THE UNIVERSITY OF MANITOBA

AN INVESTIGATION OF THE PROPOSED RELATIONSHIP BETWEEN PUPILLARY ACTIVITY AND EEG OCCIPITAL ALPHA PRODUCTION ACROSS LEVELS OF ILLUMINATION, COGNITIVE TASK DIFFICULTY, AND ALPHA AND PUPIL BIOFEEDBACK

by

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Abstract

The purpose of the present research was to investigate an oculomotor hypothesis that oculomotor activity, as reflected by the pupillary response, would serve to attenuate EEG occipital alpha production. The proposed relationship between the occipital alpha rhythm and the pupillary response was investigated under four conditions . The study was a completely within-subjects design in which each of the 20 female subjects attended two experimental sessions and served in each of the four conditions ; illumination, cognitive task, alpha biofeedback, and pupil biofeedback. The illumination condition consisted of a 4x3x10 within-subjects design with four transitions of illumination (7-0, 0-15, 15-0, and 0-7 millilamberts), three trials at each level, and 10 sequential measures of each dependent variable. The cognitive condition consisted of three levels of difficulty on a digit transformation task (Add 0, Add 1, and Add 3), three trials at each level, and six measures of loading-unloading within each trial. Both the alpha and pupil biofeedback conditions were 2x3x4 designs with two training sessions (increase and decrease), three trials within each session, and four sequential measures of each dependent variable within each trial. In each condition,

level of alpha activity (percent alpha) and pupil activity (pupil size and variability) served as the dependent variables. On the basis of the oculomotor activation theory it was suggested that pupillary activity of any sort (constriction or dilation) would attenuate alpha activity such that alpha would be prominent in the absence of pupillary activity and attenuated in its presence.

On the basis of the present experiments it was concluded that the results did not conclusively support the oculomotor theory and the predicted relationships between alpha and pupillary activity. Product-moment correlations between alpha production and pupil variability were, for the most part, insignificant. On the other hand there were some more indirect indications of support for a possible relationship between alpha and pupil activity: 1. Baseline ANOVA's revealed that eyes-closed alpha production was always greater than eyes-open production. Consequently alpha production was prominent under conditions of reduced oculomotor processing (e.g. reduced pupillary activity). 2. In the illumination condition greater alpha attenuation occured during the dark versus light conditions in contrast to the almost universal finding that alpha production is greater during dark than light conditions. The greatest pupillary activity (change in pupil size across epochs) also occured under the dark condition. 3. In the cognitive experiment, all of the digit transformation tasks resulted

in increases in pupillary activity and attenuation of alpha activity (compared to baselines). 4. There were no differences in pupil variability or alpha production in increase versus decrease sessions of alpha biofeedback when the availability of oculomotor strategies was limited. 5. The correlations between alpha density and pupil variability (cognitive, alpha and pupil biofeedback conditions), and between alpha density and pupil size (illumination, cognitive and pupil biofeedback conditions) were consistently found to be greater than would be accounted for by chance expectancies. In view of such indirect evidence (in the literature and present study) it was suggested that the oculomotor theory of alpha-pupillary relations may remain viable particularly when considering the insensitivity of the percent-alpha measurement. Largely as a result of the insensitivity and failure of this measure to reflect momentary shifts in activation by way of amplitude changes (in addition to shifts out of the alpha frequency range), it was concluded that the pupil was more sensitive to minute changes in activation than the percent- time alpha measure. Consequently, it was suggested that the present study was not able to provide an adequate assessment of the oculomotor theory of alpha-pupillary relations. Implications and suggestions for future research were discussed.

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Chapter I

INTRODUCTION

Electroencephalography (EEG) and Pupillometry

One of the most obvious conclusions that can be drawn from a review of the EEG and pupillometric literature is that reseach relating the two areas has been minimal. This is especially surprising in view of the fact that both the EEG and pupillary response have been used as physiological indicants of arousal, excitation, and activation. It becomes even more curious when one considers that both the EEG alpha rhythm and the pupillary response are intimately related to the visual system. As Janisse (1977) has stated, however, the lack of studies relating the pupillary response to other physiological measures may be a function of the relatively recent interest in pupillometry. Similarly for the EEG, despite the fact that it was first discovered by Caton in 1875 (Shagass, 1972) and distinguished in man in 1929 by Hans Berger, there has been relatively little research on normal EEG functioning. A recent surge of interest and research on EEG measures in normal subjects began in the 1960's and has been primarily focused upon EEG biofeedback.

It is the purpose of the present paper to examine the possible relationships between the EEG alpha rhythm and the pupillary response. Before addressing such relationships directly, it is first necessary to examine the EEG alpha rhythm and alpha biofeedback, and then establish the connections between alpha and the visual system. Such an extensive review is necessitated by the fact that the link between the alpha rhythm and visual processes is not as well understood as the link between the pupillary response and visual processes. Once such a connection is established it becomes feasible to explore the possible relationships between the alpha rhythm and the pupillary response.

The EEG Alpha Rhythm

The EEG is simply a record of the electrical activity of the brain. In its typical form for medical purposes it consists of a recording from eight or more electrodes or electrode pairs attached to the scalp according to a stardardized configuration known as the 10-20 system (Jasper, 1958). For most EEG biofeedback research however, it has been more common to use one or two electrode pairs.

Research into the intrinsic rhythms of the human brain (e.g., delta, theta, alpha, beta, 40 Hz, and sensorimotor rhythms) has most particularly focused on the investigation of alpha activity. Alpha has been defined by the Terminology Committee of the International Federation for Electroencephalography and Clinical Neurophysiology as a "rhythm,

usually with a frequency of 8-13 c/sec. in adults, most prominent in the posterior areas, present most markedly when eyes are closed and attenuated during attention, especially visual" (van Leeuwen, Bickford, Brazier, Cobb, Dondey, Gastaut, Bloor, Henry, Hess, Knott, Kugler, Lairy, Loeb, Magnus, Daurelly, Petsche, Schwab, Walter & Widen, 1966, p. 306). One of the most characteristic features of the EEG is that its pattern is not constant, but rather alternating between alpha and little or no alpha (Cobb, 1963; Davis & Davis, 1939; Hawkes & Prescott, 1973; Lynch & Paskewitz, 1971; Mulholland, 1971, 1972; Peper, 1973, 1974). In spite of this fact, the alpha activity for any given individual remains relatively stable over successive measures taken under uniform conditions (Amochaev & Salamy, 1979; Cobb, 1963; Creutzfeldt, Arnold, Becker, Langenstein, Tirsch, Whilhelm & Wuttke, 1976; Davis & Davis, 1939; Engel, Romano & Ferris, 1947; Grosveld, DeRijke & Visser, 1975; Hawkes & Prescott, 1973; Itil, Marasa, Saletu, Davis & Mucciardi, 1975; Johnson & Ulett, 1959; Lynch, Paskewitz & Orne, 1974; Matousek & Peterson, 1973; Mulholland, 1977; Paskewitz & Orne, 1974; Rubin, 1938; Van Dis, Corner, Dapper, Hanewald & Kok, 1979; Vogel, 1970).

According to one of the most generally accepted theories of the physiological generation of the alpha rhythm, Andersen and Anderson (1968) suggest that alpha represents repetitive synchronous polarization and depolarization of

groups of thalamic neurons known as pacemakers. The repetitive pattern is thought to be caused by the interneuron which polarizes the group of neurons it connects, depolarizing itself and reverses the process, and so on (Wertheim, 1974). The theory suggests that alpha activity is continuous unless there is a disturbance within the thalamic neurons (pacemakers), or the synchrony between them. There is, however, some disagreement as to the blocking of the alpha rhythm. According to one theory (e.g., Adrian & Mathews, 1934; Aranibar & Pfurtscheller, 1977; Berger, 1929) alpha blocking is caused by a disturbance at the level of the alpha generators. Wertheim (1974), however, suggests that there is evidence to imply that alpha blocking is the result of an increase in electrical activity within the occipital region, which has an overriding effect on the electrical activity of the alpha rhythm, such that alpha activity is no longer capable of being detected at the scalp. According to this theory, alpha activity would be ongoing even during periods of blocking. Wertheim notes that support for this theory comes from the work of Goldstein (1970) who found phase coherence of the alpha rhythm before and after blocking, and that of Maynard (1972) who found ongoing activity resembling alpha frequencies within fourier analyzed tracings of alpha blocking periods.

Alpha Biofeedback

As noted earlier, a great deal of the recent research and interest in the EEG is to be found in the studies of EEG biofeedback. Evidence has been accumulating in recent years to suggest that human subjects can alter their EEG activity when they are given feedback indicating the amount of activity in the frequency band (e.g., theta, delta, alpha, beta) which is to be enhanced or reduced (e.g., Beatty, 1971, 1972; Green, Green & Walters, 1969, 1970; Peper & Mulholland, 1970). In the case of alpha, the subjects are most often presented with auditory (e.g., Kamiya, 1968, 1969) or visual cues (e.g., Brown, 1970, 1971) which are indicative of the presence of alpha wave activity in their EEG. Successful alpha control has reportedly occurred in spite of the fact that visual stimuli, associated with visual feedback, has an initial suppressive effect on the presence of alpha (Kamiya, 1968; Short, 1953; Short & Walter, 1954; Slatter, 1960; Walter & Yaeger, 1956).

Also recently there has been substantial support to suggest that asymmetrical control can be achieved with the alpha rhythm by differential feedback to homologous scalp areas of the two hemispheres (Cunningham, 1978; Eberlin & Mulholland, 1976; Fehmi, 1971; Fox, 1979; Hord, Tracy & Haitch, 1974; Mayo, Targ & Hurt, 1975; Mikuriya, 1979; Nowlis & Wortz, 1973, Patterson, 1977; Peper, 1971, 1972; Ray, Frediana & Harman, 1977; Suter, Krone & Matthews,

1978). Such studies are suggestive of even more refined control.

Ever since the introduction of the possibility that subjects could learn to enhance and/or suppress the amount of their alpha activity when receiving continuous feedback, there has been considerable controversy as to what strategies are used by trainees to achieve such control. When viewed from an operant conditioning perspective, the feedback is considered to operate as a reinforcer on a continuous schedule of reinforcement (Beatty, 1971; Black, Cott & Pavloski, 1977; Hord & Barber, 1971; Kamiya, 1974, Wenrich & Letendre, 1975). Many authors (Beatty, 1961; Brolund & Schallow, 1976; Epstein & Blanchard, 1977; Fehmi, 1973; Gaardiner, 1971; Shapiro & Schwartz, 1972; Sheer, 1975), however, have noted that this assumption about feedback being reinforcing is perhaps only applicable when subjects are motivated to control their EEG patterns. Still other investigators have suggested mediational alternatives to a more direct operant formulation of alpha self-control. Accordingly it has been suggested that occipital alpha activity is mediated by a wide range of factors such as attention (e.g. Grauke, 1974; Lynch & Paskewitz, 1971; Sadler & Eason, 1977), cognitions (e.g. Lazarus, 1976; Meichenbolm, 1976), emotions (e.g. Brown 1970, 1971; Nowlis & Wenger, 1959; Wallace & Benson, 1972; Watanabe, Shapiro & Schwartz, 1972), arousal (e.g., Hardt, 1975; Hardt & Witmer, 1977; Lindsley, 1956), or oculomotor processes (e.g.,

Mulholland & Evans, 1966; Orne & Wilson, 1977, Plotkin, 1976, 1978). In a recent review of this area, Plotkin (1976) clearly emphasizes the close association which has been consistently found between alpha and visual control systems.

Alpha and the Visual System

The close association between vision and the occipital alpha rhythm has been known for quite some time (e.g., Adrian, 1943; Adrian & Matthews, 1934; Berger, 1930; Durup & Fessard, 1935). In almost all persons it has been found that alpha is significantly more prominent when their eyes are closed rather than open, and tends to block, desynchronate or attenuate upon opening of the eyes (e.g., Berger, 1930; Gale, Spratt, Chapman & Smallbone, 1975; Kamiya, 1963; Lindsley, 1960). In fact, as Dewan (1967) has pointed out in a review of the literature, many conditions such as eye closure, patternless visual fields (if the eyes are open), and the absence of ocular fixation favor the appearance of the alpha rhythm. On the other hand, he notes that such things as ocular fixation , pattern vision, concentration on mental tasks or on non-visual stimuli, or the perception of surprising, alerting or emotional stimuli favor the disappearance of alpha. Although such facts have been known since at least the 1930's (Adrian & Matthews, 1934) and have been investigated extensively, the interpretation of them has been somewhat inconsistent.

Visual Attention. Berger's (1929) original hypothesis to account for these data was that alpha activity originated from the brain and was blocked or attenuated by "attention". Adrian and Matthews (1934), however, concluded that alpha activity was generated in the occipital cortex rather than from the entire brain, and that it was blocked most effectively by visual rather than non-visual stimulation. Although they agreed that non-visual attenuation does occur, they felt that it could be best explained by desynchronizing activity spreading from other areas of the brain to the occipital lobe. Therefore, Adrian and Matthew's view of alpha attenuation restricted the "attention" hypothesis to that of visual attention and spread of effect from other areas of the brain. As will be noted, many investigators have elaborated on Adrian and Matthew's "visual attention" hypothesis.

Muscle Tremor. Jasper and Andrews (1938) and Lippold and Novotny (1970) have noted the close similarity between alpha rhythm and ocular muscle tremor. Although Jasper and Andrews originally hypothesized that the alpha rhythm was the result of the generation of muscle tremor, subsequent investigation could not establish a causal link (Lippold & Novotny, 1970). Lippold (1970a, 1970b, 1973), Lippold and Novotny (1970) and Ennever, Lippold and Novotny (1971), however, have further speculated and hypothesized that alpha is not generated in the occipital cortex but rather is a

function of the tremor of the extraocular muscles modulating the corneo-retinal potential via some kind of conductance change. The literature, they felt, supported their contention to the extent that alpha rhythm and tremor have the same frequency and wave form in individuals and they tend to occur together. Furthermore, with increasing age both tremor frequency and alpha frequency increase. They concluded that extraocular muscles (rather than other muscles), because of the intimate association between alpha rhythm and visual input, would be the most favorably placed and of sufficient size to generate large potential shifts. As further support they found that by varying the level of illumination of the eye, one can vary the corneo-retinal potential and hence the alpha rhythm amplitude. Furthermore, since a localized effect can be accomplished on one side of the head independent of the other, they argued that peripheral rather than central nervous mechanisms are involved.

Other investigators, however, have seriously questioned Lippold and Novotny's theory. For example Shaw, Foley and Blowers (1970) have presented an EEG record of an individual who has had both eyes removed. The record shows alpha activity and a clear reduction with attention. Lippold and Shaw (1971), however, have pointed out that the entire contents of the orbit had not been removed and therefore the effect of extraocular movement could not be ruled out.

Nevertheless, Abbott and Dymond (1970) and Chapman, Cavonius and Ernest (1971) have recorded normal alpha activity in subjects who had the entire orbital contents removed. Similarly Tait and Pavloski (1978) in a recent attempt to replicate Lippold and Novotny's theory, were unable to demonstrate any relationship between alpha and the magnitude of the corneo-retinal potential. In addition Cavonius and Estevez-Usonga(1974) were able to demonstrate highly localized suppression of alpha activity by stimulating a restricted part of the visual field. Less alpha activity was found over the hemisphere that was contralateral to the visual field in which they presented a patterned stimuli. They reasoned that Lippold's hypothesis could not account for their results as both eyes received the same stimulation and would have engaged in the same eye movements. Consequently, in spite of the fact that the amount of alpha activity is often reduced in the blind (Birbaumer, 1971; Kooi & Sharbrough, 1966; Noebels, Poth & Kopell, 1978; Novikova, 1973), such evidence supports the view that alpha activity is "not directly dependent on the corneo-retinal potential of the eyeball, tremor of the extraocular muscles, eye position, accommodation, or eyelid flutter" (Chapman et al., 1971, p. 1161).

Eye Position. Extreme eye position has also been examined as a means of enhancing alpha activity (Dewan, 1967; Fenwick, 1966; Fenwick & Walker, 1969; Kris, 1968; Mulholland, 1968, 1969a, 1969b, 1971; Mulholland & Evans,

1965, 1966; Mulholland & Peper, 1971). This unexpected artifact concerning the orientation of the eyes was first noted by Mulholland and Evans (1965) in the form of an increase in alpha when the eyes were placed in an extreme lateral or most notably upward position. This increase was quantitatively similar to that typically obtained through eye closure and has since been replicated by Fenwick and Walker (1969), Kris (1968), and Mulholland (1969a, 1969b). Mulholland and Evans (1965) suggested that the effect of orientation of the eyes was powerful enough to alter the probability of alpha occurence. In fact they demonstrated it to be sufficiently powerful to override such effects as pattern vision which would normally inhibit alpha activity. Furthermore, they suggested that the increase in alpha production under eyes closed conditions might be related to the accompanying upward movement of the eyes (Bell's phenomenon) rather than merely the reduction in visual stimulation.

Given that Mulholland and Evans (1965, 1966) only found the effect of eye orientation (the Mulholland effect) in 50% of the subjects tested, and given that they found it to be less reliable in some subjects than other subjects, many investigators questioned its generality. Fenwick (1966) concluded that alpha was not significantly correlated with eye positions. He admitted, however, that a few subjects did show the effect. Kamiya (1968) also investigated the

possibility that eye position might be related to alpha activity. In spite of the fact that a burst of alpha occurred when subjects raised their eyes, his subjects were able to learn to control alpha with their eyes in either an up or down position. Chapman, Shelburne, and Bragden (1970) in an extensive attempt to replicate the basic experiments of Mulholland and Evans, again found that vertical elevation of the eyes had no direct influence on EEG alpha activity. Rather, they found that the increase in alpha activity was controlled mainly by reducing visual input either by closing the eyes or turning out the lights.

On the basis of such evidence and similar findings (e.g., Brown, 1970; Budzynski, 1971; Dewan, 1967) , Nowlis and Kamiya (1970) concluded that, although the Mulholland effect was not ruled out for all subjects, it does not seem to be widespread or characteristic of all subjects. Mulholland (1969a) admits to this later statement and more recently (1972) has explained this phenomenon as a loss of stability of visual control processes (e.g., accommodation, fixation, pursuit tracking) which occurs at extreme eye positions.

Oculomotor Processes. Similarly, Dewan (1967) found that when he served as a subject, mere elevation of the eyes did not result in an increase of alpha activity if he also focused and converged his eyes while in that position. Subsequently, he hypothesized that the increase in alpha production may be caused by a tendency of the eyes to

defocus and relax convergence when in the extreme upward position. Therefore, he suggested that accommodation, fixation and convergence had to be avoided in order to prevent the blocking response. Such a hypothesis, he noted, was supported by earlier observations that the presence of alpha is accompanied by the absence of accommodation (e.g., Adrian, 1943; Adrian & Matthews, 1934; Oswald, 1959).

Other investigators have also pointed out the close relationship between accommodation and alpha activity. Plotkin (1976a), for example, in reference to some unpublished research by Pollen (1970) emphasizes the importance of this role. Reportedly, Pollen, by inactivating the accommodation system with a drug and setting up an artificial lens system, found that his subject was able to produce alpha while reading text. Normally such an activity would block alpha. The subject did not have to accomodate as the image was always in focus. Dewan (1967) however, reported that when he used cyclomydril (a drug causing pupil dilation and preventing accommodation) there was no effect on the ability of one of his subjects to control alpha. As a result, it would seem that other factors may also be involved in alpha blocking (Plotkin, 1976a). In fact, the relationship between oculomotor processing and the production of alpha has been the focus of many research reports.

Mulholland (1968) hypothesized that at least three oculomotor processes were involved in alpha blocking; lens accommodation, convergence, and pursuit tracking. He

suggested that when any one or more of these processes were active, alpha suppression would occur. With this in mind he designed a study in which his subjects were exposed to either a stationary or moving target and were instructed to either track the target with focused accommodation, or track the target with relaxed accommodation (blur tracking), or not to track the target under conditions of relaxed accommodation (blur no-tracking). The results of his study indicated that the greatest production of alpha occurred under blur no-tracking conditions, and the greatest blocking occurred under focused tracking conditions.

Similarly, the results of a series of studies by Peper (1970) revealed that whenever his subjects initiated tracking (involving accommodation, convergence, and pursuit tracking) their occipital alpha desynchronized. He concluded that the attention hypothesis suggesting alpha blocking is due to attention to stimuli, is inadequate. Rather, he suggested that the electrical activity which blocks alpha is the neural efferent activity involved in oculomotor activation. As Wertheim (1974) points out, support for this suggestion comes from reports of negative correlations between alpha activity and electromyographic (EMG) activity (e.g., Kreitman Shaw, 1965; Marshall & Bentler, 1975), on reports that alpha is blocked by motor efferents (e.g., Chatrian, Magnus, Petersen & Lazarte, 1959; Jasper & Penfield, 1949), and on a report of alpha blocking

during attempts to move amputated limbs (Glass & Beckford, 1957).

In a more recent study designed to determine whether alpha suppression is best accounted for by afferent visual input or efferent oculomotor influences, Goodman (1976) had his subjects orient to an auditory stimulus in the dark by changing their eye positions. As visual input was removed by darkness, his results indicated that alpha suppression occurred as a result of oculomotor activity alone. Following Goodman (1976), Bunnell and Monuk (1978) designed a study to examine the effects of deliberate eye movement and suppression of eye movement on alpha activity. They hypothesized that alpha suppression would occur under both conditions since both eye movement and suppression of eye movement would be achieved through active oculomotor processes. They concluded on the basis of their data that oculomotor activity in the absence of visual input is sufficient to effect alpha suppression. Alpha blocking was found under both instructed eye movement and eye movement suppression.

In another series of experiments reported by Dewan and Mulholland (1969), Mulholland (1969c), and Mulholland and Peper (1971), EEG alpha recordings were again taken while the subjects performed various fixation, accommodation and tracking maneuvers with both stationary and moving targets. Again it was found that alpha was clearly related to changes in the visual control system, with pursuit tracking,

convergence, and lens accommodation reliably blocking the alpha rhythm. They also noted that the relationship between EEG and visual control processes are necessarily general and not specific because of the gross nature of both EEG and visual system recordings. Furthermore, Mulholland and Peper (1971) concluded that the close relationship between the alpha rhythm and visual control systems

> . . . is hardly a surprise, since these processes are occurring in the same regions of cortex from which the occipital or parietal-occipital EEG is derived. The changes in the EEG previously attributed to "visual attention" can be explained in terms of changes occurring in cortical regions that are important for visual control processes. The reported decreases of alpha attributable to "visual imagery" and the blocking of alpha in response to auditory stimulation can be interpreted in terms of the visual orienting processes that are associated with imagery and audition (Mulholland, 1968, 1969). Zickmund (1969) has shown that an auditory stimulus presented in darkness is followed by a series of eye movements. (pp 569-570)

Mulholland (1972) and Mulholland and Peper (1971) emphasize that the oculomotor system has extensive representation in brain regions 17, 18 and 19, which include the parietal and occipital cortex (Robinson, 1968) from which the alpha wave is most often recorded. There is even some evidence to suggest that those oculomotor processes not involving areas 17, 18 and 19 (e.g., saccadic eye movements) do not have an observable effect on occipital EEG (Robinson, 1968).

Similar to Dewan (1967), Mulholland and Peper (1971) also interpreted the facilitation of EEG alpha rhythms by extreme ocular deviations in terms of their theory of oculomotor

activity. They felt that any deviation greater than 30-40 degrees resulted (at least in some subjects) in a loss of fixation and relaxation of accommodation and consequently an increase in alpha. For smaller deviations, they suggested that fixation and accommodation would still be possible. Therefore the facilitation of alpha need not occur.

According to the oculomotor theory, occipital alpha should appear in the absence of oculomotor activity (e.g., accommodation, convergence, pursuit tracking, eye movements) even in the presence of visual attention. During oculomotor activity on the other hand, alpha should be blocked. A study by Lehtonen and Lehtinen (1972) provides additional support for this hypothesis. They further tested the effects of ocular fixation and visual attention on alpha production. Consistent with the oculomotor theory, they found that when their subjects were given the opportunity for fixation, the alpha rhythm was blocked. If, however, their subjects did not fixate on the target, the rhythm was present. In addition they found that the presentation of a uniform visual field before open eyes increased the amount of alpha activity. With a uniform visual field, alpha was abundant even when subjects counted light flashes with their eyes open. In fact, the amount of alpha present in the EEG in the uniform visual field condition approched that found in the eyes-closed condition. Lehtonen and Lehtinen suggested that the enhancing effect they and others (e.g.,

Adrian & Matthews, 1934; Dewan, 1967; Reiman, Korth & Kiedel, 1974) had found for a diffuse visual field and eye closure, can be regarded as a result of there being no opportunity for fixation. Although the use of a ganzfeld instead of a uniform visual field (white paper) did not yield such consistent results in this and another study (Bunnell & Manuck, 1978), Wertheim (1974) suggested that the inconsistency could be explained as due to oculomotor activity related to an attempt to prevent blacking out of vision which is often reported to occur in the ganzfeld.

In summary then there is substantial evidence to support the theory that blocking of alpha occurs during oculomotor activity. Furthermore, evidence presented by Mulholland and Peper (1971) suggest that the magnitude of the blocking response may be contingent on the amount of oculomotor activity. As will be noted, there is a considerable amount of evidence to support the contention that alpha activity could be regulated by brain mechanisms intrinsic to cortical visual systems (Beatty, 1977a). In fact, this hypothesis can even explain some of the non-visual data.

As Mulholland and Peper (1971) have pointed out, the reported decreases of alpha attributable to visual imagery (e.g., Antrobus, Antrobus & Singer, 1964; Elguin-Body, 1977; Furst, Gardiner & Kamiya, 1974; Kamiya, 1969; Short, 1953; Slatter, 1960) may be interpreted by means of the visual orienting process associated with imagery. The blocking of alpha in response to auditory stimulation (e.g., Adrian &

Matthews, 1934; Bridgewater, Sherry & Marcoynski, 1975; Fath, Wallace & Worsham, 1967; Voronin & Sokolov, 1960) may also be explained according to the orienting response. In fact, Adrian and Matthews (1934), Selzer and Fehmi (1975) and others (e.g., Bernstein, 1979; Maltzman, 1979; O'Gorman, 1979) suggest that most forms of novel and/or significant stimuli cause an orienting response which includes desynchronization of alpha activity, particularly before habituation has occurred. O'Gorman and Lloyd (1976) even found that the omission of a regularly occurring stimulus results in increased alpha blocking. The results, they suggest support Sokolov's (1960, 1963, 1969) model of the orienting resporse in which an orienting response (one of the components of which is alpha blocking) is elicited if a predicted stimulus does not occur. In addition, habituation occurs: If an auditory stimulus that evokes alpha blocking is presented at regular intervals, the blocking response diminishes (Fath, Wallace & Worsham, 1976; Pollen & Trachtenberg, 1972b; Selzer & Fehmi, 1975; Velden, 1978). Similar habituation of alpha blocking has been found for visual stimuli (Eberlin & Mulholland, 1976; Lansing, Schwartz & Lindsley, 1959; Milstein, 1974; Morrell, 1966; Mulholland, 1977). In addition, other authors (Boudrot, Goodman & Mulholland, 1978; Lewis & McLaughli, 1976; McLaughlin, Solomon & Harrison, 1974; Orne & Wilson, 1977; Plotkin, 1976a, 1978) have noted the close association of

alpha blocking and the orienting response and suggest the orienting response has a strong visual component.

