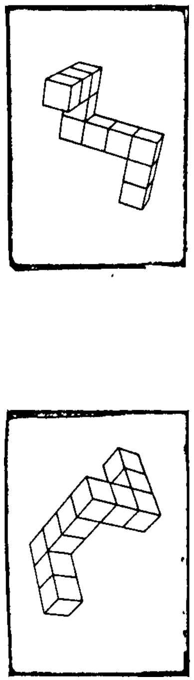

Test Items:

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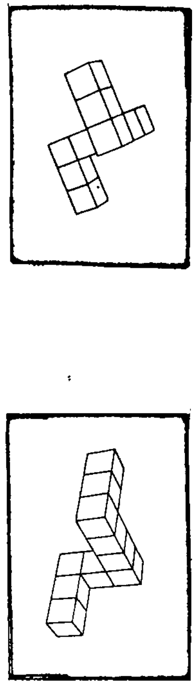

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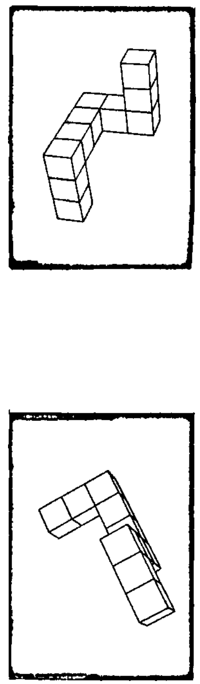

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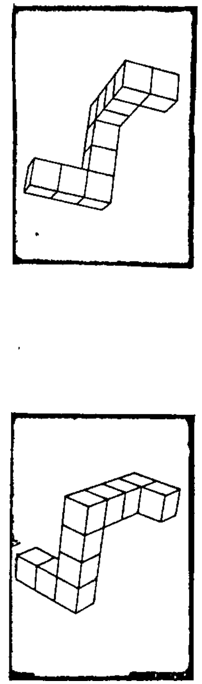

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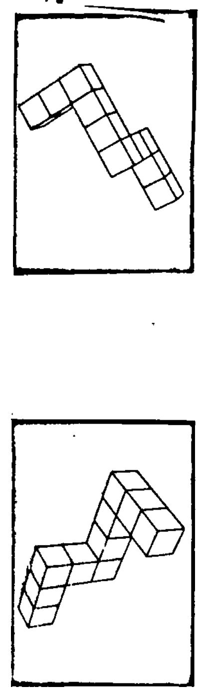