Other support for the oculomotor hypothesis is derived from the well known desynchronization associated with mental effort (e.g., Andreassi, 1973; Bauer, 1976; Cobb, 1963; Dewan, 1967; Milosevic, 1978; Mundy-Castle, 1957; Orne, Evans, Wilson & Paskewitz, 1975; Pollen & Trachtenberg, 1972b; Wertheim, 1974). Many authors have found concurrent oculomotor activity (e.g., eye movements) in association with such tasks requiring mental effort (e.g., Andreassi, 1973; Antrobus, Antrobus & Singer, 1964; Lorens, Chester & Darrow, 1962; Meyer, 1977) while others have found alpha blocking as a direct function of eye movements (e.g., Bunnell & Manuck, 1978; Goodman, 1976; Hord, Naitoh & Johnson, 1972; Leisman, 1974; Putney & Butler, 1977; Selzer, 1974). There is even some evidence to suggest that more complex tasks requiring greater mental effort (e.g., counting backwards by 7 and serial multiplication) serve to block alpha to a much greater extent that does automatic cognitive activity such as counting (Gale, Christie & Penfold, 1971; Galin, Johnson & Herron, 1978; Paskewitz & Orne, 1971; Orne et al, 1975; Pollen & Trachtenberg, 1972b).

Alpha Biofeedback and the Oculomotor Hypothesis

A great deal of the research applicable to the oculomotor hypothesis comes from the area of alpha biofeedback, and particularly from those studies which address themselves to the strategies subjects utilize for enhancement and suppression of alpha activity. Many authors have noted that learning to control the alpha rhythm is considerably easier with the eyes open than with the eyes closed (e.g., Nowlis & Kamiya, 1970; Paskewitz & Orne, 1973; Peper, 1970). As further support for this finding, Paskewitz and Orne (1973) found that when their subjects were exposed to an alpha training procedure under conditions of total darkness, there was a nonsignificant increase in alpha production over six 20-minute training trials when compared to their eyes-closed baseline alpha level. They only recovered the initial decrease in alpha caused by opening their eyes in the dark. These increases occurred within 2 or 3 minutes without any volitional effort. They found however that when the same procedure was used, under conditions of low ambient lighting, another group of subjects was capable of significantly increasing their level of alpha production. They also found this same effect for the subjects previously trained in the dark, when they introduced low ambient lighting. They observed that opening the eyes in an illuminated environment resulted in a marked suppression of alpha activity. Even in the later trials, the alpha activity never exceeded the eyes-closed baseline measure.

Paskewitz and Orne concluded that low ambient lighting has an overriding effect on alpha production as it allows the subject to engage in visual scanning during baseline periods and consequently markedly reduce his alpha production. This is not possible in total darkness. Consequently under such conditions the subjects may learn to enhance alpha by overcoming those factors which normally exert an inhibitory influence on alpha activity. In other words, subjects learn to "look" to suppress alpha and "not look" to enhance it (Peper, 1970).

There is extensive support for the hypothesis that successful control of alpha production is accomplished by reducing (or increasing) visual system activity (oculomotor processes) (Chisholm, Adams, Valle & DeGood, 1975; Grauke, 1974; Grossberg, 1972; King, 1977; Leib, 1974; Lynch, Paskewitz & Orne, 1974b; Lynch, Paskewitz, Orne & Costello, 1970; Orne & Paskewitz, 1974b; Orne & Wilson, 1977; Podlesny & Raskin, 1974; Prewitt & Adams, 1976; Plotkin, 1978; Youngqren, 1974). Furthermore, many others have found that alpha could not be significantly enhanced above eyes-closed baselines (Bridgewater, Sherry & Marzynski, 1975; Brown, 1970, 1971; Cleeland, Booker & Hosokawa, 1971; Crosson, Meinz, Lour, Williams & Andreychuk, 1977; Hodges, 1977; Hosford, 1977; Kamiya, 1968, 1969; Lehmann, Lang, DeBruyne, 1976; Leib, 1974; Leib, Tyron & Stroebel, 1976; Lynch, Paskewitz & Orne, 1974b; Orenstein & McWilliams, 1976; Orne & Paskewitz, 1974; Paskkewitz, Lynch, Orne & Costello, 1970;

Paskewitz & Orne, 1973; Peper & Mulholland, 1970; Plotkin, 1976a, 1977, 1978; Plotkin, Mazer & Lowry, 1976; Podlesny & Raskin, 1974; Regestein, Pegram, Cook & Bradley, 1973; Valle & Levine, 1975; Walsh, 1974). In a review of the literature, Plotkin (1978) found no published study where alpha production increased above an optimal eyes-closed baseline. Those that have reported increases above baseline (e.g., Kulman & Klieger, 1975; Nowlis & Kamiya, 1970; Strayer, Scott & Bakan, 1973; Travis, Kondo & Knott, 1974a, 1974b, 1975) did not use adequate eyes-closed baseline measures. Still other researchers (e.g., Hardt, 1974, 1975; Hardt & Kamiya, 1976a, 1976b) feel however that enhancement above eyes-closed baseline is possible if training time is longer (over two hours) and if the more sensitive integrated amplitude measure is used instead of the percent-time index of alpha density. Plotkin (1978) in a study designed to test out these suggestions, again failed to find enhancement above optimal eyes-closed baseline. He concluded that increases in alpha production during training are the result of the gradual dissipation of alpha-inhibitory influences (any behaviour or state accompanied by oculomotor activation; looking, anxiety reactions, and general orienting response).

In summarizing these many studies, it would appear that the evidence still largely supports Mulholland and Peper's (1971) oculomotor hypothesis. As a further test of the oculomotor strategy, Plotkin (1976a) designed a study in

which he manipulated three levels of instruction (cognitive, oculomotor, and none) and two levels of lighting (on and off). The cognitive instructions encouraged the subject to relax, let go, try to feel pleasant and serene, and to think of pleasant personal experiences to enhance alpha. To suppress alpha they were instructed to concentrate, try hard, exert themselves mentally and try to feel anxious or frustrated. The oculomotor instructions suggested the subjects blur their vision and not focus to enhance alpha, and to focus to suppress alpha. On the basis of his results, Plotkin concluded that enhancement and suppression of occipital alpha is always mediated by control of oculomotor processes, whether or not the person is aware of this strategy. He noted that this was restricted to the light condition. In the dark there were no significant increases in alpha or differences between the groups. The oculomotor group, however, was much more successful with the lights on. This finding is particularly generalizable to most alpha biofeedback studies when one considers that most studies to date use low levels of lighting and eyes-open conditions. The oculomotor hypothesis would predict that there would be minimal enhancement over optimal eyes-closed (lights off) baselines as alpha strength should already be at maximum or near maximum levels. Consequently "look" and "non-look" strategies would have little effect in the dark.

In conclusion then, on the basis of Plotkin's studies and on the basis of the close association which has been so consistently found between alpha and visual control processes, it would appear that the oculomotor strategy is the most effective alpha control technique identified to date.

Extensions of the Oculomotor Hypothesis

A review of the literature reveals that the theory of attenuation of alpha during oculomotor activity has not been accepted unequivocally. For example, Wertheim (1974) has pointed out what he considers to be shortcomings of this simple oculomotor hypothesis. He notes that Lehtenen and Lehtinen (1972) found only a slight reduction in the number of saccades during vision in a uniform visual field; Gaarder, Koresko, and Kropfl (1966) implied the presence of both alpha and fixation saccades; and Mulholland (1968, 1969c) reported alpha activity during continuous saccadic eye movements. He poses further questions when he refers to studies by Pollen and Trachtenberg (1970, 1972a, 1972b) who have observed the presence of alpha during reading of eidetic imagery with eyes open (although some blocking was present) and along with saccadic eye movements when subjects played chess blindfolded. Wertheim also refered to a study by Serafinides (1968) who found alpha when subjects were asked to initiate eye movements without visual stimulation or mental imagery, and a study by Lansing, Schwartz, and

Lindsley (1959) who found that attempts to track or focus on a visual stimuli only disrupted alpha until the task became habitual. He concluded that although alpha seems somehow associated with the activities of the visual system, such observations are inconsistent with the oculomotor hypothesis because eye movements of any kind suggest the presence of oculomotor efferents.

In view of such inconsistencies, Wertheim (1974) proposes an alternative hypothesis in which "the ever ongoing occipital alpha rhythm is attenuated, desynchronized or blocked due to contamination of the EEG trace with electrical activity evoked during activation of the neural mechanism responsible for attentive oculomotor behavior, while during intentive oculomotor behavior the occipital alpha trace remains undisturbed" (p. 249). He defines oculomotor behavior as attentive whenever sensory information or the expectancy of such information influences oculomotor behavior, and as intentive whenever the monitoring of oculomotor activity is based on internal parameters irrespective of concurrent or anticipated sensory information. Therefore, attentive and intentive activity is discriminated solely on the basis of whether or not any use is made of sensory information in oculomotor control. During intentive oculomotor behavior there is no alpha disturbing electrical activity. On the basis of this hypothesis, Wertheim felt he could explain both saccadic eye movements and habituation as intentive to the extent that

they are or become more or less independent of information derived from external stimulation. He fails however to note Mulholland and Peper's (1971) suggestion that oculomotor functions not involving areas 17, 18 or 19 would not necessarily have an observable effect on alpha activity. Consequently, saccadic movements (involving primarily the frontal eye fields) (Bach-y-Rita, 1971; Hoyt & Friesen, 1975; Iacono & Lykken, 1979) may not be associated with changes involving occipital alpha (Mulholland, 1972; Mulholland & Peper, 1971; Robinson, 1968), which is most often recorded from the posterior scalp. Furthermore, his criticisms for the oculomotor hypothesis are based on data from Pollen and Trachtenberg (1972a, 1972b) and Lansing et al. (1959) which provide evidence for alpha attenuation occurring until the task becomes habitual. Rather than serving to reject the oculomotor hypothesis then, such data are consistent with it. The data provides evidence for habituation which is again consistent with the visual orienting process.

In view of such evidence it would perhaps be more appropriate to refer to the oculomotor hypothesis as the oculomotor activation process. This seems particularly applicable when one considers the relationship between activation, arousal, attention and alpha activity.

Many researchers have suggested that the strength of occipital alpha is a function of the level of arousal.

Malmo (1959), for example, concluded that alpha activity is related to arousal or activation level by an inverted U-shaped function. Generally then, the level of alpha activity will be reduced if the subject either becomes too drowsy or too aroused. On the other hand, at an intermediate level of arousal (a state of relaxed wakefulness) alpha is said to be maximal (Bartoshuk, 1971; Hardt & Kamiya, 1976a; Kamiya, 1968; Lindsley, 1952, 1956; Malmo 1959; Sadler & Eason, 1977).

In a review of the arousal control strategy Plotkin (1976a, 1976b) notes that when investigators associate alpha with "relaxed wakefulness" and beta with "hyperarousal" they tend to confound behavioral arousal and oculomotor arousal. Behavioral arousal refers to the sleep-wakefulness continuum which is associated with changes in the dominant EEG pattern, while oculomotor arousal refers to oculomotor system activation, which is associated with changes in strength of the alpha rhythm. By combining research relevant to both types of arousal, Plotkin suggests that alpha will be maximal when the subject is awake and when there is no oculomotor processing. Furthermore, as oculomotor arousal increases, alpha strength will decrease. Although he notes that many investigators have associated increases in behavioral arousal with alpha desynchronization, he feels the literature has sufficiently demonstrated that alpha desynchronization is primarily associated with oculomotor activation. He suggests that whether or not

there is any change in behavioral arousal, desynchronization remains closely associated with oculomotor activation. Therefore, when oculomotor activation does not accompany hyperarousal, he suggests EEG attenuation does not occur. Studies by Orne and Paskewitz (1974) and Frost, Burish and Holmes (1978) provide support for this hypothesis. They found that although anticipation of an electric shock did not depress alpha, it was associated with reports of anxiety and heightened arousal as indicated by increased heart rate and skin conductance responses. Similar support comes from Suter (1977,1979) and Suter, Franconi, Johnson, and Smith (1977) who found control of alpha and skin conductance to be independent, from Kondas (1973) who found that alpha suppression did not significantly increase arousal, from reports of independent changes in alpha and EMG (electromyography) (DeGood & Chrisholm, 1977; Hardt & Kamiya, 1978; Lehtonen & Lehtinen, 1972; Marshall, 1975; Patmon & Murphy, 1978; Sadler, 1977; Suter, 1979), of independent changes in alpha and heart rate (Chisholm, DeGood & Hartz, 1977; DeGood & Chisholm, 1977; Sadler, 1977; Travis, Partlow, Bean & Kondo, 1980) and from nonsignificant correlations between alpha and anxiety (Dolecki, 1976; Frost, Burish & Holmes, 1978; Grauke, 1974; Hardt, 1974). Such reports are indicative of heightened arousal in the presence of alpha activity. On the other hand, there are several other studies that have reported significant positive relationships between alpha desynchronization and GSR (Fontaine,

1976; Stennett, 1957), EMG (Kreitman & Shaw, 1965; Marshall & Bentler, 1976), heart rate (Bean, Kondo, Travis & Knott,1979; Occhipinti, 1976), and anxiety (Amicucci, 1974; Benjamins, 1977; Ehrisman, 1973; Lally, 1976; Lehrer, Schoicket, Carrington & Woolfolk, 1980; Levi, 1976; Terelak, 1974; Utz, 1974). Such report suggest a positive relationship between heightened arousal and desynchronization.

Plotkin (1976a, 1976b), Mulholland (1968, 1973), Benignus and Benignus (1977), and Orne & Wilson (1977) suggest that such alpha desynchronization that was thought to be associated with heightened arousal may in fact be a function of the cortical oculomotor activity associated with heightened arousal. On the other hand, becoming drowsy, which need not necessarily be associated with changes in oculomotor processes, may be an effective strategy for suppressing alpha activity (Peper & Mulholland, 1970; Plotkin, 1976a) and may reflect an active inhibition of alpha by the mechanisms associated with sleep rather than low levels of arousal (Orne & Wilson, 1977). The use of this strategy however, seems to be reduced to those situations in which it is relatively easy to become sleepy or drowsy (e.g., subjects in a dark room with their eyes closed).

Although the evidence is not conclusive, it would appear that the oculomotor activation component of the arousal theory may be the most potent factor associated with changes in alpha. Consequently those researchers (e.g., Grauke,

1974; Hardt, 1977; Hardt & Kamiya, 1976; Sadler & Eason, 1977) who emphasize the relationship between alpha and arousal may indeed be referring to oculomotor arousal. On a physiological level, Mulholland (1972) notes that the "alpha blocking response involves processes in the reticular substance of the brainstem tegmentum" (p. 179). Furthermore, the oculomotor pathway is located in the same area of the brainstem tegmentum as the reticular activating system and stimulation of the RAS that can cause cortical desynchronization can also cause alterations in eye movements (Bender & Shanzer, 1964; Mulholland, 1972; Plotkin, 1976a; Robinson, 1976). Similarly, oculomotor activity is closely associated with attentional processes. As has been noted earlier, it has often been hypothesized that the amount of alpha activity is increased by decreased attention and suppressed by increased attention (e.g., Adrian & Matthews, 1934; Berger, 1929; Fuller, 1978; Jackson, 1977; Jones & Barnes, 1978; Lynch & Paskewitz, 1971). There is, however, much evidence to suggest that alpha enhancement can occur while an individual maintains a constant state of attention (Brown, 1970; Dewan, 1967; Mulholland, 1968; Mulholland & Runnals, 1962; Morrell, 1966; Peper, 1970; Williams, 1940). On the basis of such information, Plotkin (1976a) and Orne & Wilson (1977) conclude that the desynchronization of alpha activity that accompanies the orienting response (the alerting to an external stimuli) is a function of oculomotor activity (Mulholland & Evans, 1966). Since most forms

of novel stimuli cause an orienting response (Adrian & Matthews, 1934; Selzer & Fehmi, 1975), alpha is blocked when an individual orients to any stimulus presented in any modality because oculomotor activity is a general component of the orienting response (Zickmund, 1965), and because oculomotor activity leads to alpha blocking. In a review of the literature, Mulholland and Evans (1966) could not find any study in which oculomotor activity has been eliminated as a cause of the alpha desynchronization claimed to be associated with attention.

In conclusion then, there is more than ample evidence to suggest that the integrative and efferent processes related to moving and positioning the eyes (involving fixation, accommodation, pursuit tracking, eye movements, etc.) are related to the disturbance and recovery of the alpha, no-alpha cycle (Mulholland, 1972). Since there is some evidence to suggest that alpha attenuation is the result of additional elctrical activity which contaminates the EEG signal recorded at the scalp or creates interference at the level of alpha generators (Goldstein, 1970; Maynard, 1972; Wertheim, 1974), it would appear that occipital alpha is attenuated due to electrical activity evoked via oculomotor activation. Consistent with an orienting response, alpha attenuation would be expected to occur with most forms of novel stimuli and would be expected to habituate with repeated presentations (Peper & Mulholland, 1970). Accordingly, alpha should be prominent and no blocking

should appear in the absence of oculomotor activity. On the other hand, the magnitude of the blocking response should be contingent on the amount of oculomotor activity.

On the basis of the oculomotor hypothesis then, alpha activity would be blocked by any type of oculomotor processing such as eye movements, pursuit tracking, fixation, accommodation, and convergence. Given the well known relationship between the pupil and accommodation, convergence, eye movements and fixation, pupillary changes might also be added to this list of oculomotor processes which attentuate alpha activity.

As has been noted in the present review of the literature, such parameters as eye movements, fixation responses, accommodative responses and convergence responses have been actively examined in relationship to alpha activity. Similarly such parameters have also been examined in relationship to the pupillary response. On the other hand, I have found no research which has examined the relationship of pupillary activity (movements) to occipital alpha desynchronization. On the basis of the oculomotor hypothesis, one would predict that alpha would be attenuated by pupillary movements. Consequently, any examination of pupillary activity and it's relationship to alpha production would serve as a further test of the oculomotor hypothesis. If indeed pupillary behavior is related to the alpha rhythm through the visual system, one would expect that a review of

the pupillary literature might provide some evidence about the nature of this possible relationship.

The Pupillary Response

The pupillary response (the motor activity of the human iris) provides an increasingly useful source of data for both research and clinical fields. It has been widely used as a tool in studies and research concerning the physiology of the pupillomotor system (Carter, 1979; Hansmann, Semnlow & Stark, 1974; Hultborn, Mori & Tsukahara, 1978; Lowenstein & Loewenfeld, 1959), in neurological diagnosis and research (Alexandra, Krastel & Reuther, 1979; Appen, 1979; Stanten & Stark, 1960; Stark & Cornsweet, 1958), in pharmacology (Campbell, Mandelzy & Mills, 1979; Carleson, 1957; Cozan, Dundee, Buchanan & Archer 1979; Loewenfeld, 1963; Okando, Kase & Shintomi, 1978; Senay & Shick, 1978; Tress & Elsobky, 1979) and psychology (e.g., Janisse, 1973, 1976, 1977).

The iris of the eye is a complex structure composed of two opposing muscle groups, the sphincture and dilator pupillae. The innervation of the dilator muscle is from the sympathetic nervous system (superior sympathetic ganglion) and is related to pupillary dilation. The innervation of the sphincture pupillae is from the parasympathetic nervous system (Ediger-Westphal nucleus) and is responsible for pupillary constriction (for a review, see Lowenstein &

Loewenfeld, 1962). According to Lowenstein and Loewenfeld (1962) the pupil has three main functions; it controls the amount of light entering the eye, it increases depth of focus by decreasing the aperature, and it reduces aberrations especially in bright light.

Pupil diameter is variable and is determined by the momentary state of activation of the sphincture (parasympathetic) and dilator (sympathetic) muscle groups (Beatty, 1977b, 1977c). In man, the diameter of the pupil can range from about 1.3 mm. to 10 mm. although the average pupil ranges from about 2 mm. in intense light to 8 mm. in complete darkness (Lowenstein & Loewenfeld, 1962).

The most universally accepted phenomenon regarding the pupil is its reaction to light (light reflex). The pupil of the eye constricts as the amount of light reaching the eye increases. Similarly the pupil dilates as the amount of light reaching the eye decreases. The pupil regulates the amount of light enering the eye, although, like most biological control systems, pupil size is not related to the level of luminance in a clear linear fashion (Alpern, 1971). The pupil contracts whether exposed to a light flash or a dark flash (Clynes, 1962). According to Riggs (1971) acuity is fairly linearly related to pupil size at least up to a diameter of 1 mm. Although some improvement occurs if the pupil becomes larger, a high constant value of acuity holds over 2.5 to 5 mm. Riggs suggests that since the optics of

the eye are not perfect, optical aberrations increase with pupil diameter. This is the case because rays of light from a single source entering the eye through a dilated pupil do not converge on a single point on the retina. Consequently distortions appear.

There are also other well known facts about pupil size. Alpern (1971) concludes from a variety of evidence that "there are linear relations among the innervations of the accommodation response, the eye rotation, and pupil constriction" (p. 384). The relationship comprises the near-focus response in which pupil size is reduced, accommodation increases, and accommodative vergence increases, as gaze is shifted from a distant object to a near one. In fact, Allpern, Mason, and Jardinico (1961) have found that positive convergence movements cause a 0.087 mm. decrease in pupil diameter for a each degree of movement.

A great deal of the recent interest on the pupil has been with the psychology of the pupillary response. Since the intraocular muscles controlling pupil size are innervated by the autonomic nervous system, psychological variables may have an effect on pupil size. Consequently, the pupillary response has been investigated in its relationship to non verbal communication (e.g., Hess, 1978; Sallas, 1976; Sander & Fathergill, 1977), personality (e.g., Bradley & Janisse, 1976; Glaberson, 1977; Zeitner & Weight, 1979), sexual arousal (e.g., O'Neill & Hinton, 1977; Janisse, 1973;

Goldwater, 1972; Zuckerman, 1971), anxiety (e.g., Finkelstein & Walker, 1976; Kuc, 1977; Janisse, 1976), cognition and mental effort (e.g., Buckholt, 1975; Klix & Krassa, 1975), abnormal behavior (e.g., Coulter, 1978; Ikushima & Matsunaga, 1975; Patterson, 1976; Venables & Patterson, 1978), attitudes (e.g., Collins, Ellsworth & Helmreich, 1967; Hess, 1965; Metalis, 1978), and intelligence (e.g., Ahern & Beatty, 1979; Crough, 1971; Peavler & Nellis, 1976).

Alpha, the Pupillary Response, and the Visual System

It is obvious that the pupillary response is an intricate part of the visual system. From my earlier discussion, it has also been suggested that alpha activity has very close ties with the oculomotor system, even on a physiological basis. In spite of this, there are no studies that have directly addressed themselves to a study of the relationship between alpha activity and the pupillary response. Nevertheless, there are studies that have indirectly implicated a relationship between the two variables. In other cases, parallels can be drawn between the alpha and pupillometry literatures which may have implications for their relationship.

The Near-Focus Response

In the earlier discussion of the near-focus response, it has been noted that the pupil contracts with convergence of the eyes and accommodation of the lens as the gaze is shifted from a distant object to a near one. There is also some evidence to suggest that alpha activity is related to the degree of eye convergence. Eason and Sadler (1977) designed a study to investigate the effect of degree of eye convergence (and accompanying changes in accommodation) on alpha activity under both eyes-closed and eyes-open conditions. The results of their study indicated that the degree of eye convergence was inversely related to alpha activity with either eyes open or eyes closed. Furthermore, they found that alpha activity and degree of eye convergence covaried when their subjects attempted to enhance or suppress their level of alpha activity in an eyes-closed feedback condition.

The results of their study are in line with the oculomotor hypothesis as oculomotor activity was found to be inversely related to alpha activity. Furthermore, when one considers the linear relationship found between convergence, accommodation, and pupillary constriction (Alpern, 1971) and the well established fact that pupillary constriction accompanies accommodation (Borish, 1970; Provine & Enoch, 1975), it seems reasonable to hypothesize that alpha activity may be similarly related to changes in pupil size. Both alpha activity and pupil size have been found to

decrease with positive convergence movements (and accompanying changes in accommodation) as the eyes assume a position for viewing near objects. The confounding factor in this line of reasoning is that accommodation and convergence, both of which have been found to influence alpha activity, may be mediating factors to any pupillary-alpha activity relationship.

Effects of Illumination

Given the well known pupillary response to light (the light reflex) it is also possible to examine those studies which have investigated the effect of various levels of illumination on alpha production and alpha control. As has been noted earlier Paskewitz and Orne (1973) have pointed out that a subject's ability to control alpha production may be restricted to those conditions which normally lead to decreased levels of alpha output (e.g., an illuminated experimental setting). Clearly, they have stressed the importance of illumination levels on alpha production. In spite of this, this variable has only been addressed by a few studies (Cram, Kohlenberg & Singer, 1977).

Bridgewater, Sherry, and Marczynski (1975), for example, investigated the relationship between alpha activity (9-10 Hz), auditory feedback, and light input under conditions in which they claimed convergence, accommodation, smooth pursuit eye movements, and foveal fixations were eliminated. Their subjects wore light-diffusing goggles which prevented

pattern vision but allowed the entrance of varous intensities of light (1, 3, and 15 footcandles). Although the study was designed to investigate the relationship between auditory feedback and light input, Bridgewater et al. did establish a condition in which pupil size was manipulated by way of varying light intensity, while accommodation, convergence, smooth pursuit eye movements and fixations were eliminated. Since they did not report measuring eye movements however, the possibility of the occurrence of convergent movements cannot be considered completely eliminated. As noted earlier, Eason and Sadler (1977) have demonstrated that convergent movements were related to alpha even under eyes-closed conditions. The results of Bridgewater et al's study indicated that there was significantly more alpha activity with feedback in the dark than in the presence of either 3 or 15 footcandle luminence. Although the alpha activity was also greater in the dark than in the 1 footcandle condition, it was not significant. On the basis of this they concluded that diffuse light has a significant alpha blocking property during alpha contingent auditory feedback conditions. They felt however that diffuse light by itself (without auditory feedback), did not have a significant suppressant effect as there were no significant differences between eyes-closed dark, eyes-open dark or eyes-open illuminated (3 footcandle) baselines.

It should be noted, however, that initial apprehensions about the experiment, the novelty of the situation, etc., have been extensively demonstrated to have a suppressant effect on alpha during initial baseline measures (e.g., Crossen, Meinz, Laur, Williams & Andreychuk, 1977; Paskewitz & Orne, 1973; Plotkin, 1976a, 1978). Since Bridgewater et al. did not report using an adaptation period to alleviate some of these factors, their initial baseline measures, particlarly the first (eyes-closed) baseline measure of alpha activity, would be expected to be deflated. This might explain why they found a tendency for alpha enhancement with opening the eyes in the dark while others (e.g., Paskewitz & Orne, 1973) have found the reverse effect. The confounding effect of the initial eyes-closed baseline measure consequently renders it impossible to make a comparison to their third baseline measure, which introduced illumination (3 footcandles) as a variable. In addition, they made no comparisons to other illumination levels (e.g., 15 footcandles). It is also interesting to note that the amount of alpha tended to decrease across trials as the level of illumination increased from 0 to 15 footcandles. They concluded that the 40 minute feedback training period did not enhance the ability of their subjects to increase their alpha activity above baseline periods.

In summary then it remains a possibility that even diffuse light may have a suppressant effect on occipital

alpha even where other oculomotor variables have been controlled (with the possible exception of convergence). Consequently, pupillary constriction responses (associated with an increase in illumination) may have a suppressant effect on alpha activity. This of course would be consistent with the oculomotor hypothesis.

Orenstein and McWilliams (1976) also designed a study to assess the effect of differential lighting and auditory feedback on variations in alpha activity. The subjects were given biofeedback training for six sessions either under conditions of darkness or dim light (0.5 footcandle), and for a seventh condition under the opposite condition. Since the group trained under dim light conditions never exceeded their eyes-closed baseline alpha level, they concluded that dim light has a suppressant effect on alpha production. The result, of course, is consistent with the oculomotor hypothesis. On the other hand, however, they found no such effect when the group trained under six sessions of darkness was exposed to a seventh session of dim light. It is interesting to note that the subjects in this later condition had already been trained to maintain consistently high levels of alpha production. Consequently, Orenstein and McWilliams suggest that the suppressant effect of light may have been minimized because of their previous training and experience in high alpha production.

Cram, Kohlenberg, and Singer (1977) similarly designed a study to test the effect of illumination levels as well as the position of the eyelids (open versus closed) on the subject's ability to learn to control his alpha production. Essentially, the study was an extension of Paskewitz and Orne's (1973) study which clearly indicated the importance of illumination in a subjects ability to enhance alpha production. In a 3x2 factorial design, Cram et al. manipulated three levels of illumination (dark, 0 log footlamberts; ambient, 0.4 log footlamberts; and bright 4.0 log footlamberts) with two levels of eyelid position (open and closed). Consistent with Paskewitz and Orne's study, the results of their study indicated that there were no significant alpha control effects for the dark condition. Only under the light conditions and especially in the ambient light condition were there significant alpha control effects. They concluded that ambient lighting combined with eyes-open training is the optimal condition for attaining alpha control. Although Cram et al. indicate that some researchers have hypothesized that eyes-open training results from disinhibition and that increasing levels of illumination would increase inhibition and thus facilitate training, the results of their study do not indicate such a linear relationship. They suggest that bright illumination may have made it sufficiently uncomfortable for their subjects to use environmental stimuli to inhibit alpha production.

Although there are many interesting results in Cram et al.'s study, the confounding of many oculomotor functions (e.g., fixation, convergence, etc.) make it impossible to separate out the effects of illumination or pupillary changes on alpha production. It is clear that the results are consistent with the oculomotor hypothesis. For example eyes-closed measures of alpha always exceeded eyes-open measures, particularly when eyes-open measures were taken under ambient or bright illumination. It is also interesting to note that the subjects in the bright light group had a particularly difficult time attempting to inhibit alpha production. Perhaps this is because alpha suppression has a floor effect which was already reached via bright light stimulation and pupillary constriction movements. Given that the training effect was determined by differences between alpha-on and alpha-off periods, it would appear that the bright light group's difficulty in further suppressing alpha is responsible for their poor training performance. It is also interesting to note that the usually large and relatively quiet pupils of normal, alert subjects in complete darkness tend to become smaller and more active with increasing light (Lowenstein & Loewenfeld, 1962). Therefore, the increasing pupillary activity (pupillary unrest) might have had an inhibitory effect on alpha production. The oculomotor activation theory would predict that such increasing oculomotor activity would serve to block alpha.

In two other studies designed to investigate the effect of level of illumination on occipital alpha enhancement, Kondo, Travis, Knott, and Bean (1976,1979) took baseline measures of alpha activity under a light condition (10.7 footcandles) and a dark condition (0.01 footcandles). Unfortunately, the subjects' eyes were closed under both conditions which would of course minimize any effect of light. As expected, they found no significant suppressant effect of light on their eyes-closed baseline measures. It is notable, however, that it did approach significance ($p < 0.10$).

As has been noted earlier, Lippold (1970) and his colleagues (Lippold & Novotny, 1970; Ennever, Lippold & Novotny, 1971) have hypothesized that alpha is a function of the tremor of the extraocular muscles modulating the corneo-retinal potential via some kind of conductance change. Moreover, they found that by varying the level of illumination to the eye, they could vary the corneo-retinal potential and hence the alpha rhythm amplitude. Similarly, Leisman (1974) found a significant correlation (0.92) between alpha amplitude measures and the corneo-retinal potential. Again, he found the amplitude of the electro-oculogram varied with the level of illumination. What is noteworthy in the present context is the relationship between varying levels of illumination and the amplitude of the alpha rhythm. Lippold (1970) however, felt that the

results could not be explained in terms of the effect of illumination on retinal or cortical function because the corneo-retinal potential varied. A close examination of Leisman's (1974) graphs, however, reveal a general tendency for alpha amplitude to increase over the duration of the dark condition and to decrease over the period of illumination. Although Lippold's graph is not as consistent in this trend as Leisman's graph, it is difficult to determine the source of the discrepancy. Neither investigator reported the intensity of illumination, Lippold did not report on the number of subjects used, and Leisman did not report if alpha recordings were taken with eyes closed (as in Lippold's study) or with eyes open. In spite of this, the possibility remains that a relationship between level of illumination and alpha exists.

The results of other studies that have introduced light as a variable are even more inconclusive. Lehtonen and Lehtinen (1972) assessed the effect of light flashes on occipital alpha activity and found alpha to be abundant even when the subject was counting flashes with eyes-open in front a uniform visual field. Since the subject's eyes were dilated with two mydriatic drops, however, it is impossible to assess any effect of pupillary changes on alpha activity. On the other hand it is interesting to note that the light flashes did not serve to block alpha when pupillary changes were eliminated. Similarly Glass (1977) assessed the effect of light flashes (photic stimulation) on alpha activity in

three subjects who had congenital deficits that allowed only diffuse light perception through one eye. The results of his study clearly indicated that the alpha rhythm was not blocked by photic stimulation to the deprived eye although it was effectively blocked via stimulation to the good eye. Since his subjects had been deprived of vision in the defective eye since birth, he suggested that the deprivation has probably resulted in permanent alternation of the primary visual pathways and their connections with the nervous system. Again, on the basis of this study it is impossible to assess the effect of light and pupillary change on alpha activity. In another study Cavonius and Estevez-Usanga (1974) report that they varied illumination levels over blank and patterned fields and found no difference on alpha suppression. It should be noted, however, that they only varied illumination from the point that the pattern was first clearly visible to the limits of their projector. They did not report actual light levels nor did they control for eye movements, fixation responses, etc.

In conclusion, the existence of a relationship between pupillary changes and alpha activity remains a possibility. According to the oculomotor theory, one would expect oculomotor activity of any sort to block alpha activity. Also one would predict that this blocking response would habituate with continued exposure or repeated exposure. On the basis of the evidence presented earlier, it seems

reasonable that alpha suppression will occur with pupillary changes either in the direction of constriction or dilation. The evidence presented associating alpha blocking and pupillary constriction as in the near-focus response (Eason & Sadler, 1977), and the evidence associating alpha suppression and pupillary constriction as in the light response (e.g., Bridgewater et al, 1975; Cram et al., 1977) would support the contention that alpha suppression occurs with pupillary constriction. There are other lines of research, however, that suggest a possible relationship between pupillary dilation and alpha suppression.

Cognition and Mental Effort

There has been considerable research investigating the role of alpha activity in task performance (for a review, see Lawrence & Johnson, 1977). Most of this research, however, has addressed itself to the issue of efficacy of task performance in relationship to enhanced alpha activity (Bauer, 1976; Beatty, 1973; Bridges, Rallings & Rhea, 1976; Green, Green & Walters, 1970; Hawkins, 1976; Hord, Lubin, Tracy, Jesman & Johnson, 1976; Hord, Tracy, Lubin & Johnson, 1975; Jackson, 1977; Nowlis & Kamiya, 1970 Regestein, Buck land & Pegram, 1973; Survillo, 1963a 1963b, 1964, 1968; Utz, 1974; Woodruff, 1975). Although the results of such studies are somewhat at variance, Lawrence and Johnson (1977) conclude that alpha enhancement has not been demonstrated to aid task performance. In fact, they emphasize that alpha

activity is incompatible with tasks requiring any degree of effort (Orne, Evans, Wilson & Paskewitz, 1975).

As has been noted earlier, it is a well-known finding that desynchronization of alpha activity is associated with mental effort (e.g., Cobb, 1963; Dewan, 1976; Ludlam, 1979; Mundy-Castle, 1957; Orne et al., 1975; Pollen & Trachtenberg, 1972b; Wertheim, 1974). Orne et al. (1975) for example, while investigating the ability of subjects to maintain high levels of alpha activity during cognitive tasks, found little decrement in alpha while counting backwards by 1. Counting backwards by 7 however significantly blocked alpha activity. They concluded that the complexity of the task, the subject's ability to perform the task, and the amount of effort required to perform the task, were all related to the degree of alpha blocking. Similarly, Pollen and Trachtenberg (1972b) found that mental arithmetic would significantly block alpha activity even with eyes closed but only if it exceeded complexity responses available from rote memory. When subjects were asked to calculate serial powers of 4, the alpha remained present as long as he could do so easily (e.g., 4, 16, 64, 128, 256) but blocked and remained blocked as the subjects attempted higher progressions. Similarly, counting backwards from 100 by 6's or 7's effectively blocked alpha activity throughout the task. Alpha might reappear just as or after the responses were made. In spatial visualization tasks (e.g., complicated auto routes), alpha was found to

initially block, then follow a gradual yet incomplete return towards resting levels. During blindfold chess the alpha rhythm becomes blocked during those periods when the subjects claimed they required the greatest mental effort.

The results of several other investigations (Baker & Franken, 1967; Chartock, Glassman, Poon & Marsh, 1967; Doyle, Ornstein & Galin, 1974; Dumas & Morgan, 1975; Furst, 1975; Gale, Christie & Penfold, 1971; Gale, Spratt, Christie & Smallbone, 1975; Glass & Butler, 1977; McKee, Humphrey & McAdam, 1973; Meyer, 1977; Margon, McDonald & Hilgard, 1974; Paskewitz & Orne, 1971) are consistent with those presented above and suggest that tasks requiring greater mental effort serve to block alpha activity, while those requiring little effort do not significantly block alpha activity. In fact, alpha blocking on cognitive tasks is such a consistent phenomenon that it is increasingly used as an independent variable to measure hemispheric activation across a wide variety of tasks (Amochaev & Salamy, 1979; Cacioppo, Bovee, Snyder, Nolan & Superak, 1979; Chartock, Glassman, Poon & Marsh, 1975; Davidson & Marshak, 1977; Davidson, Schwartz, Saron & Colemann, 1978; Davidson, Taylor & Saron, 1978; Davidson, Taylor, Saron & Stenger, 1979; Davidson, Taylor, Saron & Snyder, 1979; Doyle, Ornstein & Galin, 1974; Dumas & Morgan, 1975; Ehrlichman & Weiner, 1979, 1980; Furst, 1976; Galin, Johnson & Herron, 1978; Gevins, Zeitlin, Yingling, Doyle, Dedon, Schaffer, Roumasset & Yeager, 1979; Gevins,

Zeitlin, Doyle, Schaffer & Gallaway, 1979; Glass & Butler, 1977; Goodman, 1978; Goodman, Beatty & Mulholland, 1980; Grabow, Aronson, Greene & Offord, 1979; Gruwald-Zuberbier, Grunwald, Rasche & Netz, 1978; Hirshkowitz, Earle & Paley, 1978; Maxwell, Fenwick, Fenton & Dollimore, 1974; Mulholland, 1979; Pfurtscheller & Aranibar, 1978; Pfurtscheller, Maresch & Schuy, 1977; Ornstein, Herron, Johnstone & Swencionis, 1979; Rebert, 1976-77; Rebert & Low, 1978; Shaw, 1978; Tojo, 1978; Trotman & Hammond, 1979). Moreover, as noted before several investigators have found evidence of concurrent oculomotor activity in association with such tasks requiring mental effort (e.g., Andreassi, 1973; Antrobus, Antrobus & Singer, 1964; Lorens, Chester & Darrow, 1962; Ludlam, 1979; Meyer, 1977).

The pupillometry literature also provides an abundance of support for a consistent relationship between pupil size and mental effort (for reviews see Beatty, 1977b; Hess, 1965, 1972, 1973; Janisse, 1977) and futher evidence for concurrent oculomotor activity in association with tasks requiring mental effort.

One of the earliest studies relating pupil size and mental effort was undertaken by Hess and Polt (1964). They presented their subjects with four multiplication problems of increasing difficulty and found that after each problem was presented pupil diameter slowly increased, reaching its maximum just before solution. Following solution and report, there was a return to baseline. Pupil size was also

found to increase as a function of problem difficulty or processing load. The average dilation ranged from a 10.8% increase for the simplest problem to a 21.6% increase for the most difficult. Their conclusion was that pupil size could be used as a direct measure of mental activity.

Since this study appeared, there has been a great deal of research which has addressed itself to the association of pupil size changes and cognitive activity. Some of the most organized research has been undertaken by the Kahneman group and the Paivio and Simpson group (Janisse, 1977), although considerable amount of independent research has provided support for their results.

The first study undertaken by the Kahneman group (Kahneman & Beatty, 1966) investigated pupillary changes during a short-term memory digit-span task. The results of this study indicated that pupil size increased with the presentation of each digit, reaching maximal size after all the digits are presented (loaded). Similarly, pupil size decreased as the subject repeated each digit, reaching baseline level after all the digits were repeated (unloaded). In addition the amount of dilation was found to be a direct function of task difficulty (the number of digits in the string). The greatest dilation was found for the largest strings. The use of more difficult digit-transformation and word-recall tasks provided additional evidence that the degree of pupillary dilation was related to task difficulty.

The series of studies that followed (Beatty & Kahneman, 1966; Kahneman & Beatty, 1967; Kahneman, Beatty & Melton, 1966; Kahneman, Beatty & Pollack, 1967; Kahneman, Onuska & Wilman, 1968; Kahneman & Peavler, 1969; Kahneman, Peavler & Onuska, 1968), led Kahneman (1973) to conclude that pupil dilation is a sensitive autonomic indicator of mental effort. He cautioned however that the effects of miscellaneous variables (e.g., stress, anxiety, drive states) may confound the relationship between mental effort and pupillary activity. Consequently, he advocated the importance of controlling such variables in using the pupillary response to gauge mental effort.

The series of studies by Paivio and Simpson and their colleagues (Paivio & Simpson, 1966, 1968; Simpson, 1969; Simpson & Climan, 1971; Simpson & Hale, 1969; Simpson & Molloy, 1971; Simpson & Paivio, 1966, 1968) similarly provided evidence that pupil size is an accurate measure of the difficulty of a cognitive task. In his review, Paivio (1973) pointed out that pupil dilation is not only associated with cognitive activity but also evaluation apprehension, muscle tension, and decisional processes.

The results of other research undertaken by independent investigators provide additional evidence for the close relationship between pupil size and cognitive activity. For example, Schaefer, Ferguson, Klein, and Rawson (1968) noted that pupillary dilations were greater for more difficult

tasks across digit span, multiplication, and word definition tasks. Elshtain and Schaefer (1968) found a positive linear relationship between processing requirements of a verbal recall task and pupillary dilation. Daly (1966) found pupil size to be larger during problem solving than control conditions. Payne, Perry, and Harasymiw (1968) in a series of multiplication problems, found dilation increased linearly with difficulty. Moreover, the list of studies that support the consistent relationship between pupillary diameter and mental effort (task difficulty, memory load, accuracy of response, brain activation, etc.) goes on (e.g., Ahern, 1978; Ahern & Beatty, 1979; Ambler, Fisicaro & Proctor, 1976; Beatty & Wagoner, 1977, 1978; Bradshaw, 1967, 1968a, 1968b, 1968c, 1969a, 1969b; Colman & Paivio, 1970; Coulter, 1978; Engle, 1975; Janisse & McIntyre, 1975; Lidsky & Anderson, 1977; Peavler, 1974; Poock, 1973; Poock & Noel, 1975; Shiga & Ohkubo, 1978; Stanners, Headly & Clark, 1972; VanOlst & Kortenarr, 1977; Wright & Kahneman, 1971).

In conclusion, a great deal of research has provided consistent evidence that pupillary dilation is a reliable index of mental effort. It is also a well-known finding that desynchronization of alpha activity is associated with mental effort. In both cases, the magnitude of the response appears to be a function of the amount of cognitive effort required to perform the task. In view of the oculomotor activation theory, it would be expected that desynchroniza-

tion of occipital alpha would be associated with increased oculomotor activity; in this case possibly changes in pupil size. Similarly it would be expected that the magnitude of the blocking response would be a function of the magnitude of the pupillary dilation response. Therefore, on the basis of the oculomotor hypothesis it could be suggested that pupillary movements (dilation) in tasks requiring mental effort may serve as the oculomotor activity which results in alpha desynchronization.

Alpha, Pupil Size and Other Physiological Indicants

In a review of the literature associating pupil size with other physiological indicants, Janisse (1977) notes that the few studies that have been undertaken have not addressed themselves to the interrelatedness of various measures. Rather, the results have been reported in more of a parallel position. Given that pupillary changes reflect changes in autonomic activity, Janisse (1977) noted that one would expect the pupillary response to be related to various other indicants of autonomic activity. This expectation has not been borne out in the literatures examining the relationship between pupil size and electrodermal response (Bell, 1973; Bond, James & Lader, 1974; Clark, 1975; Coleman & Paivio, 1969; Coulter, 1978; Kahneman, Tursky, Shapiro & Crider, 1969; McElvain, 1970; Scott, Wells, Wood & Morgan, 1967), electromyographic measures (Coulter, 1978; Simpson & Climan,

1971; Simpson & Hale, 1969), respiration (Lowenstein & Loewenfeld, 1962); evoked potential (Beatty, 1977c;; Bock, 1976; Bond et al., 1974; Dustman & Beck, 1965; Friedman, Hakerem, Sutton & Fleiss, 1973; Hakerem, 1974), heart rate (Bernick, Kling & Borowitz, 1971; Bell, 1973; Bond et al., 1974; Coulter, 1978; Kahneman et al., 1969; Kuc & Janisse, 1976; Libby, Lacey & Lacey, 1973; Zahn, Little & Wender, 1976), blood pressure (Bell, 1973), and EEG (Bond et al., 1974; Muller-Jensen & Hagenah, 1978). As Janisse has noted, the most consistent finding is a negative relationship between pupil size and heart rate; most of the other findings have been mixed or contradictory. As noted earlier, the relationship of alpha activity to various physiological measures (e.g., GSR, electromyography, heart rate) has also been an inconsistent, often contradictory one.

Only two studies were found in which measurements of both EEG and pupillary changes were assessed. Muller-Jensen and Hagenah (1978) simultaneously measured the EEG and pupillogram over a long period of time (24 hours) on an unconscious 44-year-old man who had epileptic seizures, chronic alcoholism with liver desease, Primidon intoxication, and pupillary hippus (large amplitude rhythmic constriction and dilation of the pupil). The results of simultaneous recording revealed that both the basic EEG rhythm and pupillary hippus had the same frequency. Moreover, both recordings were temporarily in phase, time-locked, and could

be blocked by painful and auditory stimuli. Pupillary hippus was also found to be unaffected by changes in illumination. The man, however, was unconscious. Consequently his EEG was characterized by delta and theta wave activity. Therefore it is not possible to assess the effect of oculomotor arousal on EEG alpha, without considering the effects of behavioral arousal. It is interesting to note, however, that when the patient regained consciousness and the EEG changed to normal alpha activity, hippus was no longer seen.

The other study in which measurements of both EEG alpha and pupillary changes were assessed was conducted by Bond, James, and Lader (1974). This study was designed to compare patients suffering from chronic anxiety states to normals on a variety of physiological (EEG, auditory evoked response, GSR, pulse rate, and pupil size) and psychological measures. The results of their study revealed that the patients had significantly less alpha activity than the controls. In addition, although there was no difference between the groups under dim illumination, under bright illumination the size of the patients' pupils were significantly larger vis-a-vis the control group. Unfortunately, however, the EEG was not compared to pupil size, nor was it assessed under dim versus bright illumination. Bond et al. concluded that both the pupillary response and alpha blocking response were a function of the higher state of arousal associated with this group of anxious patients.

Theories of arousal are often referred to in both the pupillometry and EEG alpha literatures. Beatty (1977b), who has been actively involved in research on both EEG and pupil size, suggests that several different methods can be employed to measure nervous system (cortical) activation. He includes EEG measures, event-related cortical potentials, and pupillary movements, and suggests that each has its strengths and weaknesses.

According to Beatty (1977b) and others (e.g., Bartoshuk, 1971; Hardt & Kamiya, 1976a; Kamiya, 1968; Lindsley, 1952, 1956; Malmo, 1959; Sadler & Eason, 1977), it has been well known for many years that the alpha rhythm reflects variations in arousal or activation. Alpha desynchronization reflects increased cortical activation while dominant alpha activity reflects a low state of activation. Because cortical activation also spreads to the peripheral portions of the nervous system, and particularly the autonomic nervous system, Beatty suggests that the pupil of the eye is also well suited for measuring cortical activation. In reviewing the two measures, Beatty concluded that because pupil size is capable of reflecting momentary shifts in sympathetic and parasympathetic activation it is probably most suitable for investigating relationships between cortical activation and thought, while the EEG measures might be more suitable indicators of the general state of cortical activation over longer periods of time.

Sadler and Eason (1977) found tentative support for the hypothesis that voluntary alpha control is mediated in part through changes in cortical activation and body arousal. They used several physiological indicants of such activity (EMG, skin conductance, and eye movements) but, unfortunately for the present purposes, did not measure pupillary responses. No significant differences for high and low alpha conditions were found for the group as a whole, although many of the variables (e.g., eye movements) were in the direction of the activation hypothesis. The main effects they suggest were masked by individual idiosyncracies.

At this point it is important to keep in mind the earlier discussion of arousal. As has been noted, Plotkin (1976a, 1976b) suggests that investigators often confound behavior arousal and oculomotor arousal. Behavioral arousal refers to the sleep-wakefulness continuum and is associated with changes in the dominant EEG pattern, while oculomotor arousal refers to oculomotor activation which is associated with strength of the alpha rhythm. It is important to note that Beatty (1977b) in reference to the vigilance studies (e.g., Beatty, Greenberg, Deibler & O'Hanson, 1974; Groll, 1966) is referring to behavioral arousal and changes in the sleep-wakefulness continuum. Sadler and Eason (1977) on the other hand, are making reference to both behavioral and oculomotor arousal. As has been noted in the alpha literature, there has been a great deal of confusion and

inconsistent findings when oculomotor arousal and behavioral arousal are confounded. The same may apply to the pupillometry studies that have attempted to compare behavioral arousal indicants (e.g., blood pressure, EMG) with an oculomotor process (pupillary changes). Just as there is ample evidence to indicate that suppression of alpha activity occurs as arousal decreases, however, there is ample evidence to suggest that pupil changes occur at low levels of behavioral arousal. In a review of a considerable number of studies relating pupil size and fatigue (e.g., Bartlett, Faw & Liebert, 1967; Geachintov & Peavler, 1974; Lowenstein & Loewenfeld, 1951, 1952a, 1952b; Lowenstein, Feinberg & Loewenfeld, 1963; Voss, Moyer & Hollenhorst 1970), Janisse (1977) concludes "that fatigue is associated with (1) changes in the shape of the pupillary light reflex, (2) increasing variablity in pupil size, usually slow dilations and constrictions, and (3) an overall generally smaller pupil size" (p. 75). In fact the pupil reflex has been used as a measure of fatigue (Marek, Zaryns & Noworol, 1979). Thus although Peper and Mulholland (1970) and Plotkin (1976a) have suggested that becoming drowsy need not necessarily be associated with changes in oculomotor processes, the evidence relating pupillary changes to fatigue would suggest otherwise. Again, the changes in oculomotor processes (i.e., pupillary constriction and increasing variability) could be associated with suppression of alpha activity.

Summary and Rationale

In spite of the absence of studies that have directly examined possible relationships between pupillary activity and alpha density, the two literatures have provided an abundant amount of indirect evidence to suggest that the two variables are related. As has been noted in the present review, several parallels and correlated sorts of changes have been observed in the two measures. For example, it has been noted that:

1. Photic stimulation (light flashes) which have been consistently found to attenuate alpha activity (e.g. Glass, 1977), did not do so when the pupil was rendered mydriatic and unresponsive via drugs (Lehtonen & Lehtinen, 1972). Similarly Pollen (1970) found that although reading would normally block alpha activity it failed to do so when the pupils were dilated with mydriatic drops.
2. Many researchers have suggested that alpha is prominent under dark (eyes closed) conditions and attenuated in an eyes-open illuminated environment. Further, it has been suggested (Bridgewater et al., 1975) that diffuse light (and consequent constriction pupillary movements) may have a suppressant effect on occipital alpha even when other oculomotor variables have been controlled.

3. Both alpha activity and pupil size have been found to decrease with positive convergence movements and accommodation of the lens as the eyes assume a position for viewing near objects.

4. A great deal of research has provided consistent evidence that both pupillary changes (dilation) and attenuation of alpha activity are associated with mental effort tasks. Furthermore, the magnitude of the response in both cases appears to be a function of the amount of cognitive effort required to perform the task.

5. Muller - Jensen and Hagenah (1978) reported that both the EEG and pupillogram had the same frequency, were temporarily in phase, time - locked and could be blocked by similar stimuli (at least in an unconscious man with pupillary hippus).

6. Both alpha and pupil activity have been advocated as indicants of nervous system (cortical) activation. Moreover pupillary constriction at low levels of arousal (i.e. fatique) and pupillary dilation at high levels of arousal are both associated with low levels of alpha activity.

7. Even on an anatomical and physiological basis, it has been suggested that alpha activity, and of course pupillary activity, have close ties with the oculomotor system.

All such evidence suggests that oculomotor activation, as reflected by pupillary activity serves to block or attenuate occipital alpha production in a manner consistent with the oculomotor theory. According to the oculomotor activation theory, alpha activity is blocked by any type of active oculomotor processing such as eye movements, accommodation, fixation, convergence, pursuit tracking, and as suggested, possibly pupillary changes. The integrative and efferent processes related to moving and positioning the eyes result in additional electrical activity which contaminates the EEG signal at the scalp or generator level and causes attenuation of occipital alpha. The magnitude of the blocking response remains contingent on the amount of oculomotor activity. Consistent with a visual orienting response and attentional theories, alpha attenuation would be expected to occur with most forms of novel stimuli and would be expected to habituate with repeated exposure. Consistent with arousal and activation theories, alpha attenuation will accompany both increases and decreases in arousal and/or activation at least when oculomotor activity is associated with such changes. Alpha would be prominent in the absence of oculomotor activity.

It has been suggested that alpha suppression will occur with pupillary changes either in the direction of constriction or dilation. According to the oculomotor theory, one would expect oculomotor activity of any sort (i.e., dilation

or constriction) to block alpha activity. In either case the magnitude of the blocking response would be contingent on the magnitude of the oculomotor response (i.e., the amount of pupillary activity). There has been a considerable amount of evidence presented to support the contention that alpha suppression occurs with pupillary constriction. Alpha suppression and pupillary constriction movements have been associated in the near-focus response, the light response, and with fatique. There has also been a considerable amount of evidence to suggest an association between alpha suppression and pupillary dilation (movements) in tasks requiring mental effort.

In conclusion, it is felt that the evidence suggests that oculomotor activation, as reflected by pupillary activity, serves to block or attenuate occipital alpha production. It is the purpose of the present study to explore this association.

Present Goals

In view of the indirect and suggestive evidence presented above, the present study is concerned with a systematic direct examination of the relationship between pupillary activity and occipital alpha across a variety of situations. The relationship between pupillary activity and alpha activity will be examined under four conditions which might be thought of as constituting four seperate experiments; one

involving varying levels of illumination, a second involving cognitive tasks of varying difficulty, a third involving alpha biofeedback, and a fourth involving pupil biofeedback. Since the main concern of the present study is the relationship between pupillary activity and occipital alpha, no attempt will be made to assess the effect of other oculomotor activity such as eye movements, pursuit tracking, accommodation, convergent movements or fixation. As has been noted in the review of the literature, such variables have been studied extensively in relationship to their effect on alpha activity. Rather the present study will attempt to minimize the effect of such variables by providing subject instructions, a uniform visual field, uniform illumination and a constant fixation point. In addition, eye movements and eye blinks will be detected by the pupillometer on the strip chart recorder and will be eliminated from data collection.

In the illumination experiment, the pupillary light reflex and concomitant changes in occipital alpha activity will be examined. As noted from the review of the literature, no studies have been found which have directly examined the effect of varying transitions of illumination (i.e. pupillary changes) on occipital alpha activity while controlling other oculomotor variables. There have been studies, however, which have examined the effect of very brief (e.g. 40 microseconds) flashes of light (photic stimulation) on occipital alpha activity. Although such

stimulation has been consistently found to attenuate alpha activity (Glass, 1977), it is interesting to note that Lehtonen and Lehtinen (1972) found that it did not do so when the pupil was rendered dilated and unresponsive with mydriatic drops. Similarly Pollen (1970) found that reading, which normally blocks alpha activity, did not do so when the pupils were dilated with mydriatic drops. Such results would suggest that it is not the sensory afferent activity but rather the motor efferent activity associated with eye and pupillary movements which might serve to attenuate alpha activity. This would particularly seem to be the case in Lehtonen and Lehtinen's study which effectively blocked pupillary activity and found normal alpha production. In view of such evidence, the illumination experiment in the present study will examine the suggested causal relationship. This will be accomplished by introducing four transitions in illumination (7-0, 0-15, 15-0 and 0-7 millilamberts) which will be repeated on three trials. Since it is a well-known fact that pupillary changes will accompany changes in illumination, the primary interest here is in the effect of pupillary changes (induced by changes in illumination levels) on occipital alpha activity.