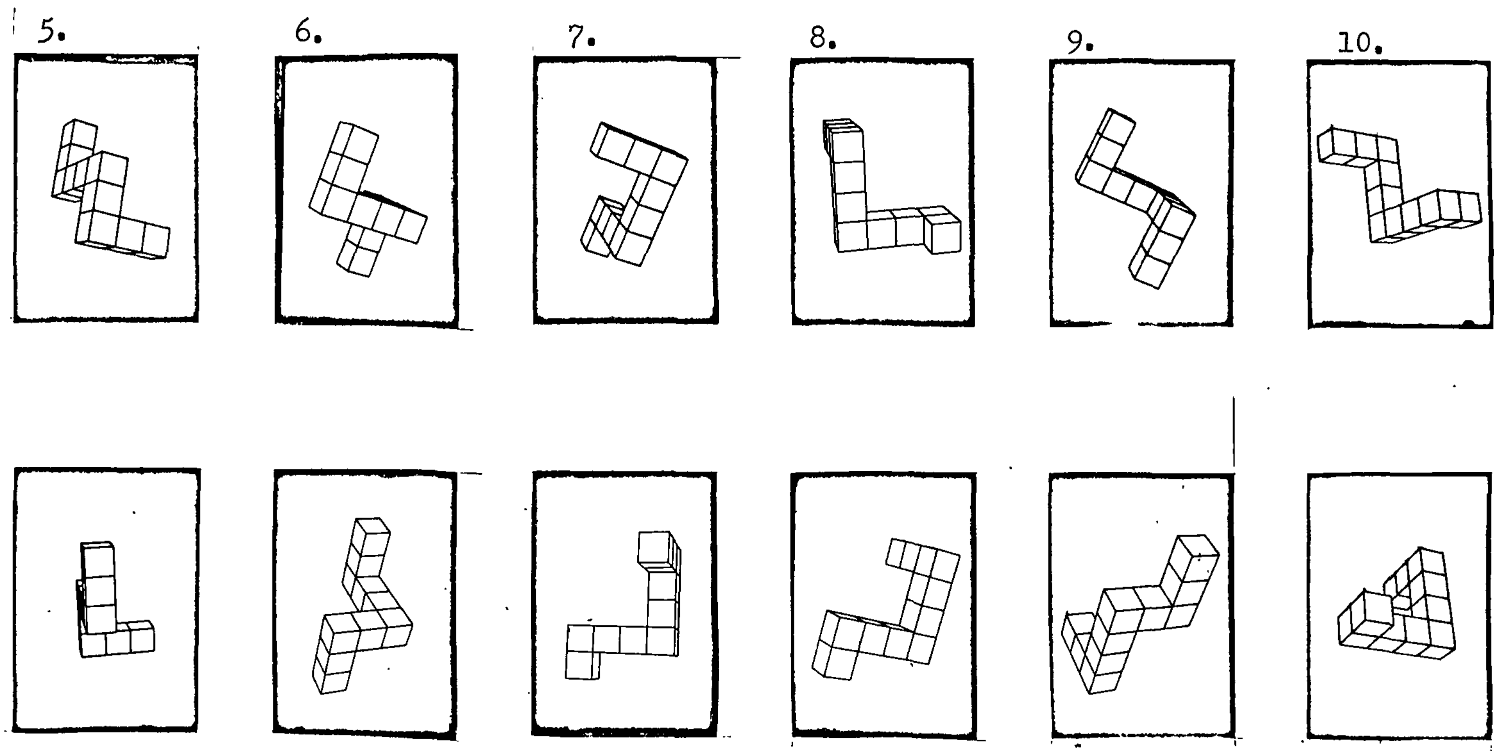
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6.
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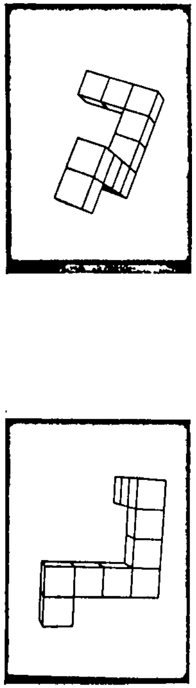
8.
9.
10.

11.



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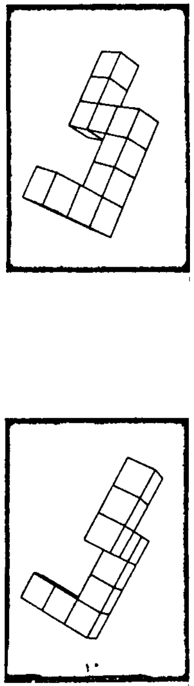

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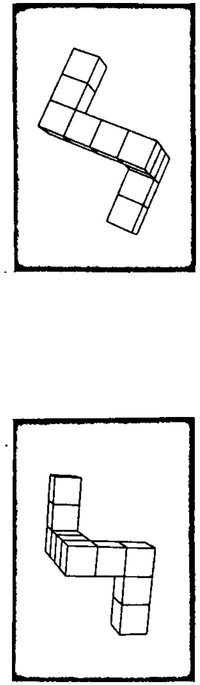

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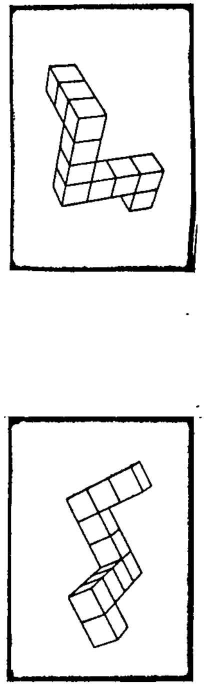