The cognitive condition or experiment is proposed to examine the effect of task difficulty on both pupil and occipital alpha activity. The review of the two literatures has indicated that there are numerous studies which have

either assessed the effect of cognitive tasks of varying difficulty on the pupil or have assessed the effect of such tasks on alpha activity. Again no study was found which has examined changes in both pupil and alpha activity under identical conditions and tasks. The present experiment is designed to do so. The predicted parallels between pupil and alpha activity will be examined over three levels of tasks difficulty (very easy to very hard) utilizing a digit transformation task. Although this condition will not provide evidence for a causal relationship, it might well provide disconfirming evidence of the hypothesized relationship. This would be the case if pupillary changes were observed in the absence of alpha attenuation.

Finally, in the biofeedback experiments, the relationship between pupil activity and alpha density will be examined under two conditions. In the first condition, an alpha biofeedback model will be used in view of the close association which has been consistently found between alpha and visual control processes and the suggestion that enhancement and suppression of occipital alpha is always mediated by control of oculomotor processes (Plotkin, 1976a). The subjects will be instructed to alternately enhance and suppress alpha activity under a condition in which oculomotor activity (with the exception of pupillary movements) will be minimized. Given that the subjects are able to control alpha, one would expect to find differences in pupil activity between enhance and suppress trials. In

order to further assess the viability of an oculomotor mediational strategy as reflected by pupillary changes, a pupil biofeedback condition will also be designed. Although a pupil biofeedback study has not been attempted, Prather, Berry, and Payne (1971), and Prather and Berry (1973) have found that pupil size could be shaped using verbal reinforcement. Consequently, it is expected that it can be similarly shaped with accurate feedback information. The subjects will be instructed to alternately constrict and dilate pupil size under conditions in which other oculomotor activity is minimized. The correlated activity of the two response systems will be examined under both forms of biofeedback.

Statement of the Hypothesis

The present experiment will test the following hypotheses generated by the oculomotor activation theory.

Related to illumination.

1. Given that the pupils of normal, alert subjects are usually large and relatively quiet in complete darkness and become smaller and more active with increasing light, it is hypothesized that alpha activity and pupil size will vary concomitantly with changes in illumination, with the greatest pupillary constriction and variability, and the

least amount of alpha activity occuring at the highest illumination level.

Related to cognition.

2. Pupil size will increase and alpha activity will decrease as a function of increasing task difficulty.

Related to biofeedback conditions.

3. There will be a significant difference in alpha activity under enhancement and suppression conditions of alpha biofeedback where it is expected that the pupil will be less variable under alpha enhancement than under alpha suppression conditions.

4. There will be a significant difference in pupil size under constrict and dilate conditions of pupil biofeedback and the amount of alpha activity will be an inverse function of the amount of pupillary activity.

Although not directly related to a test of the relationship between alpha density and pupillary activity, there are certain other results which would be expected to occur:

Given that it has been a consistent finding in the literature that alpha production is greatest when the eyes

are closed, it is expected that the greatest alpha production will occur for the eyes-closed versus the eyes-open baseline condition.

Also since initial apprehensions about an experiment and the novelty of experimental situations have been extensively demonstrated to have a suppressant effect on alpha activity during initial baseline measures, it is expected that alpha production for both eyes-closed and eyes-open baselines will be greater for the second than for the first experimental session.

Chapter II

METHOD

Subjects

The subjects were 16 female undergraduates enrolled in summer or evening courses at the University of Manitoba and 4 female volunteers from outside the university (mean age 22.45 years). All the subjects volunteered to participate in a. . . "study designed to assess the effect of varying light levels and arithmetic tasks on brain wave activity." In addition they were informed that they would be . . . "given an opportunity to learn to control their own brain waves as well as the size of their own pupils through biofeedback procedures." Eight other subjects were eliminated before they completed the experiment as result of excessive blinking (1), equipment failure (1), blindness in one eye (1), eyelid interference (3) and failure to return for the second session (2).

Experimental Design

In view of the individual variability of both alpha and pupillary activity and other practical considerations of the present study (e.g. the limited number of subjects available, the total amount of time required of each subject, the amount of time required to position subjects into the apparatus, and the need to habituate subjects to the experimental equipment), each subject served as her own control in every condition of the study. Consequently, the study was a completely within-subjects design with what might be thought of as four seperate experiments; (1) a level of illumination experiment, (2) a level of cogitive task difficulty experiment, (3) an alpha biofeedback experiment, and (4) a pupil biofeedback experiment. In each case, alpha density (a percent-alpha measure) and pupil activity (pupil size and pupil variability) served as the dependent variables.

The first experiment, related to levels (transitions) of illumination, consisted of a 4x3x14 within-subjects repeated measures design with four transitions of illumination level (7-0, 0-15, 15-0, and 0-7 millilaberts), three trials at each level, and 14 sequential epochs (measurements) of each dependent variable within each trial.

The second experiment related to level of task difficulty and was a 3x3x3 within-subjects repeated measures design with three levels of task difficulty, three trials at each

level, and three measures of loading-unloading within each trial. The data was later reorganized so as to yeild two measures of loading-unloading and three measures (early, mid and late) of sequence within each trial in what became a 3x3x2x3 within-subjects design.

Both the alpha biofeedback and pupil biofeedback experiments were 2x3x4 within-subjects repeated measures designs with two training sessions (increase and decrease), three trials within each session, and four sequential epochs (measurements) of each dependent variable within each trial.

Apparatus

The study was conducted in a quiet pupillometer and eye movement research laboratory (4.5 x 9 meters) which housed both the subject and the physiological recording equipment. The subject was seated (with the equipment behind her) as comfortably as possible in an adjustable arm chair with her head positioned against both the chin and forehead rests of the pupillometer. Care was taken to ensure the subject could comfortably view the target.

The experimental chamber provided uniformly mat-white-colored walls, ceiling, and floor to reduce contrast effects in the visual field. The subjects were placed 3 meters directly in front of a 4.5 x 2.5 meter mat-white wall which subtended their field of vision at 50 degrees horizontal and

65 degrees vertical. In the middle of their field of vision the subjects were provided with a constant X - fixation point (4 x 4 cm) with indefinite edges so as to appear blurred when it was viewed at 3 meters from the eye. It served to ensure constant illumination and reduce the effects of eye movements, convergent movements, and accommodation. Lighting was provided by 5 adjustable incandescent light sources powered by a constant voltage transformer and originating behind the subject. They were directed by aluminated reflectors so as to provide uniform illumination to the entire visual field. The intensity of the illumination was adjustable to 0, 7, and 15 millilamberts measured at the subject's eye.

The bipolar occipital EEG was recorded from positions O1 - O2 of the 10 - 20 system (Jasper, 1958) with ASI standard EEG electrode assembly housed in cylindrical sponge discs and used with a modified saline conductive solution (140 ml water, .05 ml liquid soap and 5 ml of salt). The ground electrode, which merely acts as a terminal to conduct the common mode (interference) voltage from the subject to a neutral reference, was placed on the forehead supra-orbitally to the right eye.

The EEG signal was recorded and amplified by an Autogen 120 encephalograph analyzer which was calibrated prior to the experiment at the Autogen Laboratory (Berkley, California). The EEG signal was fed through the EEG filter system (60Hz band pass filter) set to filter out a signal in the

8-13 Hz range with an amplitude requirement of 10 uV. The Autogen monitor test function was used to test for adequate electrode contact. A MFE (M-22, CAHA, 75 watt) multi-channel strip chart recorder via a BFT 231 optical isolator was interfaced with the Autogen 120 to provide a recording of filtered alpha activity (chart speed 5 mm/sec). For the alpha biofeedback experiment, the Autogen 120 was set to provide a proportional (analog) type tone feedback (through a Sony SS - 23, 6 - 12 watt speaker with 8 ohm impedance) indicative of both frequency and amplitude shifts within the alpha range.

Pupil size was monitored on a Whittaker Space Sciences Model 1992S Television Pupillometer which provided 60 measures per second. The system provided a sensitive 75 ohm silicon matrix television camera which functions at a very low illumination. The illuminator was a low level near infrared light source centered at 8500 Angstroms. The pupillometer was also interfaced with the MFE to provide a simultaneous continuous recording of both alpha activity and left eye pupil size. Pupillometer calibration and pupil diameter analog output (MFE) were checked against a standard model pupil prior to each session. A Coulbourne solid state audio generator (power supply, S15-05; audio mixer amplifier, 582-24; and voltage controlled oscillator, S24-05) coupled with a Sony SS-23 speaker and interfaced with the pupillometer provided the auditory proportional type tone feedback for the pupil biofeedback experiment.

Procedure

On arrival at the laboratory, the subjects were once again informed about the nature of the study. Also, at this time, they were informed about the procedure of electrode placement. In addition, every effort was made to reduce any tension or apprehension about the novel situation. To this end, all pertinent information about the physical set-up (e.g. the purpose of electrodes, the equipment, the sound of the feedback tone) and the general procedure (e.g., the number of trials, the various phases of the experiment) was explained to the subjects. Moreover any questions were answered when it was felt that the answers would not reveal the specific purposes of the experiment.

Each subject participated in each of the four experimental conditions; illumination, cognitive task, alpha biofeedback and pupil biofeedback. In view of the time limits on each session which made it impossible to run both of the biofeedback experiments in one session, the conditions were counterbalanced within the limits that one of the biofeedback experiments plus either the illumination or cognitive condition were run in each session. In addition, an adaptation period, an eyes-closed baseline, and an eyes-open baseline were given in both Session I and Session II. The sessions were approximately 1.5 hours each in length and averaged 3.9 days apart.

Adaptation Period. After a phase where recording electrodes were attached and the subjects were seated comfortably under low ambient lighting (7 millilamberts) with their head positioned against the chin and forehead rests, they were given a 5-minute rest or adaptation period. During this time they were allowed to move and look around so as to acquaint themselves with the environment and the most comfortable position. No recordings were made during this period.

Eyes-Closed Baseline. Following the adaptation period the subjects were instructed to place themselves in position, to close their eyes, and to refrain from moving for the next 4-minute period. During this time their eyes-closed baseline level of alpha activity was recorded.

Eyes-Open Baseline. The eyes-closed baseline was followed by another 4-minute baseline period during which time the subjects were instructed to open their eyes, to look in the direction of the target, and to refrain from excessive movements, eye blinks, or eye movements. This period served as a baseline for both eyes-open alpha activity and pupil size. This was followed by a brief rest period (4-minutes) following which the subjects received their instructions for the next condition.

Illumination Experiment. The specific experimental instructions as they were read to the subjects appear in Appendix A. In the illumination experiment the subjects were given three trials of the following combination of

transitions of three levels of illumination; 7-0-15-0-7-0-15 millilamberts. The duration of each of the 21 exposures was 30 seconds. There was a 1-minute rest period between trials. After a brief rest period the subjects completed a postexperimental questionnaire for this phase of the study (see Appendix E).

Cognitive Experiment. The specific experimental instructions for this experiment are presented in Appendix B. In the cognitive experiment the task was a digit-transformation procedure in which the subjects were presented with a randomly generated 4-digit sequence (limited to numbers between 1 and 6) (see Appendix B). The digits were presented to the subjects by the experimenter at 1-second intervals. Three levels of difficulty were introduced; Add 0, Add 1, and Add 3. During the "Add 0" (least difficult) level the subjects were asked to "Add 0 to each of the following digits and repeat". For the "Add 1" level (medium difficulty) the subjects were asked to "add 1 to each of the following digits and repeat". For the "Add 3" (most difficult) level the subjects were asked to "Add 3 to each of the following digits and repeat". No attempt was made to monitor the accuracy of the subjects responses. Three trials were presented at each level of difficulty. The same random sequence of level of difficulty were presented to each subject (see Appendix B). After a brief rest period the subjects completed a postexperimental questionnaire for each of the levels of difficulty (Appendix F).

Alpha Biofeedback Experiment. The specific instructions for the alpha biofeedback experiment appear in Appendix C. This experiment consisted of three 4-minute "alpha on" (increase) trials alternating with three 4-minute "alpha off" (decrease) trials with six 1-minute interspersed rest periods during which time auditory feedback was terminated. After a brief rest period following this condition the subjects completed a postexperimental questionnaire for the increase and for the decrease trials (Appendix G).

Pupil Biofeedback Experiment. The specific instructions for the pupil biofeedback experiment are presented in Appendix D. This experiment also consisted of three 4-minute dilation (increase) trials alternating with three 4-minute constriction (decrease) trials with 6 interspersed 1-minute rest periods. An auditory proportional-type of feedback was provided for successful changes in pupil size in the desired direction. No feedback was provided during the rest periods. Again after a brief rest period the subjects completed a postexperimental questionnaire for the increase trials and one for the decrease trials (Appendix H).

Scoring Procedure

All the raw data from the MFE recorder strip charts was analyzed by two experimental scorers. The conditions were divided between the scorers so that one analyzed Session I baseline, the illumination experiment, and the alpha biofeedback experiment while the other analyzed Session II baseline, the cognitive and the pupil biofeedback experiment. Interscorer reliabilities (Pearson Product Moment correlations) were computed for the baseline conditions, illumination experiment, cognitive experiment, and biofeedback experiments. For each condition, eight random samples of alpha density and eight samples of pupil size were derived from each of three randomly chosen subjects for a total of 24 pairs of measures of alpha density and 24 pairs of measures for pupil size in each condition. The interscorer reliabilities were r = .998 (alpha density) and r = .99 (pupil size) for baselines; r = .98 (alpha) and r = .99 (pupil) for illumination; r = .99 (alpha) and r = .97 (pupil) for the cognitive task; and r = .99 (alpha) and r = .96 (pupil) for the biofeedback experiments.

The MFE strip chart data was scored seperately for each of the experimental conditions as following:

Baseline Conditions. The baselines for both Session I and Session II were scored in an identical fashion. A total of four 20-second (100 mm) samples were taken from the middle of each minute of the 4-minute eyes-closed and 4-minute eyes-open baselines. Given that the MFE paper is

calibrated into 1 mm blocks, the percent alpha was calculated by counting the total number of 1 mm blocks crossed by the pen while deflected in the direction indicative of supra threshold alpha activity.

Ten measures of pupil size were taken over the same 20-second samples from which the alpha measures were derived. The MFE was calibrated for each subject so that 1 mm of pupil change would be represented by 1 cm of pen deflection making it possible to accurately read pupil size to 0.1 mm. Eye movements, eye blinks and the corresponding pen deflections were eliminated. If an eye movement or eye blink corresponded to a point of pupil size measurement, the point was advanced to the end of the artifact.

Illumination Experiment. Alpha density and pupil size were determined in the same fashion for the -7 (7-0), +15 (0-15), -15 (15-0), and +7 (0-7) millilambert illumination conditions. A total of 14 measures (10 mm samples) of pupil size and of alpha density were taken for each 28-second presentation (trial) of each illumination condition.

Cognitive Experiment. Again alpha density and pupil size were determined in the some fashion for the three cognitive conditions. Each presentation, however, was divided into loading (L) mid-loading (M-L) and unloading phases (UL). The loading phase corresponded to the time between the presentation of the first and last digit; mid-loading corresponded to the time between the end of the loading and beginning of unloading phases; and the unloading phase began

at the point the subject began repeating the digits and ended when the subject completed the repetition. Pupil size and alpha density were calculated for every second (5 mm) of loading, mid-loading and unloading.

Given the variability in the speed with which the subjects performed this task, the number of measures between the subjects also varied. Moreover, since the mid-loading phase was quite short (1-3 seconds) any measure of pupil variability within this phase was biased. Consequently the loading and mid-loading phases were later combined and an equal number of mean alpha and pupil size measures were calculated for loading and unloading phases (early, mid, and late loading; early, mid and late unloading).

Biofeedback Experiments. The same scoring procedure for alpha density and pupil size was used for both the biofeedback experiments. As with the baseline conditions, a total of four 20-second (100 mm) samples were taken from the middle of each minute for each 4-minute trial of increase and decrease conditions of alpha and pupillary biofeedback. Again 10 measures of pupil size were taken from the same 100 mm sample from which alpha density was calculated.

Chapter III

RESULTS

Alpha Baseline

The alpha baseline data was analyzed in a 2x2x4 completely within-subjects factorial analysis of variance with Session I versus Session II and eyes-closed versus eyes-open with four successive epochs of measurement (trials) in each condition (Table 1). The analysis of variance indicated that as expected there was a significant difference in alpha production for Session I (M = 67) versus Session II (M = 80). Also, as expected, the eyes-closed alpha production (M = 78) was greater than the eyes-open alpha production (M = 69) for both Session I (EC M = 71; EO M = 63)) and Session II (EC M = 84; EO M = 75). The trials main effect was not significant. The only significant interaction was that of session, eye-condition and trails. In view of this interaction, the Newman-Keuls Multiple Range Test was used to assess Session I versus Session II differences across trials 1 - 4 of both eye conditions (see Table 2). As shown in Table 2 both the eyes-closed and eyes-open alpha densities were significantly greater in Session II than Session I over all trials. The eyes-closed versus eyes-open

differences, however, were only significant for Trial 4 of Session I and Trials 1, 2 and 3 of Session II.

To summarize, the analysis of alpha baseline data suggest that there was greater alpha production associated with the eyes-closed versus eyes-open conditions and with Session II versus Session I. The effects were qualified by the interaction of session, eye-condition and trials such that eyes-closed alpha production was greater than eyes-open alpha production for Trial 4 of Session I and Trials 1, 2 and 3 of Session II.

TABLE 1

ALPHA BASELINE ANOVA

Source	df	MS	Error	F
Session (S)	1, 19	12393.98	1414.71	8.76*
Eye condition (E)	1, 19	5674.24	600.50	9.45*
Trials (T)	3, 57	49.07	105.12	0.47
S x E	1, 19	20.25	266.81	0.08
S x T	3, 57	19.13	55.91	0.34
E x T	3, 57	11.72	80.47	0.15
S x E x T	3, 57	291.19	59.70	4.88*

*p < .01

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TABLE 2

POST-HOC ANALYSIS OF ALPHA BASELINE SESSION BY EYE-CONDITION BY TRIAL INTERACTION

Comparison	Trial	Critical Difference	Mean Difference
ECI vs ECII	1	8.67	14.7*
	2	8.67	14.5*
	3	8.67	14.3*
	4	6.85	8.3*
EOI vs EOII	1	8.0	9.0*
	2	8.46	11.7*
	3	7.6	8.4*
	4	8.99	18.5*
ECI vs EOI	1	6.85	5.3
	2	7.31	6.7
	3	6.17	4.9
	4	8.67	14.6*
ECII vs EOII	1	8.0	11.0*
	2	7.6	9.5*
	3	8.0	10.8*
	4	5.09	4.4

*$p < .05$

Pupil Baseline

The mean pupil size over the four epochs of the eyes-open baseline across sessions (I versus II) were analyzed with a two within factor ANOVA (see Table 3). The analysis indicated a highly significant trial effect and a tendency for pupil size to decrease across trials of both Session I and Session II. There were, however, no differences in pupil size between sessions (Session I, M = 3.91; Session II, M = 3.96) nor was there an interaction between sessions and trials. Moreover, a similar ANOVA on the pupil variability measures (Table 4) indicated that there were no significant differences in pupil variability between sessions or across trials.

In summary, the only significant difference that emerged for pupil baseline data was a decrease in pupil size across trials of both sessions. This is an expected effect in pupillometry studies (Janisse, 1977).

Summary of Baseline Results. As hypothesized the results of baseline analyses indicated that greater alpha densities were associated with eyes-closed versus eyes-open conditions and with Session II versus Session I baselines. The only significant finding emerging for the pupil baselines was a significant decrease in pupil size across trials.

TABLE 3

PUPIL BASELINE ANOVA: PUPIL SIZE

Source	df	ms	Error	F
Session (S)	1,19	0.1156	0.2336	0.49
Trial (T)	3,57	0.0978	0.0085	11.45*
S x T	3,57	0.0088	0.0060	1.45

*p < .0000

TABLE 4

PUPIL BASELINE ANOVA: PUPIL VARIABILITY

Source	df	MS	Error	F
Session(S)	1,19	0.0054	0.0035	1.56
Trial(T)	3,57	0.0002	0.0015	0.12
S x T	3,57	0.0001	0.0008	0.17

Illumination Experiment

Alpha Density. The alpha data in the illumination experiment was analyzed for separate illlumination levels in a 4x3x14 completely within-subjects factorial analysis of variance design with four transitions in illumination (-7, +15, -15, +7) repeated on three trials and 14 sequential epochs per illumination trial. The results of the three-way within-subjects ANOVA indicated a significant main effect for illumination level and a significant main effect for epochs (see Table 5). Closer examination of the data however, indicated that the test of compound symmetry for the epoch error suggested a violation of the assumption of variance-covariance symmetry ($p = .035$, 19df). Consequently the Greenhouse-Geisser correction (Greenhouse & Geisser, 1959; Winer, 1971) was made to the degrees of freedom. As a result the epoch effect was no longer significant ($F(1,19) = 2.81$, $p < .12$).

Newman-Keuls Multiple - Range Tests (Table 6) confirmed that the main effect for illumination was accounted for by the difference between the two increasing illumination (+7, +15) conditions ($M = 64$) versus the two decreasing (-7, -15) illumination conditions ($M = 58$) as may be seen in Figure 1. The data do not support Hypothesis 1 which specified that the greatest amount of alpha activity would occur at the

lower illumination levels (-7, -15) and the least amount of alpha with the higher illumination levels (+7, +15).

TABLE 5

ALPHA ILLUMINATION ANOVA

Source	df	MS	Error	F
Illumination (I)	3,57	8183.23	1187.68	6.89*
Trial (T)	2,38	5307.25	6243.44	0.85
Epoch (E)	13,247	1210.92	431.49	2.81*
I x T	6,114	182.14	828.16	0.22
I x E	39,741	446.75	426.11	1.05
T x E	26,494	385.10	416.02	0.93
I x T x E	78,1482	320.05	429.12	0.75

*p < .001

TABLE 6

NEWMAN-KEULS TEST OF THE MAIN EFFECT FOR ILLUMINATION LEVELS

Comparison	Critical Difference(Cd)	Mean Difference(Md)
-7 vs +15	3.367	4.4*
-7 vs +7	4.046	5.97*
-7 vs -15	3.367	0.22
-15 vs +15	4.046	4.62*
-15 vs +7	4.451	6.19*
+15 vs +7	3.367	1.57

Note: df = 57

*p < .05

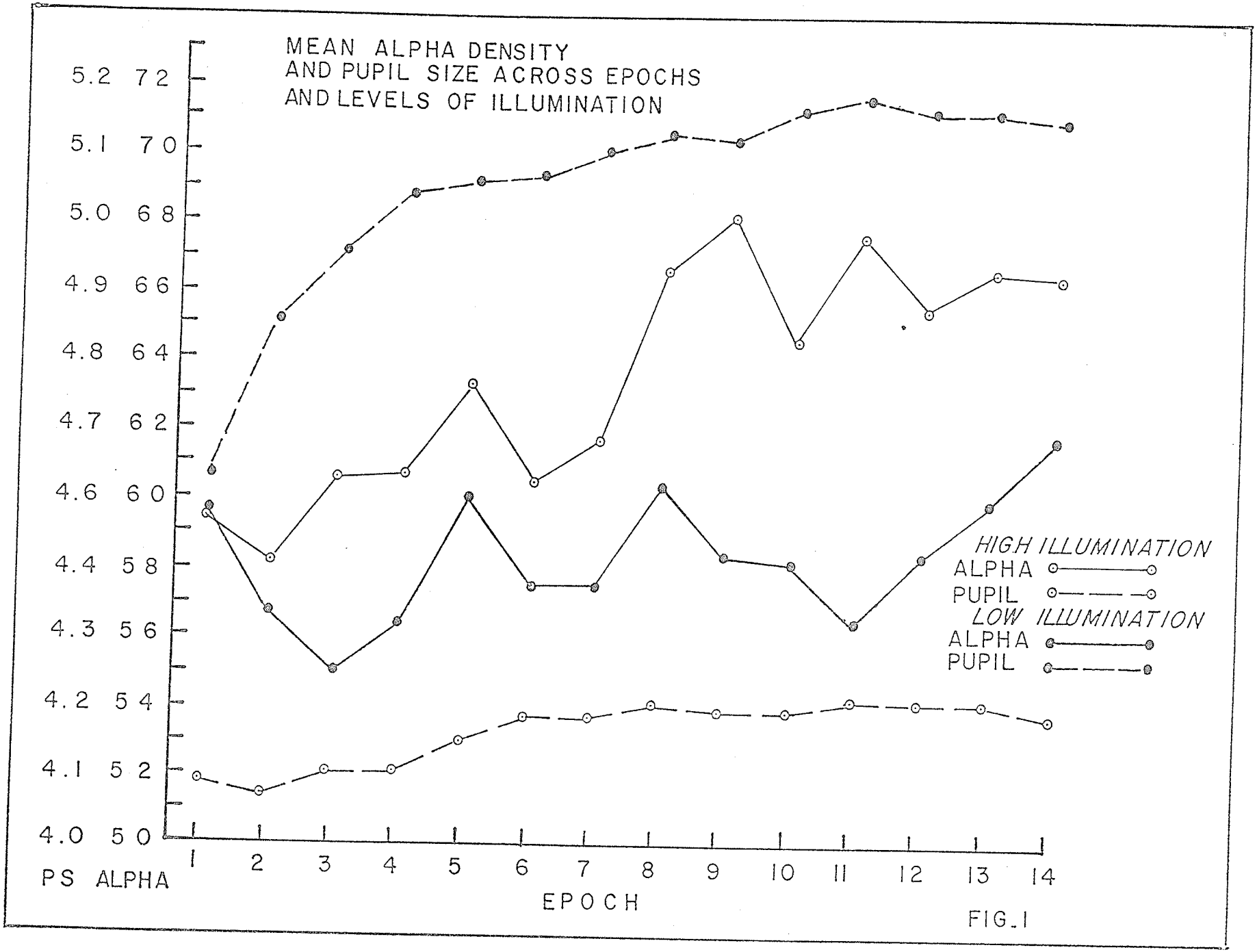
MEAN ALPHA DENSITY
AND PUPIL SIZE ACROSS EPOCHS
AND LEVELS OF ILLUMINATION
5.2 72
5.1 70
5.0 68
4.9 66
4.8 64
4.7 62
4.6 60
4.4 58
4.3 56
4.2 54
4.1 52
4.0 50
PS ALPHA
1 2 3 4 5 6 7 8 9 10 11 12 13 14
EPOCH
HIGH ILLUMINATION
ALPHA
PUPIL
LOW ILLUMINATION
ALPHA
PUPIL

FIG. 1

Pupil Size. The pupil size data for the illumination experiment was analyzed in the same fashion as the alpha data. The results of the three-way within-subjects analysis of variance are presented in Table 7. Table 7 is indicative of highly significant main effects for level of illumination and epochs, and significant interaction of illumination by epochs and illumination by trials by epochs. The compound symmetry test, however, suggested a violation of the assumptions of variance-covariance symmetry for the main illumination effect ($p = .00$, 19df), and for the epoch effect ($p = .00$, 19df). Although there were insufficient degrees of freedom for a compound symmetry test of the illumination x epochs interaction or the illumination x trials x epochs interaction, the violations for the main effects plus the significant symmetry test of the interaction of illumination and trials ($p = .015$, 19df) suggested an overall violation of compound symmetry. Consequently the Greenhouse-Geisser correction was made for the degrees of freedom of all the effects presented in Table 7. All the effects remained significant at least at the .001 level with the exception of the three way interaction of illumination, trials and epochs ($F\ (13,247) = 1.62, p < .10$).

Not surprisingly, the larger pupil size was associated with the lower illumination levels (-7, -15) and smaller pupil size was associated with the higher illumination levels (+7, +15). Newman-Keuls Multiple - Range Tests

confirmed that the illumination effect was accounted for by the difference between constrict and dilate trials (-7 vs +15, Cd(57) = .217, Md = .952, $p < .05$; -7 vs +7, Cd(57) = .197, Md = .865, $p < .05$; -15 vs +7, Cd(57) = .164, Md = .833, $p < .05$). There were no differences between the two constrict (+7 vs +15, Cd(57) = .164, Md = .087) or the two dilate (-7 vs -15, Cd(57) = .164, Md = .032) illumination levels. The effect across epochs and high versus low illlumination conditions is presented graphically in Figure 1 along with the alpha density data.

As is obvious from Figure 1 there was a much more dramatic change in pupil size associated with the dilate (-7 and -15 combined) conditions. This was particularly the case with the first 7 epochs. Although the difference was not significant [$t(82) = 1.43$, $p < .20$] it is also interesting to note that the greatest between and within-subject pupil variability was associated with the -7 (M = .45) and -15 (M = .47) dilate conditions vis-a-vis the +7 (M = .36) and +15 (M = .39) constrict conditions. This is particularly relevant in view of Hypothesis 1 which assumed that the greatest pupil variability would be associated with the constrict (highly illumination) conditions. The data here suggest that this was not the case but rather the greatest within-and between-pupil variability tended to be associated with the dilate conditions.

Also as can be seen from Table 7, the main effect for epochs (the significant increase in pupil size across epochs) was qualified by a significant interaction of illumination level by epochs. As depicted in Figure 1 the increase in pupil size across epochs was significantly greater for the dilate (-7, -15) versus the constrict (+7, +15) illumination levels. Again this confirmed that the greatest change in pupil size was associated with the dilate conditions; not with the constrict conditions as hypothesized.

In summary then the analysis of the pupillary data demonstrated the obvious inverse relationship between pupil size and illumination level. The data also indicated that there was a significant increase in pupil size across epochs for the lower (dilate) illumination levels. Although it had been assumed that the greatest pupil variability would be found under the constrict conditions, the present data suggest a slight tendency for greater pupil variability with the dilate conditions.

TABLE 7

PUPIL ILLUMINATION ANOVA

Source	df	MS	Error	F
Illumination Level(I)	3,57	224.313	2.861	78.39**
Trials(T)	2,38	1.0392	0.4066	2.56
Epochs(E)	13,247	2.2968	0.0555	41.37**
I x T	6,114	0.3645	0.2744	1.33
I x E	39,741	0.2791	0.0388	7.20**
T x E	26,494	0.0348	0.0307	1.13
I x T x E	78,1482	0.0522	0.0321	1.62*

*p < .001
**p < .0001

Alpha and Pupil Size Correlations. The relationship between alpha density and pupil size for individual illumination levels was investigated with Pearson product-moment correlations. Since correlation coefficients were computed for each epoch in each of the three trials, there were a total of 42 comparisons for each illumination level (Table 8). In view of the small sample size (n = 20) on which each correlation was based and therefore the low probability of finding significant correlations unless they were quite large (r = .38 for significance at .05 level in one-tailed tests) the correlations were averaged for seperate illumination levels and tested by procedures described by McNemar (1966) to determine whether the obtained correlations represented a nonchance relationship. Z - transformations and test of significance for each illumination level indicated that the average correlation of r=.15 for the +7 condition (Mz = .155 SE = .037, $p < .0001$), the average correlation of r=.13 in the +15 condition (Mz = .13, SE = .037, $p < .0002$) and the average correlation of r= -.07 in the -7 condition (Mz = -.072, SE = .037, $p < .03$) could be considered significantly greater than zero. The average correlation for the -15 condition of -.05 (Mz = .054, SE = .037, $p < .08$) could not be considered as deviating significantly from a nonchance occurence. At best then the tendency for alpha and pupil size to vary together seems only minimal and most noticeable for the higher illumination levels where the pupil was also less variable.

TABLE 8

ALPHA AND PUPIL SIZE CORRELATIONS FOR ILLUMINATION LEVELS

Comparison		+7 r	+15 r	-7 r	-15 r
Trial 1, Epoch	1	-.07	-.19	-.07	-.14
	2	.33*	.04	.20	.01
	3	.37*	.01	.27	-.17
	4	.10	.13	-.09	.12
	5	.51**	.34*	.25	.42**
	6	.33*	.45**	-.24	-.35*
	7	.31*	-.12	-.17	.12
	8	.48**	.44**	.20	.31*
	9	.10	.50**	.20	.31*
	10	.16	.29	-.15	-.53**
	11	.19	.30	.42**	-.08
	12	.09	-.02	-.02	.20
	13	.05	-.04	-.48**	-.06
	14	-.21	.04	-.27	.00
Trial 2 Epoch	1	.01	.25	-.24	-.08
	2	-.29	-.20	.19	-.40**
	3	.03	.06	.05	.31*
	4	.03	.41**	-.13	-.09
	5	-.01	.24	.17	-.19
	6	.19	.33*	-.30	.20
	7	.25	.33*	-.24	-.05
	8	.23	.05	.08	-.06
	9	.05	.10	-.17	-.23
	10	.40**	.36*	-.17	-.23
	11	.03	.18	-.25	-.08
	12	.28	.22	-.30	-.03
	13	.45**	-.04	-.04	.23
	14	.18	-.01	-.32*	-.04
Trial 3, Epoch	1	-.04	.10	-.13	.06
	2	-.01	-.09	.08	-.13
	3	.15	-.02	.38**	-.10
	4	.06	.34*	-.03	-.07
	5	.15	.34*	-.03	-.07
	6	-.04	-.07	.15	-.24
	7	-.25	.64**	-.14	-.39**
	8	.25	-.16	-.26	.05
	9	-.20	-.13	-.24	-.26
	10	.31*	.04	-.17	-.30
	11	.11	-.31*	-.24	-.01
	12	-.13	.08	-.13	.00
	13	.40**	.08	.06	-.21
	14	.31*	.19	.06	.09

*p < .10
**p < .05

Postexperimental Questionnaire. The subjects mean rating and the frequency distribution across the 12 rating scales of the postexperimental questionnaire are presented in Table 9. The means represent the subjects ratings over all levels of illumination. The questionnaire was not designed to compare various illumination levels (See Appendix B-1). Overall (as depicted in Table 9) the subjects rated the experiment as requiring some alertness, attentiveness and concentration and as being relaxed, easy and unfrustrating.

TABLE 9

POST-EXPERIMENTAL QUESTIONNAIRE : ILLUMINATION CONDITION

Scale	Rating 1	2	3	4	5	6	Mean
Alert(1) - Drowsy(6)	3	9	1	4	3	0	2.75
Unpleasent(1) - Pleasent(6)	0	1	8	5	6	0	3.8
Relaxed(1) - Unrelaxed(6)	4	9	1	4	2	0	2.55
Actively Thinking(1)- Not thinking(6)	0	7	5	6	2	0	3.15
Anxious(1) - Not anxious(6)	1	1	3	3	7	5	4.45
Not Frustrated(1)- Frustrated(6)	12	5	2	1	0	0	1.6
Unmotivated(1)- Motivated(6)	2	1	3	9	2	3	3.85
Attentive(1)- Inattentive(6)	6	11	2	1	0	0	1.9
Effortful(1)- Effortless(6)	6	1	3	3	3	4	3.4
Difficult(1) - Easy(6)	0	1	4	6	5	4	4.35
Actively Concentrating(1)- Not Concentrating(6)	4	7	6	2	1	0	2.45
Clear Vision(1)- Blurred Vision(6)	1	4	5	2	4	4	3.8

Note: 1 = very
2 = moderately
3 = slightly
4 = slightly
5 = moderately
6 = very

Summary of Illumination Results. As expected, the larger pupil size was found for the lower illumination levels (-7, -15) and smaller pupil size was found for the higher illumination levels (+7, +15). Greater alpha production, contrary to expectations, was found during higher illumination (constrict) conditions. In addition, the results indicated that there was a significant increase in pupil size across epochs for the dilate illumination conditions which suggested that the greatest change in pupil size (and lowest alpha production) was associated with the dilate conditions. It was expected that the pupil would be more variable and consequently there would be less alpha under the constrict conditions. In any event, the greatest alpha production occured under the higher illumination (constrict) conditions where there was a slight tendency for lower between and within-subject pupil variability.

The correlational analysis, revealed at best only a minimal tendency for alpha density and pupil size to vary together between subjects. This tendency was most pronounced for the higher illumination constrict conditions where the pupil was less variable within subjects and where pupil size and alpha density tended to covary between subjects in a positive fashion. Overall the subjects rated the experiment as requiring some alertness, attentiveness and concentration and as being relaxed, easy and unfrustrating.

Cognitive Experiment

Alpha Density (L, U-L). The alpha density data for the cognitive task condition was inititally analyzed in a 3x3x2 within-subject design with three levels of task difficulty, three trials at each level, and two measures of loading for each trial (L = loading, and UL = unloading). Since the mid-loading (M-L) phase was often very short and in many cases only contained a single measure, it was eliminated from analysis. The results of the ANOVA (Table 10) suggested that there were no differences in alpha production for level of difficulty or trials. Only the effect for loading was significant and suggested that there was a decrease in alpha production from L (M = 54.91) to U-L (M = 48.66) phases.

TABLE 10

COGNITIVE ANOVA (L, U-L) FOR ALPHA DENSITY

Source	df	MS	Error	F
Difficulty(D)	2,38	350.32	386.22	0.91
Trial(T)	2,38	359.00	594.43	0.6
Loading(L)	1,19	3520.53	417.02	8.44*
D x T	4,76	551.82	380.87	1.45
D x L	2,38	4.57	394.81	0.01
T x L	2,38	105.82	268.99	0.39
D x T x L	4,76	173.49	295.64	0.59

*p < .01

Alpha Density (Sequence). In order to include the M-L data into the analysis and in order to explore the trends within the loading and unloading phases, the data was regenerated. The L and M-L phases were combined and an equal number of mean alpha measures were calculated for loading (early, mid and late loading) and unloading (early, mid and late unloading). The data were analysed in the same fashion above with the addition of three levels of sequence (early, mid and late). The results of the repeated measures ANOVA are presented in Table 11.

As may be seen from table 11 only the main effect for sequence was significant ($p = .0258$). There was a tendency for alpha to decrease across early ($M = 52.6$), mid ($M = 51.25$) and late ($M = 48.30$) phases of both loading and unloading trials. The compound symmetry test however revealed a violation of symmetry of variance-covariance matrices ($p = .0342$, 19df). With the Greenhouse-Geisser correction, the sequence effect only approached the chosen level of significance ($F(1,19) = 4.04$, $p < .06$). The effect for loading also only approached significance ($F(1,19) = 4.03$, $p = .0592$) indicating a tendency for a higher alpha density during loading ($M = 52.13$) than during the unloading phase ($M = 48.53$).

Although it was hypothesized (Hypothesis 2) that alpha production would decrease as task difficulty increased, there was no effect for difficulty. It is interesting to note, however, that alpha density during all of the

cognitive tasks was significantly lower than the eyes-open baseline level [$t(19) = 3.04$, $p < .005$]. On the basis of this it might appear as though alpha production was equally blocked by all the cognitive tasks and this blocking effect was maintained over both loading and unloading phases of the cognitive tasks.

TABLE 11

COGNITIVE ANOVA (SEQUENCE) FOR ALPHA DENSITY

Source	df	MS	Error	F
Difficulty(D)	2,38	715.49	1059.96	0.68
Trial(T)	2,38	140.12	1846.98	0.08
Loading(L)	1,19	3902.60	969.02	4.03
Sequence(S)	2,38	1683.43	417.16	4.04*
D x T	4,76	1661.35	1009.21	1.65
D x L	2,38	369.50	1444.99	0.26
T x L	2,38	81.67	727.60	0.11
D x S	4,76	768.20	517.37	1.48
T x S	4,76	539.02	437.47	1.23
L x S	2,38	1228.14	678.44	1.81
D x T x L	4,76	321.95	946.82	0.34
D x T x S	8,152	328.22	464.42	0.71
D x L x S	4,76	219.87	430.93	0.51
T x L x S	4,76	1205.53	521.62	2.31
D x T x L x S	8,152	855.99	460.81	1.86

*p < .05

Alpha Variability (L, U-L). In view of the fact there were few changes in average alpha production with the cognitive tasks, yet some indication that alpha was blocked by the tasks, the data for alpha variability (within-subject standard deviations) for each subject was also analysed. The results of this analysis for three levels of difficulty, three trials and two levels of loading (L, U-L) are presented in Table 12. The analysis revealed a significant main effect for loading, qualified by an interaction of difficulty and loading. The effect for level of difficulty (Add 0, Add 1, Add 3) only approached significance ($p = .0586$) indicating only a slight tendency for alpha variability to increase as difficulty increases (Add 0 M = 13.06; Add 1 M = 18.4; Add 3 M = 19.08).

The significant main effect for loading revealed that alpha was significantly more variable during the loading versus the unloading phase. The loading effect, however, was qualified by a significant loading by level of difficulty interaction. Newman-Keuls Post-hoc analysis revealed that the loading versus unloading effect was only significant for the Add 0 (L vs U-L, $Cd(76) = 4.02$, $Md = 11.13$, $p < .01$) and the Add 1 (L vs U-L $Cd(76) = 4.02$, $Md = 4.61$ $p < .05$) levels of difficulty. There was no difference in alpha variability between the loading and unloading phases of the Add 3 level of difficulty (L vs U-L, $Cd(76) = 3.43$, $Md = 0.51$). The trend in this data suggest that as level of

difficulty increased the loading effect decreased; Alpha remained more variable and did not recover by the U-L phase.

TABLE 12

COGNITIVE ANOVA (L, U-L) FOR ALPHA VARIABILITY

Source	df	MS	Error	F
Difficulty (D)	2,38	763.17	249.35	3.06
Trial (T)	2,38	149.01	140.67	1.06
Loading (L)	1,19	2320.21	184.21	12.60*
D x T	4,76	144.27	153.43	0.94
D x L	2,38	1021.83	149.54	6.83*
T x L	2,38	195.23	113.60	1.72
D x T x L	4,76	45.19	111.04	0.41

*p < .01

Summary of Alpha Results. Although it was hypothesized that alpha density would decrease as level of difficulty increased, the hypothesis was not supported by the present analysis. Rather the data suggested that alpha was equally blocked by all of the cognitive tasks. Moreover this blocking effect was maintained over both loading and unloading phases of the cognitive tasks (i.e., loading effect, sequence effect).

In addition, there were differences in alpha variability which suggested that alpha variability tended to increase as level of difficulty increased. In addition alpha was much more variable during the loading phase than during the unloading phase at least for the Add 0 and Add 1 levels of difficulty. As difficulty increases, however, the loading effect decreased, suggesting that at the Add 3 level of difficulty alpha remained variable and did not recover by the U-L phase.

Pupil Size (L, U-L). The pupil size data were analyzed in the same fashion as the corresponding alpha data. The results of the within subjects ANOVA (Table 13) for three levels of difficulty, three trials, and two phases of loading (L, U-L) indicated a main effect for level of difficulty, and trials. There were no significant interactions.

As hypothesized, pupil size increased as the level of difficulty increased. The Newman-Keuls test demonstrated

that pupil size was smaller in the Add 0 condition than in either Add 1 [Cd(38) = .0386, Md = .08, p < .05) or in the Add 3 condition (Cd(38) = .046, Md = .101, p < .05). On the other hand pupil size was not substantially different for the Add 1 versus the Add 3 level of difficulty [Cd(38) = .0386, 38df, Md = .021].

There was also a significant main effect for trials for the pupil size data and a tendency for pupil size to decrease over trials. Although the compound symmetry test indicated a violation of symmetry of variance-covariance matrices (p = .0058, 19df), the main effect for trials remained significant with the Greenhouse-Geisser correction [F(1,19) = 12.97, p < .0005]. Post-hoc analysis (Newman-Keuls) indicated that pupil size decreased significantly from Trial 1 to Trial 2 (Cd(38) = .0458, Md = .046, p < .05) and from Trial 2 to Trial 3 (Cd(38) = .0458, Md = .054, p < .05).

TABLE 13

COGNITIVE ANOVA (L, U-L) FOR PUPIL SIZE

Source	df	MS	Error	F
Difficulty(D)	2,38	0.2941	0.0207	14.18**
Trial(T)	2,38	0.3978	0.0307	12.97*
Loading(L)	1,19	0.0012	0.0232	0.05
D x T	4,76	0.0121	0.0163	0.74
D x L	2,38	0.0383	0.0155	2.48
T x L	2,38	0.0136	0.0138	0.99
D x T x L	4,76	0.0020	0.0102	0.20

* $p < .0001$
** $p < .0000$

Pupil Size (Sequence). The data for pupil size were also regenerated in a manner similar to that with the alpha data and analysed in a 3x3x2x3 ANOVA with three levels of difficulty, three trials, two levels of loading, and three levels of sequence (early, mid, late). The results of the analysis are presented in Table 14.

As with previous analyses pupil size was found to increase as task difficulty increased. Although this effect was in violation of compound symmetry assumptions ($p = .032$, 19df) it remained significant with the Greenhouse-Geisser correction [$F(1,19) = 12.41$, $p < .0005$]. Again there was a significant difference between the Add 0 level of difficulty and the more difficult Add 1 and Add 3 levels (Newman-Keuls, $p < .05$). Also again the Add 1 ($M = 4.33$) and Add 3 ($M = 4.354$) pupil sizes were not significantly different suggesting that the tasks are almost of equal difficulty. The differences in pupil size, however, were in the predicted direction.

Also consistent with previous analyses pupil size tended to decrease across trials suggesting habituation of the pupillary dilation response with repeated exposure. Trial 3 pupil sizes were significantly smaller than either Trial 1 ($Cd(38) = .0595$, $Md = .092$, $p < .05$) or Trial 2 pupil sizes [$Cd(38) = .049$, $Md = .051$, $p < .05$]. The difference between Trial 1 and Trial 2 although in the predicted direction only approached significance ($Cd(38) = .049$, $Md = .041$).

As may be observed in Table 14, there was a significant interaction of loading by sequence which from observation of the loading sequences (1. M = 4.273, 2. M = 4.324, 3. M = 4.342) versus the unloading sequences (1. M = 4.341, 2. M = 4.317, 3. M = 4.285) suggested that pupil size tended to increase across loading sequences and decrease across unloading sequences. The Newman-Keuls test (Table 15) confirmed this, although the sequence effect was for the most part only significant for differences in pupil size between sequence 1 versus sequence 3.

The analysis of cognitive data also was indicative of a significant three-way interaction of difficulty, loading, and sequence. As may be seen from the post-hoc analysis presented in Table 16, this interaction is explained by the loading by sequence interaction which occurs only in the Add 1 and Add 3 levels of difficulty. The loading-sequence interaction was not significant for the Add 0 level of difficulty.

TABLE 14

COGNITIVE ANOVA (SEQUENCE) FOR PUPIL SIZE

Source	df	MS	Error	F
Difficulty (D)	2,38	0.9476	0.0764	12.41**
Trial (T)	2,38	0.7599	0.1074	7.08*
Loading (L)	1,19	0.0006	0.0457	0.01
Sequence (S)	2,38	0.0163	0.0313	0.52
D x T	4,76	0.0630	0.0444	1.42
D x L	2,38	0.0985	0.0324	3.04
T x L	2,38	0.0186	0.0293	0.64
D x S	4,76	0.0021	0.0124	0.17
T x S	4,76	0.0068	0.1234	0.55
L x S	2,38	0.3587	0.0214	16.74***
D x T x L	4,76	0.0139	0.2940	0.47
D x T x S	8,152	0.0040	0.0099	0.41
D x L x S	4,76	0.0486	0.0098	4.99*
T x L x S	4,76	0.0275	0.0140	1.96
D x T x L x S	8,152	0.0051	0.0089	0.57

* $p < .01$
** $p < .0001$
*** $p < .00001$

TABLE 15

NEWMAN-KEULS TEST: LOADING BY SEQUENCE COGNITIVE INTERACTION

Critical Comparison	Mean Difference(Cd)	Difference(Md)
L1 vs L2	.051	-.051*
L1 vs L3	.0567	-.069*
L2 vs L3	.046	-.018
U-L1 vs U-L2	.046	+.024
U-L1 vs U-L3	.051	+.056*
U-L2 vs U-L3	.038	+.032
L1 vs U-L1	.054	-.068*
L2 vs U-L2	.038	+.007
L3 vs U-L3	.054	+.057*

Note: df = 38

* $p < .05$

TABLE 16

NEWMAN-KEULS TEST: DIFFICULTY BY LOADING BY SEQUENCE COGNITIVE INTERACTION

Critical Comparison	Mean Difference(Cd)	Difference(Md)
+0 L1 vs L2	.0517	-.036
L1 vs L3	.044	-.028
L2 vs L3	.044	+.008
+0 U-L1 vs U-L2	.044	+.021
U-L1 vs U-L3	.0368	-.013
U-L2 vs U-L3	.0368	+.008
+1 L1 vs L2	.056	-.046
L1 vs L3	.06	-.074*
L2 vs L3	.044	-.028
+1 U-L1 vs U-L3	.0517	+.021
U-L1 vs U-L3	.0577	+.071*
U-L2 vs U-L3	.0486	+.05*
+3 L1 vs L2	.0577	-.07*
L1 vs L3	.0615	-.107*
L2 vs L3	.0486	-.037
+3 U-L1 vs U-L2	.0486	+.03
U-L1 vs U-L3	.059	+.085*
U-L2 vs U-L3	.0541	+.055*

Note: df = 76

* $p < .05$

Pupil Variability (L, U-L). Within-subject pupil variability (correlated for each trial of loading and unloading for each level of difficulty) were analysed in the same fashion as alpha variability. The results of the ANOVA for three levels of difficulty, three trials, and two levels of loading (L, U-L) are presented in Table 17. Only the effect for level of difficulty approached significance [p = .07] suggesting a tendency for pupil variability to increase as level of difficulty increased.

TABLE 17

PUPIL VARIABILITY (L, U-L) COGNITIVE ANOVA

Source	df	MS	Error	F
Difficulty (D)	2,38	0.0131	0.0046	2.85
Trial (T)	2,38	0.0083	0.0044	1.89
Loading (L)	1,19	0.0002	0.0047	0.04
D x T	4,76	0.0060	0.0059	1.03
D x L	2,38	0.0126	0.0066	1.90
T x L	2,38	0.0008	0.0053	0.15
D x T x L	4,76	0.0029	0.0039	0.74

Summary of Pupil Results. As was hypothesized (Hypothesis 2) pupil size increased as a function of increasing task difficulty. The consistent trial effect for pupil size across all analyses indicated that the pupil dilation response tended to habituate (decrease) across trials with repeated exposure.

Also as expected on the basis of the pupillary literature, pupil size increased during the loading phase and decreased during the unloading phase at least for the more difficult (Add 1, Add 3) levels of task.

Alpha and Pupil Size Correlations. The relationship between alpha and pupil size was also investigated with the Pearson correlation. Initially these correlations were computed between alpha and the corresponding measure of pupil size across three levels of task difficulty and two levels of loading (L, U-L) with three levels at each phase of loading (see Table 18).

Although most of the correlations were negative as would be expected if increases in pupil size were associated with decreases in alpha density, few were significant. In a procedure described earlier the correlations for each level of difficulty were transformd to z - scores and averaged. Only the mean correlation ($r = -.19$) for the Add 3 level of difficulty ($Mz = -.197$, $SE = .099$, $p = .023$) could be considered significantly greater than zero and representing more than a chance factor.

The same procedure was also applied to the regenerated sequence data (see Table 19). Again most of the correlation coefficients were negative in nature but few of these were significant. Again only the average correlation in the Add 3 level of difficulty (r= -.17) was significantly greater than what would be expected by chance (Mz = -.168, S.E. = .057, p = .0016).

TABLE 18

ALPHA DENSITY AND PUPIL SIZE CORRELATIONS ACROSS THREE TRIALS OF L AND U-L

Comparison	Add 0	Add 1	Add 3
L Trial 1	-.102	.111	-.268
2	-.373*	-.043	-.235
3	-.012	-.195	-.045
U-L Trial 1	-.074	.072	-.427**
2	-.075	-.232	-.078
3	.106	.102	-.229

* $p < .055$
** $p < .05$

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TABLE 19

ALPHA DENSITY AND PUPIL SIZE CORRELATIONS ACROSS TRIALS, LOADING AND SEQUENCE

Comparison	Add 0	Add 1	Add 3
T1 L1	-.18	.223	-.178
T1 L2	-.053	-.155	-.33*
T1 L3	-.121	-.08	-.355*
T1 U1	-.092	.176	-.063
T1 U2	-.11	.052	-.352*
T1 U3	-.151	.092	-.443**
T2 L1	.018	-.06	-.234
T2 L2	-.455**	-.049	-.189
T2 L3	-.375*	-.01	-.019
T2 U1	-.047	-.273	.179
T2 U2	-.196	-.249	-.155
T2 U3	-.132	-.015	.187
T3 L1	.084	-.433**	-.202
T3 L2	-.031	-.098	-.111
T3 L3	-.058	-.485**	-.132
T3 U1	.096	.092	-.126
T3 U2	.209	.066	-.252
T3 U3	.114	.083	-.139

Note: T = trial
L = loading sequence
U = unloading sequence

* $p < .08$
** $p < .05$

Alpha and Pupil Variability Correlations. Measures of alpha density and pupil variability were also subjected to correlational analysis across three levels of task difficulty and two levels of loading (Table 20). Since it had been suggested that alpha would be blocked with pupillary changes it was expected that alpha density and pupil variability would be negatively correlated. Although many of the correlations were in the predicted direction only one of the comparisons was significant ($p < .05$). None of the mean correlations were significantly greater than chance expectancies.

TABLE 20

ALPHA DENSITY AND PUPIL VARIABILITY CORRELATIONS ACROSS THREE TRIALS OF L AND U-L

Comparison		Add 0	Add 1	Add 3
L	Trial 1	-.32*	-.29	-.02
	2	-.06	.15	.18
	3	-.22	.03	-.21
U-L	Trial 1	-.08	-.26	.21
	2	-.13	.02	-.29
	3	.07	-.42**	.21

* $p < .09$
** $p < .05$

Alpha Variability and Pupil Size Correlations. Measures of alpha variability and pupil size were subjected to the same analysis (Table 21). One would expect alpha variability to increase with either increases or decreases in pupil size. The results of the analysis indicate that six of the 18 correlations were significant or approached significance. The relationships tended to be mixed (i.e., positive and negatively correlated). Again, none of the average correlations were significantly greater than zero.

TABLE 21

ALPHA VARIABILITY AND PUPIL SIZE CORRELATIONS ACROSS THREE TRIALS OF L AND U-L

Comparison		Add 0	Add 1	Add 3
L	Trial 1	.01	-.15	-.096
	2	.33*	-.037	.364*
	3	.11	.266	-.337*
U-L	Trial 1	-.44**	-.064	-.314
	2	-.099	-.31*	.007
	3	-.26	-.136	-.104

* $p < .10$
** $p < .05$

Alpha Variability and Pupil Variability Correlations. Correlations were also computed between corresponding measures of alpha variability and pupil variability across three levels of loading (Table 22). It was expected that alpha variability would vary directly with pupil variability. The correlational analysis tended to support this expectation as most of the correlations were in the predicted direction. Only the average correlation at the Add 3 level of difficulty (r=.20) was significantly greater than zero (Mz = .201, SE = .099, p = .022).