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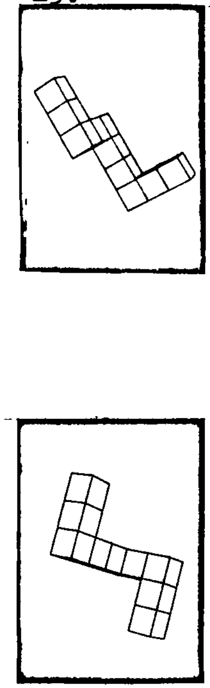

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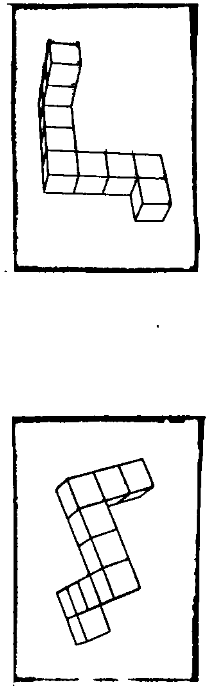

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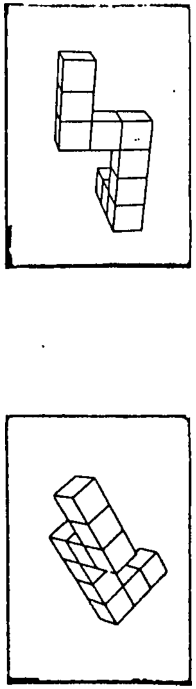

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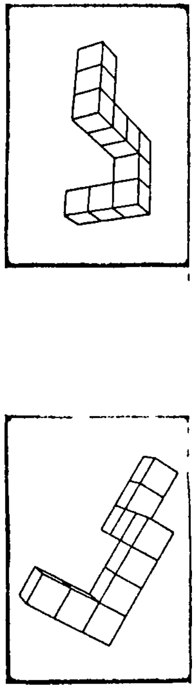

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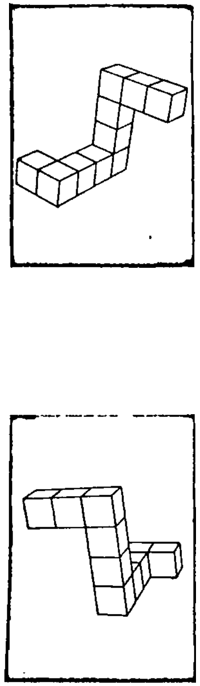

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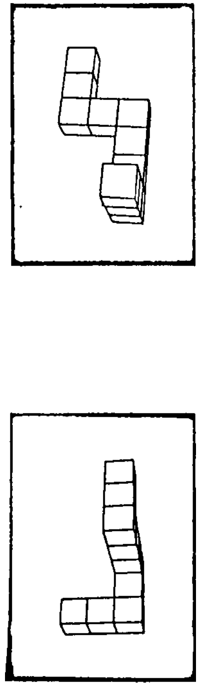

ANSWERS

Mathematical Problems:

1.	(A)	4.	(C)
2.	(B)	5.	(C)
3.	(D)	6.	(D)

Verbal Analogies:

1.	(C)	4.	(A)
2.	(D)	5.	(B)
3.	(A)	6.	(D)

Facial Recognition:

1.	Same	8.	Same	15.	Same
2.	Different	9.	Different	16.	Different
3.	Same	10.	Different	17.	Different
4.	Different	11.	Same	18.	Same
5.	Same	12.	Different	19.	Different
6.	Same	13.	Different	20.	Same
7.	Different	14.	Same		

Geometric Figure Recognition:

1.	Same	8.	Different	15.	Different
2.	Different	9.	Different	16.	Same
3.	Different	10.	Same	17.	Different
4.	Same	11.	Same	18.	Different
5.	Different	12.	Different	19.	Same
6.	Same	13.	Same	20.	Different
7.	Same	14.	Same		