TABLE 22

ALPHA VARIABILITY AND PUPIL VARIABILITY CORRELATIONS ACROSS THREE TRIALS OF L AND U-L

Comparison	Add 0	Add 1	Add 3
L Trial 1	.15	.14	-.04
2	.04	-.23	.13
3	-.15	-.07	.19
U-L Trial 1	.28	-.27	.25
2	.31*	.48**	.05
3	.26	.32*	.55**

*p < .10
**p < .05

Postexperimental Questionnaire. As may be seen in Appendix F the postexperimental questionnaire for the cognitive experiment was rated seperately for each level of difficulty (Add 0, Add 1, and Add 3). The differences were then analysed for each scale by the repeated measures analysis of variance. The means for each level of difficulty for each scale, and the results of analysis are presented Table 23.

As may be seen from Table 23 the level of difficulty consistently differentiated between the subjects rating on each scale with one exception (clear vision - blurred vision). The Add 0 level of difficulty was clearly differentiated from the Add 1 and Add 3 levels. Overall the Add 3 versus Add 0 condition was rated in the following manner: more alert, more unpleasent, more unrelaxed, more anxious, more frustrating, more motivated, more attentive, more active thinking, more effortful, more difficult and more active concentrating.

TABLE 23

POSTEXPERIMENTAL QUESTIONNAIRE: COGNITIVE CONDITION: REPEATED MEASURES ANOVA

Scale (1-6)	+0	+1	+3	F(2,38)
Alert - Drowsy	1.95	1.90	1.50	4.24*
Unpleasent - Pleasent	4.45	3.75	2.65	23.70**
Relaxed - Unrelaxed	2.45	3.70	4.55	24.52**
Actively thinking- Not thinking	2.30	1.95	1.45	8.69**
Anxious - Not anxious	3.70	3.55	2.50	10.99**
Not frustrated- Frustrated	1.80	3.0	3.95	31.98**
Unmotivated - Motivated	4.50	4.90	5.30	9.41**
Attentive - Unattentive	2.50	1.80	1.40	14.49**
Effortful - Effortless	3.55	2.45	1.55	20.87**
Difficult - Easy	5.50	3.90	2.40	50.92**
Actively Concentrating- Not concentrating	2.50	1.85	1.40	13.59**
Clear Vision- Blurred vision	3.0	3.20	3.35	2.31

Note: 1 = Very
2 = Moderately
3 = Slightly
4 = Slightly
5 = Moderately
6 = Very

* < .025
** < .001

Summary of Cognitive Results. As was hypothesized pupil size increased as a function of task difficulty. Although it was hypothesized that alpha density would decrease as level of difficulty increased, the hypothesis was not supported by the present analysis. Rather the data suggested that alpha density might have been equally blocked by all of the cognitive tasks. The measure of alpha variability, however, tended to increase as level of difficulty increased.

As was expected for loading, pupil size increased during the loading phase and decreased during the unloading phases approaching initial levels (especially for the Add 1 and Add 3 levels of difficulty). The blocking effect for alpha density, was maintained over both loading and unloading phases of the cognitive tasks. There was no evidence of recovery by the end of the U-L phase. The alpha variability data, however, indicated that alpha was significantly more variable during the loading versus unloading phase for the Add 0 and Add 1 levels of difficulty. This in turn is suggestive of a tendency to recover during the U-L phase. At the Add 3 level of difficulty, however, alpha remained variable and did not recover by the end of the U-L phase.

The consistent trial effect for pupil size indicated that the pupil dilation response tended to habituate across trials although it never completely returned to baseline level ($M = 3.93$). There was no trial effect for the pupil variability, alpha density, or alpha variability data.

The correlational data did not clearly support the hypothesis that any change in pupil size would result in a decrease in alpha production. At best there was only minimal support to suggest that alpha and the pupil tended to vary together. Evidence for a relationship comes from correlations between pupil variability and alpha variability which suggested that the two were positively correlated at least at the Add 3 level where the average correlation was significantly greater than zero. Other support comes from the correlations between alpha density and pupil size. Again, however, few of the correlations were significant and only the correlations for the Add 3 level of difficulty were significantly greater than those expected by chance alone.

The subjects responses to the postexperimental questionnairee were clearly differentiated among the Add 0, Add 1 and Add 3 levels of difficulty in the expected direction. The Add 3 versus the Add 0 condition was rated as significantly more frustrating, unpleasent, unrelaxed, alert, anxious, motivated, attentive, effortful, difficult and as requiring more active concentration and thinking.

Alpha Biofeedback Experiment

Alpha Density. The within subjects ANOVA was applied to the alpha density data in a 2x3x4 design with two training sessions (increase and decrease), three trials of each session, and four epochs (measurments) within each trial. The results of this analysis (Table 24) for alpha density

clearly indicated that contrary to expectations (Hypothesis 3) there were no significant effects for training and no difference in mean alpha production between the increase (M = 64%) or decrease (M = 64%) training sessions. Also there was no effect for trials, epochs, or interaction of any of these effects. Moreover, the mean alpha density (M = 64%) did not exceed that of the mean eyes-closed (M = 78%) or mean eyes-open baselines (M = 67%).

TABLE 24

ALPHA BIOFEEDBACK ANOVA: ALPHA DENSITY

Source	df	MS	Error	F
Session (S)	1,19	3.33	542.55	0.01
Trial (T)	2,38	158.20	448.22	0.35
Epoch (E)	3,57	312.42	191.89	1.63
S x T	2,38	355.55	401.74	0.89
S x E	3,57	210.39	119.93	1.75
T x E	6,114	82.12	122.33	0.67
S x T x E	6,114	138.26	106.80	1.29

Pupil Size. The results of the analysis with pupil size as the dependent measure (Table 25) indicated pupil size was significantly larger during the increase (M = 4.08) alpha training sessions versus the decrease (M = 4.0) alpha training sessions. In addition, there was a significant decrease in pupil size across epochs for all trials. Although there was a violation of the compound symmetry assumption for this effect ($p < .02$, 19df), the epoch effect remained highly significant with the Greenhouse-Geisser correction [$F(1, 19) = 57.09$, $p < .0000$).

TABLE 25

ALPHA BIOFEEDBACK ANOVA: PUPIL SIZE

Source	df	MS	Error	F
Session (S)	1,19	0.8416	0.0508	16.56*
Trial (T)	2,38	0.0247	0.0341	0.72
Epoch (E)	3,57	1.3307	0.0233	57.09**
S x T	2,38	0.0527	0.0168	3.13
S x E	3,57	0.0132	0.0149	0.89
T x E	6,114	0.0097	0.0075	1.30
S x T x E	6,114	0.0050	0.0106	0.47

*p < .001
**p < .0000

Pupil Variability. Similar analysis for the pupil variability measure (Table 26) indicated that there were no differences in pupil variability for increase versus decrease alpha sessions, across trials, or across epochs.

TABLE 26

ALPHA BIOFEEDBACK ANOVA: PUPIL VARIABILITY

Source	df	MS	Error	F
Session (S)	1,19	0.0007	0.0010	0.65
Trial (T)	2,38	0.0003	0.0021	0.15
Epoch (E)	3,57	0.0008	0.0015	0.51
S x T	2,38	0.0016	0.0015	1.05
S x E	3,57	0.0005	0.0016	0.30
T x E	6,114	0.0016	0.0017	0.98
S x T x E	6,114	0.0002	0.0017	0.13

Alpha and Pupil Size Correlations. The relationship between alpha density and pupil size during alpha biofeedback was investigated via correlational analysis (Table 27). None of the correlations were significant. The correlations depicting the relationship were mixed (positive and negative). The average correlations were not significantly greater than those expected by chance alone (increase Mz = .099, SE = .07; decrease, Mz = .05, SE = .07).

TABLE 27

ALPHA BIOFEEDBACK: ALPHA DENSITY AND PUPIL SIZE CORRELATIONS ACROSS TRIALS AND EPOCHS

Comparison	Increase	Decrease
Trial 1, Epoch 1	-.02	-.04
2	.10	-.01
3	.23	.19
4	.09	.24
Trial 2, Epoch 1	.12	.15
2	-.14	.05
3	.11	-.14
4	-.01	-.34*
Trial 3, Epoch 1	.05	.05
2	.12	.19
3	.27	.17
4	.23	.20

* $p < .07$

Alpha and Pupil Variability Correlations. Correlations were also computed for alpha density and pupil variability (Table 28). It was expected that decreases in alpha production would be associated with increases in pupil variability . Six of the 24 possible correlations were significant in the predicted direction while another three approached significance. The mean correlations for both the increase ($r = -.26$) and decrease ($r = -.23$) trials exceeded those that would be expected by chance alone (increase, $Mz = -.269$, $SE = .07$, $p < .0000$; decrease, $Mz = -.232$, $SE = .07$, $p < .0006$).

TABLE 28

ALPHA BIOFEEDBACK: ALPHA DENSITY AND PUPIL VARIABILITY CORRELATIONS ACROSS TRIALS AND EPOCHS

Comparison	Increase	Decrease
Trial 1, Epoch 1	-.38**	.11
2	-.56**	-.59**
3	-.01	-.31*
4	-.33*	-.33*
Trial 2, Epoch 1	-.21	-.50**
2	-.44**	-.14
3	-.26	-.27
4	-.14	-.01
Trial 3, Epoch 1	-.24	.07
2	-.11	.05
3	-.29	-.25
4	-.10	-.41**

* $p < .10$
** $p < .05$

Postexperimental Questionnaire. As may be observed in Appendix G, the postexperimental questionnaire for the alpha biofeedback experiment was rated seperately for increase and decrease training sessions. The data for these sessions were analysed by a within-subjects ANOVA. The means for each session for each scale and the results of the ANOVA are presented in Table 29. As depicted by Table 29 the subjects rated the increase alpha biofeedback session as more unpleasent, more anxious, less difficult and less frustrating than the decrease alpha biofeedback session. Twelve subjects reported that they felt they had some control over alpha. Only two subjects reported an attempt to use an oculomotor strategy. All the others reported using variants of thinking - concentrating (n = 12) and tensing - relaxing (n = 6).

TABLE 29

POSTEXPERIMENTAL QUESTIONNAIRE: ALPHA BIOFEEDBACK ANOVA

Scale (1-6)	Increase	Decrease	F(1,19)
Alert - Drowsy	1.95	2.40	1.22
Unpleasent - Pleasent	1.95	3.10	10.75**
Relaxed - Unrelaxed	2.80	3.60	2.86
Actively thinking- Not thinking	1.80	2.25	0.54
Anxious - Not anxious	3.90	2.90	5.95*
Not frustrated- Frustrated	3.35	4.10	6.69*
Unmotivated - Motivated	4.80	5.10	3.33
Attentive - Inattentive	2.0	2.0	0.0
Effortful - Effortless	2.45	2.0	1.63
Difficult - Easy	3.05	1.45	16.52***
Actively concentrating- Not concentrating	2.15	1.90	0.29
Clear vision- Blurred vision	3.70	4.10	2.46

Note: 1 = Very
2 = Moderately
3 = Slightly
4 = Slightly
5 = Moderately
6 = Very

* $p < .025$
** $p < .005$
*** $p < .001$

Summary of Alpha Biofeedback Results. In summary the hypothesis (Hypothesis 3) of a significant difference in alpha activity under enhancement and suppression conditions of alpha biofeedback was not supported by the data. In addition the expectation (Hypothesis 4) that the pupil would be less variable under alpha enhancement than under alpha suppression conditions, also was not substantiated by the data. There were no differences for alpha density or pupil variability between enhancement or suppression conditions. There was, however, a significant difference in pupil size with the largest pupil size occuring for the enhancement condition. It is also interesting to note that the subjects rated the enhancement condition as significantly more unpleasent than the suppression condition.

The correlational data again do not clearly support the expectation that any change in pupil size would result in a decrease in alpha production. Minimal support comes from the negative correlations between alpha and pupil variability that were in the predicted direction and significantly greater than those that would be expected by chance alone.

Pupil Biofeedback Experiment

Pupil Size. The pupil biofeedback experiment was analyzed in the same fashion as the alpha biofeedback experiment. The ANOVA (Table 30) revealed a significant main effect for epochs and significant interaction of session, trials, and epochs. It was noted, however, that the assumption of compound symmetry was violated ($p = .05$, 19df) for the interaction, so the Greenhouse-Geisser correction was made. In view of the correction, the interaction was no longer significant [$F(1, 19) = 2.64$, $p < .20$].

Although it was predicted (Hypothesis 4) that there would be a significant difference in pupil size under the constrict (decrease pupil size) and dilate (increase pupil size) conditions of pupil biofeedback, there were no differences in pupil size between increase or decrease training sessions. Clearly there was no effect for training on pupil size. Similar to the pupil decrease in the alpha biofeedback experiment, there was a significant decrease in pupil size across epochs.

TABLE 30

PUPIL BIOFEEDBACK ANOVA: PUPIL SIZE

Source	df	MS	Error	F
Session (S)	1,19	0.0067	0.0332	0.2
Trial (T)	2,38	0.1325	0.0703	1.89
Epoch (E)	3,57	0.6295	0.0140	44.9**
S x T	2,38	0.0451	0.0169	2.67
S x E	3,57	0.0187	0.0092	2.03
T x E	6,114	0.0072	0.0086	0.83
S x T x E	6,114	0.0226	0.0086	2.64*

* $p < .02$
** $p < .0000$

Pupil Variability. Using pupil variability measures with the same analysis as used with pupil size data (Table 31), there was no difference found for pupil variability between increase or decrease training sessions of pupil biofeedback, nor any other significant effects or interactions.

TABLE 31

PUPIL BIOFEEDBACK ANOVA: PUPIL VARIABILITY

Source	df	MS	Error	F
Session (S)	1,19	0.00002	0.0023	0.01
Trial (T)	2,38	0.0017	0.0012	1.46
Epoch (E)	3,57	0.0032	0.0012	2.60
S x T	2,38	0.0002	0.0015	0.14
S x E	3,57	0.0001	0.0001	0.06
T x E	6,114	0.0009	0.0010	0.89
S x T x E	6,114	0.0014	0.0010	1.51

Alpha Density. As may be seen in Table 32 the only significant effect for alpha density data was a significant difference in alpha production for the increase versus decrease training sessions of pupil biofeedback. The mean alpha production was greater during the decrease pupil size (M = 78%) than the increase pupil size trials (M = 69%).

TABLE 32

PUPII BIOFEEDBACK ANOVA: ALPHA DENSITY

Source	df	MS	Error	F
Session(S)	1,19	8203.84	1852.18	4.43*
Trial (T)	2,38	345.36	524.14	0.66
Epoch (E)	3,57	154.27	141.24	1.09
S x T	2,38	288.26	222.78	1.29
S x E	3,57	21.49	87.89	0.24
T x E	6,114	64.78	97.67	0.66
S x T x E	6,114	30.70	81.37	0.38

* $p < .05$

Alpha and Pupil Size Correlations. Only two of the possible 24 correlations between alpha density and pupil size were significant while five others approached significance (see Table 33). Only the average correlation of r= -.16 for the increase session was significantly greater than zero [Mz = -.164, S.E. = .07, p < .02].

TABLE 33

PUPIL BIOFEEDBACK: ALPHA DENSITY AND PUPIL SIZE CORRELATIONS ACROSS TRIALS AND EPOCHS

Comparison	Increase	Decrease
Trial 1, Epoch 1	-.15	-.35*
2	-.15	-.22
3	-.06	-.40**
4	-.25	-.31*
Trial 2, Epoch 1	-.40**	.03
2	-.31*	.16
3	-.17	.30*
4	-.36*	.26
Trial 3, Epoch 1	.01	-.21
2	.01	-.07
3	-.04	-.03
4	.03	.17

* $p < .10$
** $p < .05$

Alpha and Pupil Variability Correlations. Only two of the 24 correlations between alpha density and pupil variability (Table 34) were significant while two others approached significance. Although most of the correlations were in the predicted direction, only the average correlation of $r = -.14$ for the decrease pupil size session was significantly greater than those expected by chance ($Mz = .142$, $SE = .07$, $p < .023$).

TABLE 34

PUPIL BIOFEEDBACK: ALPHA DENSITY AND PUPIL VARIABILITY CORRELATIONS ACROSS TRIALS AND EPOCHS

Comparison	Increase	Decrease
Trial 1, Epoch 1	.09	.15
2	-.37*	-.05
3	.01	-.49**
4	-.28	.14
Trial 2, Epoch 1	.01	.06
2	-.05	.06
3	-.10	-.22
4	.14	-.19
Trial 3, Epoch 1	-.21	-.51**
2	.15	-.01
3	-.18	-.21
4	-.27	-.31*

* $p < .09$
** $p < .02$

Postexperimental Questionnaire. As may be seen in Appendix H the postexperimental questonnaire for the pupil biofeedback experiment was also rated seperately for increase and decrease training sessions. The means for each session and each scale, and the results of the analyses are presented in Table 35. For the most part the subjects ratings for the increase and decrease pupil biofeedback sessions did not differ. Only the alertness scale differentiated between the sessions. The subjects rated themselves as more alert during the increase pupil size session. Of those subjects who felt they had control over the tone (n = 9), two reported using variants of tensing - relaxing, seven used variants of a cognitive strategy and four made use of an oculomotor strategy.

TABLE 35

POSTEXPERIMENTAL QUESTIONNAIRE: PUPIL BIOFEEDBACK ANOVA

Scale (1-6)A	Increase	Decrease	F(1,19)
Alert - Drowsy	1.90	2.55	4.64*
Unpleasent - Pleasent	3.45	3.25	1.0
Relaxed - Unrelaxed	3.45	3.50	0.01
Actively thinking- Not thinking	2.0	2.50	2.21
Anxious - Not anxious	2.65	3.15	2.31
Not frustrated- Frustrated	4.10	3.80	0.86
Unmotivated - Motivated	4.85	4.85	0.0
Attentive - Inattentive	2.05	2.20	0.19
Effortful - Effortless	1.80	2.05	1.19
Difficult - Easy	2.10	2.10	0.0
Actively Concentrating- Not concentrating	1.50	1.95	2.85
Clear vision- Blurred visicn	3.85	4.30	1.96

Note: 1 = very
2 = moderately
3 = slightly
4 = slightly
5 = moderately
6 = very

*p < .05

Summary of Pupil Biofeedback Results. In summary the hypothesis (Hypothesis 4) of a significant difference in pupil size under constrict and dilate conditions of pupillary biofeedback was not supported by the data. There was , however, a significant decrease in pupil size across trials which was similar to the effect seen in the pupil baseline data. There was no difference in pupil variability between sessions. There was, however, significantly more alpha in the decrease pupil size session. The subjects rated the decrease session as more drowsy, less anxious, and requiring less concentration and thinking.

The correlational data again did not clearly support the expectation that any change in pupil size would result in a decrease in alpha production. Only minimal support comes from the significant negative correlations between alpha density and pupil variability for the decrease sessions and between alpha density and pupil size for the increase sessions.

Alpha and Pupil Biofeedback Comparisons

In order to determine whether there were any significant differences in the two biofeedback experiments or any effect for order for those who received alpha biofeedback first (n = 9) versus those who received pupil biofeedback first (n = 11), the data for both alpha and pupil biofeedback were combined. The data were analysed in a 5-way mixed model analysis of variance design (2x2x2x3x4) with two between -

subjects factors of order (alpha biofeedback first or pupil biofeedback first) and the within - subject factors of mode (alpha versus pupil biofeedback), session (increase versus decrease), trials (3) and epochs (4). The analysis was performed seperately for alpha density, pupil size, and pupil variability data.

Alpha Density. The results of the analysis for the alpha density data are presented in Table 36. The Table shows a significant effect for mode qualified by the interaction of mode and order.

The significant effect for mode indicated that the mean alpha production for the alpha biofeedback mode (M = 64%) was significantly less than that for the pupil biofeedback mode (M = 74%). This effect, however, was qualifid by a significant mode by order interaction. Post-hoc analysis (Newman-Keuls Tests) indicated that in alpha biofeedback mode those who received alpha biofeedback first (M = 52%) had lower alpha densities than those who received alpha biofeedback second (M = 74%) [Cd(18) = 13.27, Md = 21.58, $p < .05$]. Moreover, this group had significantly less alpha than those in the pupil biofeedback mode who either received alpha biofeedback first (M = 72%) [Cd(18) = 10.92, Md = 19.58, $p < .05$] or pupil biofeedback first (M = 75%) [Cd(18) = 14.7, Md = 23.28, $p < .05$]. Consequently the mode effect was accounted for by the lower alpha density associated with the alpha biofeedback mode (data) and those subjects who received alpha biofeedback first.

TABLE 36

COMBINED BIOFEEDBACK ANALYSIS: ALPHA DENSITY

Source	df	MS	Error	F
Order (O)	1,18	37990.74	9386.94	4.05
Mode (M)	1,18	26951.10	3210.99	8.39**
Session (S)	1,18	3644.69	857.49	4.25
Trial (T)	2,36	300.89	516.77	0.58
Epoch (E)	3,54	444.51	242.04	1.84
M x O	1,18	18959.93	3210.99	5.90*
S x O	1,18	428.23	857.49	0.50
M x S	1,18	3922.38	1615.0	2.43
T x O	2,36	369.59	516.77	0.72
M x T	2,36	169.38	472.63	0.36
S x T	2,36	267.11	243.66	1.10
E x O	3,54	141.70	242.04	0.59
M x E	3,54	41.01	101.07	0.41
S x E	3,54	99.76	73.40	1.36
T x E	6,108	66.22	104.28	0.63
M x S x O	1,18	566.81	1615.0	0.35
M x T x O	2,36	295.87	472.63	0.63
S x T x O	2,36	26.13	243.66	0.11
M x S x T	2,36	472.36	389.49	1.21
M x E x O	3,54	12.04	101.07	0.12
S x E x O	3,54	43.25	73.40	0.59
M x S x E	3,54	126.24	133.22	0.95
T x E x O	6,108	31.63	104.28	0.30
M x T x E	6,108	84.79	123.86	0.68
S x T x E	6,108	114.34	94.24	1.21
M x S x T x O	2,36	443.30	389.49	1.14
M x S x E x O	3,54	186.31	133.22	1.40
M x T x E x O	6,108	41.81	123.86	0.34
S x T x E x O	6,108	142.47	94.24	1.51
M x S x T x E	6,108	69.66	94.23	0.74
M x S x T x E x O	6,108	40.40	94.23	0.43

* p < .03
* p < .001

Pupil Size. The results of the analysis for the pupil size measures are presented in Table 37. The results of the ANOVA indicated a significant main effect for training session and epochs and significant interactions for mode x session, session x trials, epochs x order, and mode x epoch. Due to violation of compound symmetry assumptions ($p < .05$) the Greenhouse-Geisser correction was made to the epoch x order interaction and the interaction no longer reached significance levels [$F(1,19) = 3.40$, $p < .10$].

As presented in Table 37 there was a significant main effect for increase versus decrease training sessions with pupil size being significantly larger for the increase sessions. The main effect for session was qualified by the interaction of session and mode (alpha versus pupil biofeedback). Consistent with the individual analysis, the session effect was accounted for by the significant mean difference between the alpha biofeedback increase and decrease sessions [$Cd(18) = .051$, $Md = .084$, $p < .05$]. It is interesting, however, to note that the alpha biofeedback decrease session had the lowest mean pupil size ($M = 4.0$) of all sessions. It was also significantly lower than either the pupil biofeedback decrease ($M = 4.07$) [$Cd(18) = .038$, $Md = .069$, $p < .05$] or increase session ($M = 4.08$) [$Cd(18) = .046$, $Md = .076$ $p < .05$]. There was no difference in pupil size among any of the other sessions (i.e., pupil biofeedback increase, pupil biofeedback decrease, alpha biofeedback

increase). Consequently the session effect described here was accounted for by the significantly smaller pupil size in the alpha biofeedback decrease session.

The main effect for session was also qualified by the interaction of session and trials. Post-hoc analysis indicated that the session effect was only significant for Trial 1 [Cd(36) = .033, Md = .09, $p < .05$] and Trial 3 [Cd(36) = .031, Md = .05, $p < .05$]. The difference for increase versus decrease trials for Trial 2, although in the same direction, was not significant [Cd(36) = .031, Md = .015].

Also as may seen from Table 37 there was a significant main effect for epochs and a tendency for pupil size to decrease over epochs. This was qualified, however, by a mode and epochs interaction. Although the epoch was significant for both alpha biofeedback [Cd(54) = .042, Md = .043, $p < .05$] and pupil biofeedback [Cd(54) = .038, Md = .57, $p < .05$] the effect was greater for the alpha biofeedback mode.

TABLE 37

COMBINED BIOFEEDBACK ANALYSIS: PUPIL SIZE

Source	df	MS	Error	F
Order (O)	1,18	1.4754	4.1415	0.36
Mode (M)	1,18	0.1723	0.6395	0.27
Session (S)	1,18	0.4625	0.0435	10.62**
Trial (T)	2,36	0.1206	0.0665	1.81
Epoch (E)	3,54	1.9432	0.0237	81.92****
M x O	1,18	0.2539	0.6395	0.40
S x O	1,18	0.0527	0.0435	1.21
M x S	1,18	0.3693	0.0401	9.22**
T x O	2,36	0.1562	0.0665	2.35
M x T	2,36	0.0422	0.0347	1.21
S x T	2,36	0.0883	0.0161	5.50**
E x O	3,54	0.0806	0.0237	3.40*
M x E	3,54	0.0729	0.0109	6.70***
S x E	3,54	0.0241	0.0164	1.47
T x E	6,108	0.0117	0.0075	1.56
M x S x O	1,18	0.0394	0.0401	0.98
M x T x O	2,36	0.0054	0.0347	0.16
S x T x O	2,36	0.0097	0.0161	0.60
M x S x T	2,36	0.0137	0.0183	0.75
M x E x O	3,54	0.0058	0.0109	0.53
S x E x O	3,54	0.0110	0.0164	0.67
M x S x E	3,54	0.0079	0.0084	0.94
T x E x O	6,108	0.0029	0.0075	0.39
M x T x E	6,108	0.0056	0.0088	0.64
S x T x E	6,108	0.0103	0.0091	1.14
M x S x T x O	2,36	0.0133	0.0183	0.73
M x S x E x O	3,54	0.0012	0.0084	0.14
M x T x E x O	6,108	0.0093	0.0088	1.07
S x T x E x O	6,108	0.0050	0.0091	0.55
M x S x T x E	6,108	0.0162	0.0107	1.51
M x S x T x E x O	6,108	0.0034	0.0107	0.32

* p < .03
** p < .01
*** p < .001
**** p < .0000

Pupil Variability. There were no significant effects for the pupil variability analysis (Table 38).

TABLE 38

COMBINED BIOFEEDBACK ANALYSIS: PUPIL VARIABILITY

Source	df	MS	Error	F
Order (O)	1,18	.0033	.0192	0.17
Mode (M)	1,18	.0067	.0069	0.97
Session (S)	1,18	.0003	.0019	0.16
Trial (T)	2,36	.0011	.0013	0.81
Epoch (E)	3,54	.0008	.0017	0.45
M x O	1,18	.0071	.0069	1.03
S x O	1,18	.0013	.0019	0.69
M x S	1,18	.0001	.0014	0.10
T x O	2,36	.0005	.0013	0.35
M x T	2,36	.0009	.0021	0.41
S x T	2,36	.0013	.0017	0.78
E x O	3,54	.00002	.0017	0.01
M x E	3,54	.0030	.0012	2.65
S x E	3,54	.0002	.0014	0.16
T x E	6,108	.0017	.0013	1.28
M x S x O	1,18	.0009	.0014	0.62
M x T x O	2,36	.0011	.0021	0.54
S x T x O	2,36	.0005	.0016	0.31
M x S x T	2,36	.0006	.0014	0.39
M x E x O	3,54	.0016	.0012	1.36
S x E x O	3,54	.0006	.0014	0.40
M x S x E	3,54	.0002	.0012	0.14
T x E x O	6,108	.0005	.0013	0.35
M x T x E	6,108	.0009	.0014	0.66
S x T x E	6,108	.0011	.0014	0.77
M x S x T x O	2,36	.0014	.0014	0.99
M x S x E x O	3,54	.0011	.0012	0.98
M x T x E x O	6,108	.0014	.0014	1.02
S x T x E x O	6,108	.0008	.0014	0.59
M x S x T x E	6,108	.0006	.0014	0.44
M x S x T x E x O	6,108	.0008	.0014	0.58

Postexperimental Questionnaire. The postexperimental questionnaire data from both the alpha and pupil biofeedback experiments were compared in order to investigate differences between the two biofeedback conditions (Table 39). Only the pleasentness and anxiety scales were rated as significantly different for alpha versus pupil biofeedback modes. The subjects rated the alpha biofeedback mode as more unpleasent and as more anxious.

TABLE 39

POSTEXPERIMENTAL QUESTIONNAIRE: ALPHA VERSUS PUPIL BIOFEEDBACK

Scale (1-6)	Alpha Biofeedback	Pupil Biofeedback	t(19)
Alert - Drowsy	2.18	2.25	0.14
Unpleasent - Pleasent	2.53	3.35	2.21*
Relaxed - Unrelaxed	3.20	3.48	0.49
Actively Thinking- Not Thinking	2.03	2.25	0.75
Anxious - Not Anxious	3.40	2.90	3.01**
Not Frustrated- Frustrated	3.73	3.95	0.79
Unmotivated - Motivated	4.95	4.85	0.22
Attentive - Inattentive	2.0	2.13	0.37
Effortful - Effortless	2.23	1.93	1.35
Difficult - Easy	2.25	2.10	0.47
Actively Concentrating- Not Concentrating	2.03	1.73	1.20
Clear Vision- Blurred Vision	3.90	4.08	0.33

Note: 1 = very
2 = moderately
3 = slightly
4 = slightly
5 = moderately
6 = very

Note: Combined Increase and Decrease Sessions.

Note: Two - tailed test

* $p < .05$
** $p < .01$

The post-experimental questionnaire data was also analysed in an attempt to compare the alpha biofeedback group which received alpha biofeedback first to the pupil biofeedback group who received alpha biofeedback first and to the pupil and alpha biofeedback groups who received alpha biofeedback second (Table 40). Analysis of the postexperimental questionnaire indicated that the alpha biofeedback group who received alpha biofeedback first and who had significantly lower alpha production scores rated the mode as more frustrating, more unpleasent, more effortful and as involving less concentration.

TABLE 40

POSTEXPERIMENTAL QUESTIONNAIRE ALPHA BIOFEEDBACK FIRST VERSUS LAST

Scale (1-6)	Comparison	df	t
Alert - Drowsy	A - B	18	1.76
	A - C	8	1.75
	A - D	18	0.24
Unpleasent - Pleasent	A - B	18	0.16
	A - C	8	1.23
	A - D	18	2.85**
Relaxed - Unrelaxed	A - B	18	0.73
	A - C	8	0.00
	A - D	18	0.91
Actively Thinking- Not Thinking	A - B	18	1.24
	A - C	8	0.01
	A - D	18	0.11
Anxious - Not Anxious	A - B	18	0.54
	A - C	8	1.68
	A - D	18	0.57
Not Frustrated- Frustrated	A - B	18	2.65**
	A - C	8	2.29
	A - D	18	2.52*
Unmotivated - Motivated	A - B	18	0.29
	A - C	8	0.01
	A - D	18	0.18
Attentive - Inattentive	A - B	18	0.74
	A - C	8	0.89
	A - D	18	0.47
Effortful - Effortless	A - B	18	1.28
	A - C	8	2.43*
	A - D	18	0.75
Different - Easy	A - B	18	0.40
	A - C	8	1.28
	A - D	18	0.43
Actively Concentrating- Not Concentrating	A - B	18	2.51*
	A - C	8	2.49*
	A - D	18	2.41*
Clear Vision- Blurred Vision	A - B	18	1.24
	A - C	8	0.60
	A - D	18	1.54

Note: 1 = very
2 = moderately

3 = slightly
4 = slightly
5 = moderately
6 = very

Note: A = alpha biofeedback - alpha biofeedback first
B = alpha biofeedback - alpha biofeedback second
C = pupil biofeedback - alpha biofeedback first
D = pupil biofeedback - alpha biofeedback second

* $p < .05$
** $p < .02$

Summary of Biofeedback Mode Comparisons. The biofeedback mode comparisons revealed that the mean alpha production for the alpha biofeedback mode was significantly less than for the pupil biofeedback mode. It is interesting to note that the subjects rated the alpha biofeedback mode as more unpleasent and as more anxious than the pupil biofeedback mode.

The mode effect, however, was qualified by a significant mode by order interaction suggesting that the lower alpha density was asssociated with the alpha biofeedback mode (data) and those subjects who received alpha biofeedback first. The subjective ratings indicated that this condition was seen as more frustrating, unpleasent, effortful and as requiring less concentration than other conditions. The mode effect or mode by order interaction was not paralleled in the pupil size or pupil variability data.

The session effect for alpha density only approached a level of significance and only suggested a slight trend for lower alpha production for the increase sessions versus the decease sessions [$F(1, 18) = 4.25$ $p = .054$]. Pupil size, however, was found to be significantly larger for the increase sessions (especially for Trials 1 and 3). Consistent with the individual analysis, however, the effect was accounted for by the significantly smaller pupil size in the alpha biofeedback decrease session. This session was rated by the subjects as significantly more anxious and more difficult than the increase alpha session ($p < .05$).

Although there was no epoch effect for the alpha density data, there was a significant decrease in pupil size across epochs especially for the alpha biofeedback mode. There was no difference in pupil variability between the two biofeedback modes.

In summary then, comparing the alpha biofeedback experiment to the pupil biofeedback experiment revealed that the alpha biofeedback mode was characterized by a lower alpha density; was rated as more unpleasent and anxious; had lower alpha density for that group who received alpha biofeedback first; was rated by this group as more frustrating, unpleasent, effortful and requiring less concentration; had a more significant decrease in pupil size across epochs; significantly smaller pupil sizes in the decrease alpha session; was rated in this session as more anxious and more difficult; and exhibited a slight trend for lower alpha production in the increase alpha versus decrease alpha session. There were no significant differences in pupil variability between increase or decrease sessions of alpha or pupil biofeedback.

In conclusion, the hypothesis (Hypothesis 3) of a significant difference in alpha activity between increase and decrease sessions or the hypothesis (Hypothesis 3) of a significant difference in pupil size between increase and decrease sessions, was not supported by the data. In addition, the expectation (Hypothesis 3) that the pupil would be less variable under alpha enhancement conditions

was not supported. Rather for the alpha biofeedback experiment there was a significant difference in pupil size with the smaller pupil size occuring in the decrease alpha session. On the other hand, for the pupil biofeedback experiment, a higher alpha density was associated with the pupil decrease session.

The correlational data did not clearly support the expectation that the amount of alpha activity would be a function of pupillary activity. Some support come from consistently greater than chance average correlations between alpha density and pupil variability, and alpha density and pupil size.

Chapter IV

DISCUSSION

It was the purpose of the present study to investigate the possible relationship between alpha production and pupillary activity across a variety of situations and the suggestion that oculomotor activation, as reflected by pupillary activity, would block or attenuate occipital alpha production in a manner consistent with the oculomotor theory. Although the results overall do not conclusively or consistently support the oculomotor activation theory and a close relationship between alpha and pupillary activity, there is some evidence to suggest that the two variables may be related. The present goal is to examine such evidence within the context of each experiment and then in terms of the overall results of the study.

Baseline Conditions

Consistent with the hypothesis and the well documented finding in the literature (e.g. Berger, 1930; Gale, Spratt, Chapman & Smallbone, 1975; Kamiya, 1963; Lindsley, 1960), alpha production was greatest when the subjects' eyes were closed and attentuated when the subjects' eyes were open in a dimly illuminated environment. This was found for baselines at the beginning of both sessions. These findings

are consistent with the oculomotor activation theory which suggests that alpha activity would be prominent in the absence of oculomotor activity. In view of the fact that most other forms of oculomotor activity were restricted in the present experiment, the difference between eyes-open and eyes-closed conditions may be a function of pupillary activity. Lowenstein and Loewenfeld (1962) have found that the pupil tends to become smaller and more active with increasing light.

It was also found, as expected, that alpha density for both the eye conditions was greater in Session II than in Session I. It had been hypothesized that this would occur because the initial apprehensions about the experiment and the novelty of the experimental situation would have had a suppressant effect on alpha activity during the initial baseline measure. Again the differences between Session I and Session II would be consistent with the oculomotor theory which suggests that most forms of novel stimuli, before habituation has occured, will cause an orienting response which includes desynchronization of alpha activity. In the present experiment, Session I would be the most novel situation and the one in which one would expect a greater attenuation effect to occur. It is also interesting to note that when comparing the differences between Session I and Session II eyes-closed baseline across trials (Table 2) that by Trial 4 the differences between the two sessions (although still significant) had decreased. In view of the

increase in Session I eyes-closed baseline across Trials 1-4 (68%, 70%, 70%, 74%) the results could suggest that at least partial habituation to the novel situation ocurred as early as Trial 4. This effect across Trials 1-4 did not occur for Session II (84%, 85%, 85%, 83%) suggesting perhaps that the alpha recovery effect was complete. The evidence for the eyes-open group, however suggest that alpha recovery ccurred much more quickly in Session II (73%, 75%, 74%, 78%) than in Session I (64%, 64%, 65%, 60%). By Trial 4 of Session II the difference between eyes-closed and eyes-open alpha production was not significant suggesting that alpha had also recovered in the eyes-open condition.

Although pupil size did not differentiate between Session I and Session II baselines, it is interesting to note that there was a significant reduction in pupil size across trials within each baseline. Janisse (1977) has described this effect as an arousal decrement and adaptation phenomenon that can occur over a large number of trials as well as within lengthy trials (100 seconds). In the present experiment it is interesting to note that both alpha density and pupil size tended to recover from the initial effects of novelty. The effect for alpha density data across trials however was not significant. Since there were no significant differences in pupil variability across trials, the oculomotor hypothesis would not suggest any difference in alpha activity. There was, however, a significant difference in alpha activity between sessions which cannot be

accounted for by differences in pupil variability. It may best be accounted for by habituation to a novel situation and thus occur through mechanisms of a non-oculomotor variety.

Illumination Experiment

As was expected larger pupil sizes were found for the lower illumination levels (0-dark) and smaller pupil sizes were found for the higher illumination levels (+7, +15). This is consistent with the universal finding that an increase in illumination level will result in constriction while a decrease in illumination level (in this case, darkness) will cause dilation (Janisse, 1977). As may be seen from Figure 1, however, the shape of the constriction response differed from that of the dilation response. For example, there was a significant increase in pupil size across epochs for the dilation response but not for the constriction response. The results are consistent with those of Hansmann, Semnolow and Stark (1974) who have reported that the light-reflex shows a rapid overshooting constriction response to the onset of light followed by a redilation response, while the dilation response to the offset of light is much slower. In addition, they reported that the overshoot effect is only characteristic of the constriction response. As a result of the scoring procedure utilized in the present study, it would appear that the overshoot constriction effect occured before the first

measurement was taken at the 2-second point. What is presented in Figure 1 then is the redilation response. The dilation response to the onset of darkness, however, is a much slower response and probably would be pictured accurately in Figure 1.

On the basis of other literature (e.g. Lowenstein & Loewenfeld, 1962), which suggested that the pupils are usually large and quiet in complete darkness and become smaller and more active with increasing light, it had been assumed for the basis of hypothesis 1, that the greatest pupillary constriction and pupil variability would be associated with the highest levels of luminance. While this effect would be accurate if the subjects had been exposed to the same illumination levels over considerably longer periods of time, on the basis of the Hansmann et al. study and the present data, it may not be applicable to immediate pupillary reactions to the onset and offset of light. The trial length in the present study was only 30 seconds. As depicted by Figure 1 (where each epoch = 2 seconds) it appeared to take more than 20 seconds for the pupil to begin to stabilize to the onset of darkness.

In view of this differential response then, the greatest pupil changes in the present study occured with the transitions to darkness (dilate conditions). It is interesting to note that the least amount of alpha also occured under these conditions. This would be consistent with the hypothesis that lower alpha densities would occur

under conditions of greatest pupil variability or change. Consequently the evidence is in support of the oculomotor theory which would predict that oculomotor activity of any sort would tend to block alpha activity. In the present context the oculomotor activity accounting for the difference in the dilate versus constrict conditions, was pupillary activity. Indeed it may be such pupillary activity that may account for the suppressant effect of light on alpha density that has been reported by other investigators (e.g. Bridgewater, Sherry & Marcznski, 1975; Cram, Kohlenberg & Singer, 1977; Orenstein & McWilliams, 1976). As reported earlier, however, the confounding of many oculomotor variables (e.g. fixation, convergence) makes it difficult to seperate out the effects of illumination (and pupillary changes) on alpha production in such studies. The possibility remains that in such studies the pupillary activity associated with bright light would have a suppressant effect on alpha production. As the pupillary activity stabalizes over time, one would expect some recovery in alpha density.

The important difference in the present study is that alpha was reduced during darkness. Similarly Aranibar and Pfurtscheller, (1977) have reported consistent decreases in alpha with photic stimulation to both light-on and light-off trials. Consequently it would be difficult to explain the phenomenon on the basis of visual attention, fixation,

visual scanning, etc. Rather pupillary activity would seem to account for the present results. The results of the study by Lehtonen and Lehtinen (1972) would support this suggestion. As may be recalled, they effectively blocked alpha activity by the introduction of mydriatic drops and found that photic stimulation had no blocking effect on occipital alpha even when the subjects attended to (counted) the flashes. Indeed, theories of visual attention would hypothesize alpha blocking even under these conditions. The oculomotor activation theory, however, would predict that oculomotor activity (in this case reflected by pupillary activity) would serve to attenuate occipital alpha. On the other hand, alpha would be expected to be prominent in the absence of such activity. Consequently it would be expected that as the dilation response stabalizes and pupillary activity is reduced, alpha would recover. There is some suggestion of that occuring in the present study, although the effect was not yet significant (Figure 1).

As was noted, the tendency for alpha density and pupil size to vary together (i.e. correlate), although for the most part greater than would be expected by chance alone, was minimal and insignificant. The predominance of positive correlations for the constrict conditions, may reflect the tendency (although insignificant) for both pupil size and alpha density to increase over epochs. On the other hand the predominance of negative correlations for the dilate conditions may reflect a tendency for increases in pupil

size to be associated with decreases in alpha activity. Of course, no causal argument or even an argument of a relationship can be made on the basis of such correlations. In fact it was not hypothesized that pupil size and alpha density would be correlated but rather that pupillary changes would be related to decreases in alpha density. The present analysis compared mean alpha density measures over 2-second samples to one measure of pupil size in the same sample. Perhaps comparisons between alpha production and pupillary changes may need to be made on a more molar level in view of the slower responsiveness and possible reduced sensitivity of the EEG measure (Beatty, 1977b).

The results of the illumination experiment, taken as a whole, tend to support the contention that oculomotor activity serves to attenuate alpha production. Since the effect of other oculomotor variables were minimized, it would appear that pupillary activity blocked occipital alpha. As futher support of this suggested relationship, it would be beneficial to repeat the present study while immobilizing the pupil with a mydriatic solution. If, indeed, alpha was not blocked under such conditions, the results would yeild futher support to a causal relationship between pupillary activity and alpha blocking.

Cognitive Experiment

Consistent with expectations, the cognitive experiment clearly demonstrated that pupil size increased as a function of task difficulty and mental effort. Moreover, as would be expected on the basis of the pupillary literature (e.g. Hess & Polt, 1964; Kahneman & Beatty, 1966) pupil size increased during the loading phase, reached its maximum, decreased during the unloading phase, and returned to its baseline level. Although this trend was evident for all levels of difficulty it was only significant for the more difficult digit transformation tasks. This would demonstrate that the digit span task (+0) was much easier than the digit transformation tasks (+1) and +3). In fact the size of the pupil clearly differentiated between the digit span and digit transformation tasks as has been found by others (e.g. Kahneman, Peavler & Onuska, 1968; Kahneman, Tursky, Shapiro & Crider, 1969). Although it was in the predicted direction, pupil size did not clearly differentiate between the two digit transformation tasks. Given the consistent relationship which has been found between pupil size and task difficulty it would appear as though the tasks were of almost equal difficulty. In any case the most difficult and effortful task (Add 3) according to subjective reports was associated with the largest pupil response (M = 4.354), and the least difficult task (Add 0) with the smallest pupil response (M = 4.256). The present study served to replicate

the results of a study by Kahnman, Tursky, Shapiro and Crider (1969) which used the same levels of task difficulty.

As may be recalled pupil size tended to decrease upon repeated presentations of the tasks; an effect that was more dramatic between the second and third trials. Again this has been found by others (e.g. DuPont, 1971; Francis & Kelly, 1969; Lehr & Bergum, 1966) and is further support for the tendency of the pupillary response to habituate over time and repeated exposure to similar stimuli. As will be recalled a similar effect occured during the pupil baseline condition.

Pupil variability, however, did not clearly differentiate level of difficulty or trials across all analysis. In fact the effect for level of difficulty only approached significance. Consequently pupil variability may not be the best measure of task difficulty. Janisse (1977) has suggested several indices of pupillary activity (e.g. latency, size, variability) the utility of which he suggests is open to further research. The present study would support the usefulness of pupil size versus pupil variability as a measure of task difficulty.

Although it was hypothesized that alpha activity would decrease as a function of task difficulty, the alpha measurement did not serve to differentiate between levels of difficulty. In fact the mean alpha production across all levels of difficulty was very similar. It is interesting to

note that the average alpha production for all the cognitive tasks was significantly lower than eyes-open baseline levels. In view of this one might suggest (as did Bunnell, 1980) that alpha density was equally blocked by all the cognitive tasks. The results are in support of other studies which have demonstrated significantly less alpha during problem solving versus baseline periods (e.g. Bauer, 1976; Grabow, Aronson, Greene & Offord, 1979; Meyer, 1977). Unlike many other studies (e.g. Baker & Franken, 1967; Dumas & Morgan, 1975; McAdam, 1973), however, the alpha density measure did not differentiate between levels of difficulty. Although no studies could be found which used a digit-transformation task and assessed its effect on alpha activity, Bauer (1976) used a digit-span task and found significantly less alpha in the EEG than during baseline conditions. It is also interesting to note that Doyle, Ornstein and Galin (1974) and Gevins, Zeitlin, Yingling, Doyle, Dedon, Shaffer, Raumasset and Yeager (1979) have suggested that tasks requiring motor output (e.g. limb movements) result in suppression of alpha activity. In view of the fact that the all the tasks in the present study required a motor output, (i.e. verbal repetition) they may have equally suppressed alpha activity. It is also relevant that motor responses have been found to augment pupillary responses (Kahnemann, Peavler & Onuska, 1968; Simpson, 1969). This suggests another parallel between the two systems.

It is also important to point out other major differences in the present study and some of the other studies that have claimed that alpha decreases over levels of difficulty. A great number of the more recent studies (e.g. Gevins, Zeitlin, Doyle, Schaffer & Gallaway, 1979; Goodman, Beatty and Mulholland, 1980; Grabow, Aronson, Greene & Offord, 1979) have used a greater number of electrode placements (i.e., occipital, parietal, central, frontal, temporal) in an attempt to study alpha hemispheric asymmetries in response to a variety of verbal-analytic and spatial processing tasks. In view of the number and placements of electrodes it would be expected that such measurements would be more sensitive to changes in task difficulty than the occipital placement used in the present study. Grabow et al. (1979) have provided evidence to suggest that attenuation of alpha activity occurs in the activated hemisphere involved in the task. For example, they found significant differences in both parietal and occipital areas for a task in which the subjects were required to say words beginning with "S" aloud while they found significant differences for only the parietal area for a task in which a subject was shown a picture and asked to make up a story and repeat it to herself.

Furthermore and perhaps most relevant to the present study, many of these studies have used EEG measures other than percent-time alpha. Goodman, (1978) for example has used EEG alpha contingent stimulation and derived an alpha

control ratio statistic (calculated by dividing mean alpha bursts durations to visual stimulation by the standard deviation of those alpha durations) and has found the measure to be more sensitive than either percent alpha or evoked potential discrimination index to the detection of differences in cortical activity. Similarly Goodman et al. (1980) have found the control ratio to be a more sensitive measure (i.e. better discriminator among variables) than either standard deviation or mean alpha duration. Also Ehrichman and Wiener (1979) have reported that the percent-time measure did not differentiate significant task effects (across a variety of verbal and spatial tasks) and was less reliable than an integrated amplitude measure.

Indeed, in the present study, the alpha variability measure was much more sensitive to task performance. Although the effect for difficulty was not significant, it did approach significance ($p < .06$) and was suggestive of a trend for alpha variability to increase as task difficulty increased. Moreover it differentiated loading and unloading phases at least for the two easier tasks (Add 0, Add 1). Alpha was found to be more variable during the loading versus the unloading phase which would suggest that some recovery in alpha was occuring. As difficulty increased, however, the loading effect decreased, in turn suggesting that for the most difficult task alpha remained variable and showed no signs of recovery during the unloading phase.

In view of the suggestions made here regarding the alpha blocking phenomenon, it would have been interesting to monitor pupil activity and alpha activity beyond the cognitive task and into an intertrial interval. Unfortunately the design of the present study did not incorporate an intertrial interval. Consequently it is impossible to assess alpha recovery during this phase. Certainly the oculomotor hypothesis would suggest that as pupil activity stabalized (usually by the end of the loading phase), alpha activity would also recover.

As noted earlier, the correlational data do not clearly support the hypothesis that any change in pupil size would result in a decrease in alpha production. Although most of the correlations were in the predicted direction, only the mean correlations between alpha and pupil size (Add 3 condition) and between alpha variability and pupil variability (Add 3 condition) were significantly greater than chance expectancies. Possibly the failure to find significant correlations between alpha and pupil activity may be a function of the insensitivity of the percent alpha measure to reflect minute changes in pupil size. In the present experiment percent alpha measures were taken over 1-second samples and correlated with one measure of pupil size taken from the corresponding sample. Perhaps a measure of alpha amplitude would be more sensitive to such pupillary changes (Ehrlichman & Wiener, 1979 as it would reflect not only

shifts out of the alpha frequency range but also momentary shifts in activation. Unfortunately in the present study, instrumentation limitations precluded alpha amplitude measurement.

In summary, the results of the cognitive experiment do not unequivocally support the oculomotor activation theory. There are however, some suggestions of support. The cognitive tasks resulted in changes in pupillary activity as well as desynchronization of alpha activity. Consequently, the results of this experiment did not provide clear disconfirming evidence of the hypothesized relationship between pupillary movements and alpha attenuation. This is particularly interesting in view of the fact that there no clear explanation as to why alpha activity is blocked by cognitive tasks. Although many might argue that the relationship is explained by arousal, the relationship between alpha and arousal and pupil size and arousal is not a monotonic one. As has been noted earlier the relationship between alpha activity and other physiological indicants of arousal has been an inconsistent often contradictory one. In addition, the contradictory relationship found between pupil size and measures of arousal, would suggest the relationship between pupil size and arousal is not monotonic. The possibility then remains, that rather than alpha and pupil size being related via behavioral arousal, they may be related via oculomotor arousal (activity). This is

particularly feasible in view of the consistent alpha blocking and pupillary response which has been found for cognitive tasks.

Alpha Biofeedback Experiment

The most obvious conclusion to be drawn from the alpha biofeedback experiment is that there was no significant effects of training. In fact, alpha production in both the increase and decrease sessions was virtually identical (both 64%). Moreover the mean alpha production for both sessions fell short of both eyes-open (M = 67%) and eyes-closed (M = 78%) baseline measures. As was noted earlier there have been an extensive number of studies that have found that alpha production could not be enhanced over eyes-closed baselines. In fact Plotkin (1978) found no studies where alpha production with training was found to increase over optimal eyes-closed baseline. In the present study, however, the subjects as a whole did not differ from their eyes-open baseline. There may be several possible theoretical and methodological reasons for the failure of the present study to demonstrate an alpha biofeedback training effect.

The results of the present study are particularly interesting from a theoretical standpoint in view of the substantive support for the hypothesis that successful control of alpha production is accomplished by reducing or

increasing visual system activity (e.g. Chisholm, Adams, Valle & DeGood, 1975; King, 1977; Plotkin, 1976a, 1978). Plotkin (1976a) and others (e.g. Peper, 1970) have suggested that enhancement and suppression of occipital alpha is always mediated by the control of oculomotor processes. The present study, however, sought to minimize the subjects utilization of oculomotor responses by instructions and by providing a minimally stimulating and uniform visual environment. The subjects were instructed not to open or close their eyes, they were asked to refrain from body movements and eye movements, they were provided with a uniform visual field, and they were presented with a target that was slightly out of focus (which would make blurring and focusing strategies difficult). In view of all these restrictions, the training session would literally be more similar to those studies which have attempted to train subjects in darkness. As has been reported earlier, many researchers have noted that alpha control is considerably easier with the eyes open (e.g. Nowlis & Kamiya, 1970; Peper, 1970; Travis, Kondo & Knott, 1974b). In fact, some have claimed that training is not possible in total darkness (e.g. Paskewitz & Orne, 1973; Plotkin, 1976a). In view of the setting in the present study then, the subjects may not have been able to effectively use oculomotor strategies to control alpha density. In spite of the fact that decreasing alpha has been reported to be much easier (Paskewitz, Lynch, Orne & Costello, 1970; Paskewitz & Orne, 1973, Peper

& Mulholland, 1970) than increasing alpha, none of the "non-look" strategies were readily available to the subjects.

Although many studies in the literature using comparable designs have reported significant training effects (e.g. Beatty & Kornfield, 1972; Cram, Kohlenberg & Singer, 1977; Hord & Barber, 1971; Martindale & Armstrong, 1974; Martindale & Hines, 1975; Nowlis & Kamiya, 1970; Peper & Mulholland, 1970; Plotkin & Cohen, 1976; Suter, 1979), there are possible, methodological reasons (form and length of training) for the present results. In a recent review of methodological issues, Ancoli and Kamiya (1978) suggest that although trial lengths in alpha biofeedback studies typically vary from 2-10 minutes, trial lengths of less than 10-20 minutes may be too short for effective training (especially for alpha enhancement). A review of the alpha biofeedback studies also indicates that some have had sessions as long as 29 hours (Regestein, Pegram, Cook & Bradley, 1973) while some have been as short as 10-minutes (Martindale & Armstrong, 1974). Typically a single session is all that is given, although some studies have used six or more (e.g. Ancoli & Green, 1977; Orenstein & McWilliams, 1976; Paskewitz & Orne, 1973). Ancoli and Kamiya (1978) suggest that the chances of effective training are greatly increased if at least four training sessions are used. Moreover they suggest that rapid alterations of suppression

and enhancement trials may also make learning difficult. In view of such suggestions, then, it is possible such methodological parameters may have contributed to the present results.

Also, in view of these suggestions it is interesting to note that Suter (1979) in an alpha biofeedback study used a similar design and identical training time as the present study. In spite of this he found significant differences between increase and decrease sessions, at least when he used an amplitude measure of alpha strength. The percent alpha measure used in the present study, as noted earlier, would be insensitive to shifts in amplitude strength and may well have contributed to the insignificant training effect.

In spite of the failure to demonstrate differential control of alpha production, there were some interesting results. An unexpected result in the present study was the difference in pupil size between suppress and enhance conditions of alpha biofeedback. The largest pupil size occured during the enhancement (increase) sessions in spite of the fact that the subjects rated the suppression (decrease) condition as more difficult, anxious, and frustrating (Table 29). This particularly seems contradictory in view of the suggestion that anxiety and difficulty are consistent with pupil size increases. Although it cannot be ascertained on the basis of the postexperimental questionnaire, perhaps it is possible that the subjects found alpha suppression so difficult that they tended to

give up quickly, while in the enhancement condition they may have continued their effort. Perhaps this is why there was a tendency to rate the increase condition as requiring more effort, more active thinking, and as being less relaxing (although these effects were not significant). If this did occur, there might be a tendency for slightly larger pupil sizes in the enhancement condition. It was also found that the subjects rated the enhancement condition as significantly more unpleasent. Perhaps this also may have contributed to larger pupil size in the increase condition although it is unclear how pleasentness of a task would relate to pupil size. There is some evidence, however, to suggest that unpleasent stimuli are associated with larger pupil sizes than pleasent stimuli (e.g. Libby, Lacy & Lacy, 1973).

It is also noteworthy that the subjects in their subjective reports rated the suppression condition as more difficult than enhancement when other investigators have suggested that alpha enhancement is much more difficult (e.g. Ancoli & Kamiya, 1978; Kamiya, 1968; Nowlis & Kamiya, 1970; Peper & Mulholland, 1970). Again this may relate to the unavailability of oculomotor strategies.

The results also indicated that the expectation that the pupil would be less variable under alpha enhancement versus alpha suppression, was not borne out. It was expected that greater pupil variability would be associated with lower alpha production. There were, however, no differences in

alpha density so the fact that there were no differences in pupil variability would tend to support the oculomotor hypothesis at least to the extent that it did not provide clear disconfirming evidence of the hypothesized relationship. Had there been differences in pupil variability between trials or epochs, the oculomotor hypothesis would also predict differences in alpha activity.

The correlational analysis again did not clearly suggest a relationship between alpha density and pupillary activity. It should be noted, however, that 25 percent of the correlations between alpha density and pupil variability were significant and in the predicted (negative) direction while another 10 percent approached significance. It is also noteworthy that the correlations between these two variables were dramatically more significant than would be expected by chance alone in both the enhance ($p < .0000$) and suppress conditions ($p < .0006$).

In summary the results of the alpha biofeedback experiment also do not clearly support the oculomotor theory. Indirect evidence comes from the fact there was no difference in pupillary activity over trials or sessions and as would be predicted (on the basis of the oculomotor theory), there were no differences in alpha density. In addition it was suggested that alpha control may be particularly difficult in those situations where oculomotor strategies are not available to the subjects. The only other source of direct support in the present experiment comes from the

correlations between alpha density and pupil variability which tend to be more suggestive of a relationship between the two variables than has been the case in the other experiments.

Pupil Biofeedback Experiment

The pupil biofeedback experiment also indicated that there were no significant effects for training. There was no difference in pupil size for the increase (M = 4.08) versus decrease (M = 4.07) sessions of pupil biofeedback. There was, however, a significant decrease in pupil size across epochs. The effect in this and other experiments (i.e. baselines, cognitive, alpha biofeedback) clearly demonstrates the tendency of the pupil to habituate over time.

In view of the failure to demonstrate control in the present experiment, and the success claimed by Prather and Berry (1973) in the only other published study which attempted to condition pupil size, it is important to examine the differences in the two studies. The subjects in the Prather and Berry study were not informed about the nature of the study but were informed they should concentrate on getting as many "goods" as possible. Prather and Berry then verbally reinforced (i.e. saying "good") each subject to dilate and contract pupil size to tones which served as discriminative stimuli. The subjects were then

given a 17.5 minute taped sequence consisting of repetitions of ten 25-second tone periods with 5-second pauses between each tone and a 1-minute rest period after the presentation of ten tones. Three tones were presented in random with the limitation that all tones occured ten times and no tone occured in consecutive order. The tones were counterbalanced across groups and served as discriminative stimuli for differential reinforcement of dilation, contraction or non-reinforcement such that during dilation and contraction periods the experimenter shaped increases and decreases of pupil size by using "good" as verbal reinforcement. No reinforcement was given during the non-reinforcement periods. Prather and Berry found that in spite of which tones were used, mean pupil diameter was largest when shaped to dilate, smallest when shaped to contract and in between for the non-reinforced condition. The mean pupil size was calculated by combining the largest and smallest pupil size for each 5-second period. They did not compare the conditions to a baseline.

One of the major differences between the present study and Prather & Berry's study is the length of the training sessions. As noted Prather and Berry used 25-second training trials while the present study used 4-minute trials. Consequently it may have been difficult for the subjects to maintain a response (or strategy) over that length of time especially in view of the fact that pupil size was decreasing over trials probably in spite of what

they were doing. Prather and Berry, did not report any tendency for pupil size to decrease over time although they did report it was difficult for their subjects to maintain dilation. On the basis of available information (Woodman-see, 1966) however, one would not expect pupil size to decrease in a 25-second period (as in the illumination experiment) but more likely after about 100-seconds. There may, however, have been some decrease over repeated presentations although one would not expect that the effect on the subjects would be as dramatic, as little decrease would occur in the 25-second trial. As a result of this trial length difference the present study may have presented the subjects with a very difficult task. The subjective reports (Table 35) would indicate that the pupil biofeedback task was seen as quite difficult, effortful and somewhat unpleasent.

Although there are other possible differences in the two experiments (e.g. different reinforcers, subject's level of motivation, etc.) probably the trial length is the most outstanding. The habituation effect (decrease in pupil size across epochs) found in the present experiment would make it very difficult for subjects to accurately use the feedback in an attempt to control their own pupil size.

Perhaps the most interesting finding from the pupil biofeedback experiment was that, in spite of the fact that there was no difference in pupil variability across the increase or decrease conditions, there was a significant

difference in alpha production. The mean alpha production was greater during the decrease session (M = 78%) than during the increase session (M = 69%). It was hypothesized that the amount of alpha activity would be a function of the amount of pupillary activity. Consequently the differential amount of alpha in the absence of any significant difference in pupil activity would seem to argue against the oculomotor theory, although even if there were a relationship a significant change in pupil size would not necessarily result in a significant change in alpha density.

There may be, however, other reasons that alpha activity might change in the absence of pupillary changes. It was not argued that the two systems would be completely interdependent. On the contrary, changes in alpha activity (or for that matter pupil size) may be effected through a wide range of oculomotor, behavioral, arousal and/or emotional factors. As was discussed earlier many investigators have suggested a relationship between heightened behavioral arousal and alpha desynchronization (e.g. Fontaine, 1978; Kreitman and Shaw, 1975; Malmo, 1959). This is particularly noteworth in view of the fact the subjective ratings indicated that the subjects were significantly more aroused (alert versus drowsy) in the increase pupil size session. In fact the overall mean rating fell into the very alert category. This would suggest a possible difference in behavioral arousal. As a result it would appear as though the subjects overall were much more relaxed in the decrease

session. This, it is suggested would contribute to the significantly higher alpha density in the decrease pupil size session ($p = .049$).

The correlational data again did not clearly support the expectation that any change in pupil size would result in a decrease in alpha production. Once again, however, most of the correlations between alpha density and pupil variability were in the predicted direction, although they were only significantly greater than chance expectations in the decrease condition.

In summary the pupil biofeedback experiment provided little evidence to support the oculomotor hypothesis. Since there were no difference in pupil size or pupil variability across sessions or trials it was not possible to assess the effect that different levels of pupil activity might have on alpha activity or to assess the viability of change in pupillary activity as an oculomotor mediational strategy. There was, however, a difference in alpha activity between sessions, but in view of the fact it was not suggested that pupil and alpha activity would be completely interdependent, the effect may be the result of other behavioral, arousal, and/or emotional factors. Indeed the subjective reports suggested that this was the case.

Alpha and Pupil Biofeedback Comparisons

The comparison of alpha versus pupil biofeedback did not provide any additional test of the oculomotor theory. It did, however, point out the important role that subjective factors may play in physiological research.

It is an interesting finding when comparing the alpha biofeedback to the pupil biofeedback experiment, that the alpha biofeedback mode had an overall lower level of alpha production in spite of the fact there was no difference in pupil variability. As was noted, however, the effect between the two experiments was primarily accounted for by those subjects in the alpha biofeedback experiment who received alpha biofeedback first (i.e. Session I). This particular condition was rated as more frustrating, unpleasent and effortful. Such factors may well have had an effect on the overall level of arousal and anxiety. The subjects may have found this condition very stressful. Consequently, in view of a number of studies which have suggested that alpha and anxiety are inversely related (e.g. Ehrisman, 1973; Levi, 1976; Lally, 1976; Terelak, 1974), this may account for the reduction in alpha activity. Moreover, the fact that they received alpha biofeedback first may indicate that some of the initial apprehensions and novelties of the experimental situation served to block alpha. Of course this wouldn't explain why the postexperimental ratings in the group that received pupil biofeedback

first were not similarly affected. There is a possibility, however that the subjects had more expectations and/or apprehensions (and were more knowledgeable) of "brainwave" biofeedback than control of pupil size. It has been consistently demonstrated that subjects expectations of alpha biofeedback can affect their performance (e.g. Elquin-Body 1977; Knox, 1978; Plotkin, 1976a, 1977, 1979, 1980). In the present experiment their expectations or apprehensions may have served to attentuate alpha activity.

A comparison of the two biofeedback experiments using pupil size as the dependent variable yielded another interesting result. The decrease session of alpha biofeedback had the smallest mean pupil size of all conditions, yet it was rated by the subjects as more anxious and difficult than alpha increase ($p < .05$) and as somewhat more difficult than increase or decrease pupil size ($p < .10$). There were no other differences between this particular condition and the others in terms of pupil variability or alpha production. Possibly the subjects found this condition so difficult they had a tendency to give up. Consequently they relaxed and in comparison to other sessions it become easier. In this case one would expect smaller overall pupil size. In spite of the fact that decreasing alpha is usually seen as much easier by most subjects (e.g. Paskewitz & Orne, 1973; Peper & Mulholland, 1970), the subjects in the present study may have found this task extremely difficult in view

of the fact that the typical oculomotor suppressant strategies were not readily available to them.

In part, this may also be the reason why there was a greater decrease in pupil size over epochs (epoch effect) for the alpha biofeedback experiment. Although the epoch effect was significant for both biofeedback experiments, it was greater for alpha biofeedback. It was not, however, significantly greater for the alpha biofeedback decrease condition. This, in itself, is interesting as one would expect the decrease in pupil size to be greater in those conditions where pupil size was larger (law of initial values: Janisse, 1977). In view of this then this group may have actually habituated to a greater extent than any of the other groups. Such an effect would be consistent with a tendency to give up on a task. Moreover, alpha biofeedback was rated as more unpleasent and anxious than pupil biofeedback. In view of the differential epoch effect, there is a suggestion that the subjects overall found alpha biofeedback as more difficult (had lower alpha densities) and tended to give up in both the enhancement and suppression conditions resulting in a greater decrease in pupil size and a more rapid habituation effect. Again this may relate to the relative unavailability of potential oculomotor strategies. The fact that alpha density did not recover in a parallel fashion may represent the need for a longer habituation time and/or the insensitivity of the percent alpha measure in reflecting momentary changes.

In conclusion, then, the comparison of biofeedback modes provided little data that would support the oculomotor activation hypothesis. It is interesting that the greater epoch effect was associated with the lowest alpha production. This effect, however, was also complicated by an order effect. Overall it must be concluded that the comparison of biofeedback experiments demonstrate the important role that subjective factors may play in biofeedback experiments. In the present experiment, it has been suggested that such factors have contributed to changes in both alpha production and pupil size.

Conclusions

On the basis of the present experiments it must be concluded that the results do not conclusively support the oculomotor activation theory and the predicted relationship between pupillary activity and EEG alpha production. It had been hypothesized that alpha would be prominent in the absence of pupillary activity and would be attenuated in its presence. There were few clear indications that this occured in the present experiment. On the other hand, there were several indirect indications that pupillary activity and occipital alpha production might be related. The results of the present experiments suggest the following:

1. Consistent with the oculomotor theory, eyes-closed alpha production was always greater than eyes-open

alpha production. Consequently alpha production was prominent under conditions of reduced oculomotor processing (e.g. reduced pupillary activity).

2. The greatest pupillary changes (epoch effect) and the lowest alpha production occurred with the dilation response to changes from high to low levels of illumination. Moreover, in the illumination experiment, greater alpha attentuation occured during the dark versus light conditions, in contrast to the almost universal finding that alpha production is greater during dark versus light conditions. In the illumination condition the greatest pupillary activity (change in pupil size across epochs) was also found under the dark condition. Consequently the results of this condition provide the most direct support for the suggestion that oculomotor activity, as reflected by pupillary changes, serve to attenuate occipital alpha.

3. All the cognitive tasks resulted in increases in pupillary activity as well as attenuation of alpha activity (as compared to baselines). Consequently, the cognitive condition did not provide any direct disconfirming evidence of the hypothesized relationship.

4. There were no differences in alpha production or pupil variability in increase or decrease sessions of

alpha biofeedback and again no clear disconfirming evidence.

5. There were no differences in alpha production in the enhance or suppress conditions of alpha biofeedback when the availability of oculomotor strategies was limited.

6. The lowest mean alpha production and the greatest decrease in pupil size across trials were found for the alpha biofeedback versus the pupil biofeedback experiment.

7. Both alpha production and pupillary responses appear to have been influenced by subjective states in both biofeedback experiments.

8. The correlations between alpha density and pupil variability (cognitive, alpha and pupil biofeedback experiments), and alpha density and pupil size (illumination, cognitive and pupil biofeedback experiments) were consistently found to be greater than would be accounted for by chance expectancies.

To be sure, on the basis of such results, no causal argument can be made relating the effects of pupillary activity to occipital alpha production. In the review presented earlier it was suggested that there is more than ample indirect evidence to suggest that the two variables may be related. The result of the present experiments provide some direct (i.e. illumination condition), but for

the most part additional indirect evidence and support for this possiblility. Certainly the most damaging evidence to this suggestion comes from the failure of evidence to support it (e.g. correlational data). On the other hand, there were no significant differences in pupil variability in the various conditions of the experiments which could be utilized to directly assess the effect of differential levels of pupillary activity on alpha production. Consequently there was no evidence to clearly contradict or support the oculomotor activation hypothesis on the basis of different levels of pupil variability. As a result it must be concluded that the oculomotor activation theory remains a viable one and may well provide a mechanism by which the two variables are related.

It also has to be concluded that in many respects the present experiments were not able to provide an adequate assessment of the oculomotor theory. The present study suggests some methodological issues which provide direct considerations for future research.

Methodological Issues and Considerations for Future Research. alpha measurement technique, which in the present study was precluded by equipment limitations. Although it did reflect attentuation of alpha activity during a cognitive task, it was not sensitive to varying levels of task difficulty. An alpha variability measure was more sensitive to task difficulty. Moreover, Ehrlichman and Wiener (1979) have recently reported that an integrated-amplitude measure was much more sensitive to task effects than

the percent-alpha measure. Indeed, this may well be the reason why the correlation data in the present study did not reflect the expected relationship. It would appear that the suggestion that the pupil is much more sensitive to momentary shifts in activation than EEG measures (Beatty, 1977b) may be particularly relevant when considering the percent - time measure. The results of the present experiments (especially the cognitive experiment) would reinforce this suggestion. On the other hand, an integrated amplitude measure may have reflected momentary shifts in activation via amplitude changes within the alpha frequency range. The percent-alpha measure would only reflect changes in dominant EEG patterns and shifts out of the frequency range; thus by its nature being a much more gross measurement technique. In the present experiments it was the comparisons on the molar level which were most suggestive of a relationship between alpha and pupillary activity (e.g. illumination experiment). The percent alpha measurement seemed quite insensitive to more minute changes in pupillary activity (i.e. correlational analysis). Consequently the results may have been much more suggestive of a relationship had a more sensitive measure been used. In view of this, any future research addressing itself to any of the questions presented here, would be advised to utilize a more sensitive measure of alpha activity.

In view of the sensitivity issue, it has also been suggested that using a greater number of electrode placements (necessitating more sophisticated EEG apparatus) might also provide a more sensitive measure of changes in cortical activity, although for oculomotor concerns it would seem that the occipital placement would be most appropriate. Although alpha activity is prominent occipitally, it is present in other locations and may well be effected by the kinds of tests provided in the present experiment. Consequently it is suggested that the use of additional electrode sites may serve to increase the sensitivity of the measurement technique and provide a more accurate assessment of the effect of a wide array of factors on alpha activity.

In view of the substantial amount of evidence which suggests a possible relationship between EEG alpha and pupillary activity, it is suggested that further investigation is warranted. Any replication or extension of the present study, however, could make use of a more sensitive measure of EEG alpha and possibly multiple electrode placements. Moreover, there are several other considerations which may provide a more adequte test of the oculomotor hypothesis. For example it would be helpful to increase the length of the baseline periods to more accurately assess the changes in both alpha and pupillary activity over time. Also the addition of an eyes-open dark baseline condition might serve as a more appropriate comparison for the illumination experiment. Furthermore, when assessing the

effects of various luminence levels on alpha and pupil response systems, it may be fruitful to extend the length of the trial so as to compare the effect of the change state (immediate reactions to changes in luminence levels) to the effect of the more stable state after habituation has occured. In the cognitive experiment, it would be helpful to make use of multiple and varied tasks, and phase-locked presentations with a much longer intertrial interval to provide a more accurate measurement of recovery for both alpha and pupil response. The present study would also suggest the use of a longer training time, a greater number of training sessions, longer training trials, and slower transitions from enhancement to suppression in order to assess the possibility of controlling alpha activity when oculomotor strategies are restricted. Finally, any replication of pupil biofeedback would necessitate the need for shorter training trials to reduce the effect of the habituation response.

Concluding Remarks. relationship between pupillary activity and alpha production largely as a result of the insensitivity of the percent-alpha measurement. Consequently it must be concluded that the results of the present experiments do not conclusively support the oculomotor activation theory and the predicted relationship between pupillary activity and EEG occipital alpha production. In in view of the ample amount of indirect evidence, (in the

literature and the present study) which suggest that the two variables may be related and view of the lack of evidence which directly contradicts the oculomotor theory, it may be suggested that the theory may remain a viable one and may provide a mechanism by which the two variables are related. Given the abundance of indirect evidence and the possible ramifications of a causal relationship between pupillary activity (and other oculomotor behavior) and EEG alpha (e.g. theoretical, electroencephalography, task performance, autonomic conditioning, utility of alpha biofeedback) further investigation of the relationship with a more sensitive alpha measurement technique seems warranted.

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APPENDICES

Appendix A

ILLUMINATION EXPERIMENT

Subject Instructions

Subject Instructions

As you are aware you are participating in a study of brain wave activity. While you have been sitting here, a measurement of your brain wave activity has been taken. Now I would like to see how different levels of light affect brain wave activity. Consequently, the level of brightness in the room will vary. As before, you are requested to position yourself appropriately, to keep your eyes open, to look in the direction of the target and to refrain from excessive eye movement, eye blinks, or bodily movements. When the lights are out, you are requested to follow the above instructions keeping your eyes open and looking in the same direction. I will inform you when we are ready to begin.

Appendix B

COGNITIVE EXPERIMENT

Subject Instructions

Subject Instructions

As you are aware you are participating in a study of brain wave activity. While you have been sitting here, a meaurement of your brain wave activity has been taken. Now I am interested in studying the effect of mental effort on your brain wave activity. In order to do so you will be presented with a series of four numbers, then asked to add a number to each digit and then asked to repeat the series. For example if I presented the series 4123 then asked you to add "1" to each digit, the correct response would be 5234. As before, the lights will be on and you are requested to position yourself appropriately, to keep your eyes open, refrain from excessive movements, eye movements, and eye blinking and to look in the direction of the target.

COGNITIVE EXPERIMENT

Digit Sequence Presented to Each Subject

(a) Add "0" to each of the following digits

3862 "Repeat"

(b) Add "3" to each of the following digits

4152 "Repeat"

(c) Add "1" to each of the following digits

7138 "Repeat"

(d) Add "0" to each of the following digits

4967 "Repeat"

(e) Add "1" to each of the following digits

2813 "Repeat"

(f) Add "3" to each of the following digits

6145 "Repeat"

(g) Add "1" to each of the following digits

3857 "Repeat"

(h) Add "3" to each of the following digits

5324 "Repeat"

(i) Add "0" to each of the following digits

2981 "Repeat"

Appendix C

ALPHA BIOFEEDBACK EXPERIMENT

Subject Instructions

Subject Instructions

On this task you have the opportunity to learn to control your own brain waves. Although there are many patterns of brain wave activity, only one has been selected for today's study. The tone that you hear in the background is turned on by that brainwave. Therefore when you hear that tone it means that that particular brainwave is present. Also an increase in the volume of that tone will be indicative of an increase in the strength of that brain wave pattern. Conversely a decrease in the volume will be indicative of a decrease in the strength of that brain wave pattern. Your job is to learn to turn that brainwave pattern "on" and "off" over the next six 4-minute trials. During the "on" periods you are requested to increase the amount of time the tone is present. During the "off" periods you are requested to decrease the amount of time the tone is present. The nature of each trial will be announced to you in advance. The particular strategy you choose is up to you. Control of brainwave activity is not easy but it is possible if you keep trying and searching for the most effective control strategy for you. During this task the lights will be on. As before you are requested to position yourself appropriately, to keep your eyes open, to refrain from excessive movements, eye movements and eye blinks, and to look in the direction of the target.

Appendix D

PUPIL BIOFEEDBACK EXPERIMENT

Subject Instructions

Subject Instructions

On this task you have the opportunity to learn to control the size of your own pupils. I am interested in studying the effect of such control on your brainwave activity. A tone like the one you hear in the background will reflect changes in the size of your pupils. A higher tone will reflect an increase in the size of your pupil. Conversely a lower tone will indicate a decrease in the size of your pupil. Your task is to learn to increase and decrease the size of your pupils over the next six 4-minute trials. During the "increase" periods you are requested to try to make the tone higher. During the "decrease" periods you are requested to try to make the tone lower. The nature of each trial will be announced to you in advance. The particular strategy you use is up to you. As before you are requested to position yourself appropriately, to keep your eyes open, to refrain from excessive movements, eye movements, and eye blinks, and to look in the direction of the target.

Appendix E

ILLUMINATION EXPERIMENT

Postexperimental Questionnaire

P.E.Q. - Varying Light Levels

1. What did you think this part of the experiment was about? Please explain.

---

2. Please rate your feelings during this phase of the experiment on the following rating scales during <u>this part of the experiment</u>. Remember there are no right or wrong answers. Do not spend too much time on any one statement but place an "x" at that one position on the rating scale (1, 2, 3, 4, 5 & 6) which best describes your feelings during this part of the experiment.

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

Appendix F

COGNITIVE EXPERIMENT

Postexperimental Questionnaire

P.E.O. - Digit Recall

1. What did you think this part of the experiment was about? Please explain.

_____

_____

_____

2. Please rate your feelings during this phase of the experiment on the following rating scales during <u>this part of the experiment</u>. Remember there are no right or wrong answers. Do not spend too much time on any one statement but place an "X" at that one position on the rating scale (1,2,3,4,5 & 6) which best describes your feelings during this part of the experiment.

ADD "0" CONDITION

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

ADD "1" CONDITION

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

ADD "3" CONDITION

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

Appendix G

ALPHA BIOFEEDBACK EXPERIMENT

Postexperimental Questionnaire

P.E.Q. - Brainwave Control

1. What did you think this part of the experiment was about? Please explain.

_____

_____

_____

2. Please rate your feelings during this phase of the experiment on the following rating scales during <u>this part of the experiment</u>. Remember there are no right or wrong answers. Do not spend too much time on any one statement but place an "X" at that one position on the rating scale (1,2,3,4,5 & 6) which best describes your feelings during this part of the experiment.

3. Did you feel you had any influence over the tone?

(a) YES_____

(b) NO_____ If so, how did you feel you could influence it?

(a)_____

(b)_____

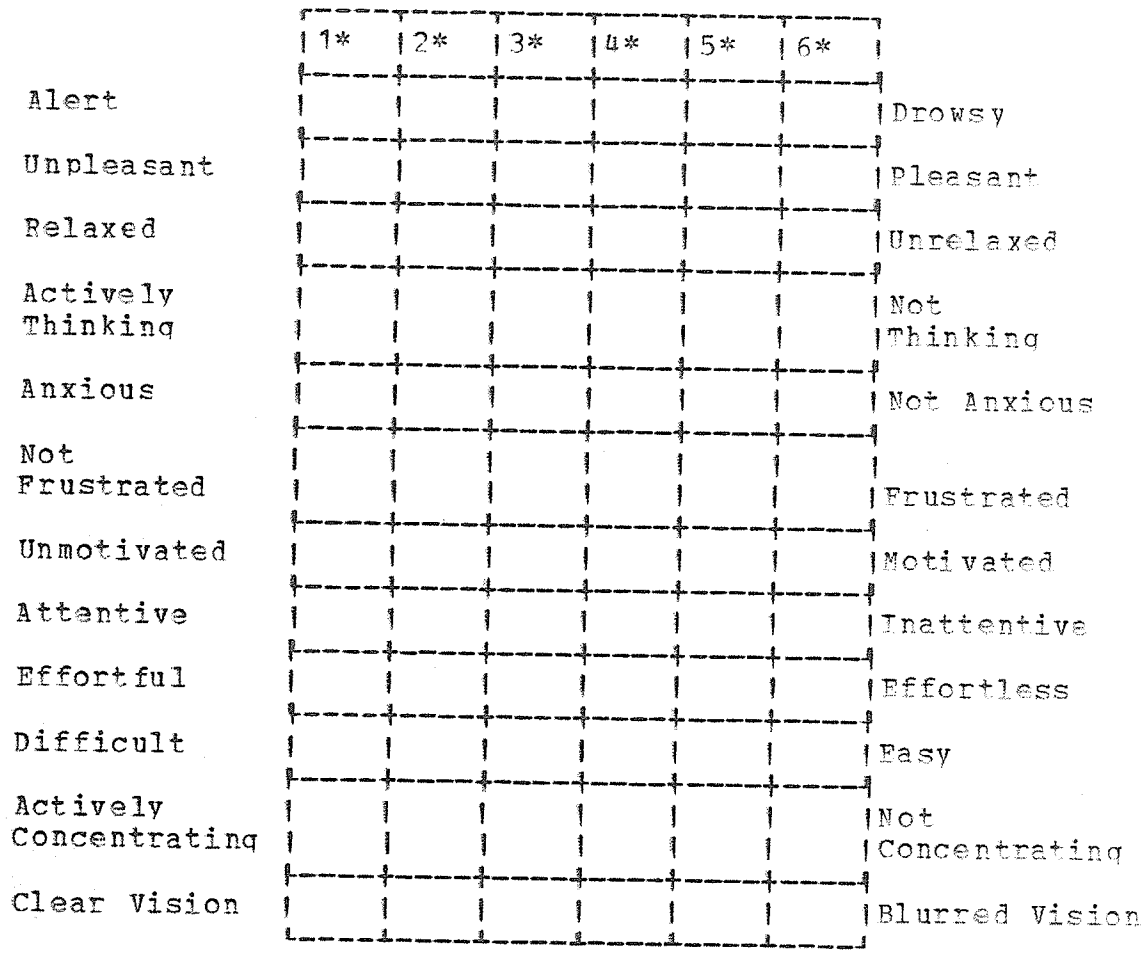
(c)_____

Increasing Brainwave Activity

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

Decreasing Brainwave Activity



*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

Appendix H

PUPIL BIOFEEDBACK EXPERIMENT

Postexperimental Questionnaire

P.E.Q. - Pupil Size Control

1. What did you think this part of the experiment was about? Please explain.

_____

_____

_____

2. Please rate your feelings during this phase of the experiment on the following rating scales during this part of the experiment. Remember there are no right or wrong answers. Do not spend too much time on any one statement but place an "X" at that one position on the rating scale (1,2,3,4,5 & 6) which best describes your feelings during this part of the experiment.

3. Did you feel you had any influence over the tone?

(a) YES_____

(b) NO_____

If so, how did you feel you could influence it?

(a)_____

(b)_____

(c)_____

Increasing Pupil Size

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very

Decreasing Pupil Size

	1*	2*	3*	4*	5*	6*	
Alert							Drowsy
Unpleasant							Pleasant
Relaxed							Unrelaxed
Actively Thinking							Not Thinking
Anxious							Not Anxious
Not Frustrated							Frustrated
Unmotivated							Motivated
Attentive							Inattentive
Effortful							Effortless
Difficult							Easy
Actively Concentrating							Not Concentrating
Clear Vision							Blurred Vision

*1 - Very
*2 - Moderately
*3 - Slightly
*4 - Slightly
*5 - Moderately
*6 - Very