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PUPILLARY DILATION AND VERTEX EVOKED POTENTIAL SIMILARITY IN MONOZYGOTIC AND DIZYGOTIC TWINS AND SIBLINGS

by

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Abstract

PUPILLARY DILATION AND VERTEX EVOKED POTENTIAL
SIMILARITY IN MONOZYGOTIC AND DIZYGOTIC TWINS AND SIBLINGS

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Frances A. Bock

Advisor: Dr. Gad Hakerem

The twin study method is a traditional and valuable design for studying the role of genetic determinants of behavior. In the present study, pairs of monozygotic and dizygotic twins, nontwin siblings and unrelated persons were compared with respect to the similarity of evoked potential and pupillary waveforms they generated during a cognitive task. Auditory average evoked potentials were recorded from vertex, and simultaneous average pupillary motility was recorded under conditions of certainty and uncertainty. In the certain condition, the subject was told in advance whether a "single" or "double" click would be presented on each trial. In the uncertain conditions, the subject was required to predict in advance which stimulus would be presented on the next trial. Both stimuli were actually double clicks, with the interclick interval set just below and just above discrimination threshold.

The hypothesis that biologically-related persons would generate more similar waveforms than unrelated persons was confirmed for both evoked potential and pupillary correlates of decision making. This greater similarity was most marked for the uncertain conditions and for those late components of the evoked response most susceptible to

manipulation of complex psychological variables.

Directional trends, as well as accuracy of matching of waveforms for twin pairs by visual inspection, support the tentative conclusion that genetic factors are largely responsible for the familial effect.

Males were more alike than females, regardless of genetic relationship, on late components of the evoked response, but not on early components or on pupillary motility.

Males were also better able than females to match their guessing strategies to the stated probability of occurrence of single and double clicks. Females were more conservative with respect to their willingness to guess that the less frequent stimulus would occur.

All pairs, regardless of genetic relationship, were more alike on trials yielding the more likely outcome.

The finding that related persons had more similar waveforms than unrelated persons in the present study supports the view that familial, and probably genetic, factors are significant determinants of complex information processing on cognitive tasks.

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To Harold and Richard
who make all things possible

Much evidence has accumulated in recent years linking certain characteristics of the cortical evoked potential in man to complex processing of information which goes beyond the registration of stimuli upon the sensorium (Sutton, Braren, Zubin, & John, 1965). Similar relationships have been observed between cognitive processes and aspects of the pupillary dilation response (Levine & Hakerem, 1969; Friedman, Hakerem, Sutton, & Fleiss, 1973). The present study seeks to investigate the degree to which such cortical and pupillary correlates of information processing are influenced by genetic factors, using the twin-study method.

The Twin-Study Method

The twin-study method has been, since its introduction by Sir Francis Galton in 1875, the most basic tool by which psychologists have investigated that most basic of questions: the age-old "nature-nurture" controversy. Although the emphasis over the past century has swung from "nature" to "nurture" to "interactionism," the method remains viable today (Vandenberg, 1966).

The rationale is simple: monozygotic (MZ) twins have identical genotypes, while dizygotic (DZ) twins are no more alike genetically than are nontwin siblings; therefore, intrapair similarity should be highest for MZ twins on those measures largely determined by genetic factors, while intrapair similarity for DZ twins should be no higher than that for nontwin siblings on these traits. Measures without

significant genetic components should not yield higher intrapair similarity for MZ twins (Vandenberg, 1966).

The "classical" twin study has traditionally been designed to yield a numerical estimate of the degree to which a given behavioral characteristic is genetically determined (called a heritability estimate), calculated by a number of alternative formulas (Osborne & Gregor, 1966; Osborne, Gregor, & Miele, 1967; Mittler, 1971). Such studies generally focus upon intelligence, personality or psychopathology. The literature is voluminous and numerous reviews are available (Erlenmeyer-Kimling & Jarvik, 1963; Vandenberg, 1967a, 1967b; Gottesman & Shields, 1972).

However, the kind of useful data twin studies can provide is far broader (Vandenberg, 1965). Recently, for example, investigators of psychopathology in twins have begun to focus on the discordant MZ pair in an effort to pinpoint triggering mechanisms in genetically predisposed individuals (Pollin, Stabenau, Mosher, & Tupin, 1966; Pollin & Stabenau, 1968).

The twin study can also be used as an initial tool in the search for variables which may shed light on polygenic mechanisms underlying complex psychological processes (Vandenberg, 1965). It is actually in this context that the present twin study has been conceived and designed. It is not intended to be a "classical" study leading to the derivation of heritability estimates but rather an initial investigation into the feasibility of using the cortical average evoked potential and the averaged pupillary dilation response to study possible genetic determinants of complex cognitive processes in normal human subjects.

Electroencephalographic Similarity in Twins

Striking electroencephalographic (EEG) similarity among MZ twins was reported thirty years ago by Lennox, Gibbs, and Gibbs (1945), leading those pioneers of EEG research to conclude that brain-wave pattern was "an hereditary trait." Additional support for the genetic basis of EEG patterns was provided by a confirmation of EEG similarity in MZ twins reared apart (Juel-Nielsen & Harvald, 1958).

More recently, the congruence in raw EEG of MZ twins has been used to provide a basis for blind classification of zygosity (Vogel, 1970).

Greater MZ similarity in alpha activity, including alpha blocking and habituation of alpha blocking, has also been reported (Young, Lader, & Fenton, 1972; Claridge, Canter, & Hume, 1973).

An incompletely resolved problem in such research, however, is the lack of an adequate statistic by which to quantify the similarity between any two EEG records. Visual matching, or "eyeballing" of polygraph records, has been deplored by Clarke and Harding (1969), who were unable to confirm greater MZ similarity by this technique.

A more sophisticated approach to raw EEG analysis involves breaking down each EEG sample into its frequency spectrum. Within-pair comparisons can then be made by quantitative analysis of the parameters of the spectra. This approach confirms the reports of relatively greater MZ similarity based on eyeballing (Dumermuth, 1968; Young et al., 1972; Lykken, Tellegen, & Thorkelson, 1974). Using six parameters to describe the most salient characteristics of each spectrum, and intraclass correlations to express within-pair similarity, Lykken and colleagues (1974) found MZ twins resembled their co-twins 96% as much as they resembled themselves. Dizygotic twins were generally indistinguishable

from unrelated persons.

The evidence seems clear, then, that MZ twins are uniquely alike in EEG, suggesting an underlying genetic similarity in basic neural functioning, but the behavioral significance of this is unclear. One implication may be that MZ twins respond to the experimental stimuli more similarly than do other persons. In order to assess this possibility, one must record EEG characteristics which bear definable temporal relationships to specific stimulus events.

With the advent of average response computers in the 1950s it became possible to expand the EEG technique to include measurement of event-related potentials (Vaughan, 1969). The average response computer extracts small, time-locked signals from the high amplitude background noise, thus enabling one to study brain responses evoked by particular stimulus situations (hence the term "average evoked potentials"). Such computers have also been used to study the effect of psychological variables on the pupillary response (Hakerem, 1967). Using an electronic infrared pupillograph, Hakerem and colleagues (Hakerem & Sutton, 1966; Levine & Hakerem, 1969; Friedman et al., 1973) have shown that pupillary motility during complex cognitive tasks is a highly individual characteristic which is quite stable over time. There is only the scantiest evidence in the literature relating pupillary response characteristics to zygosity. Preliminary data suggest, however, that a large proportion of the variance in pupillary responsivity may be explained by genetic factors (Hakerem, 1974, personal communication). Reference has also been made to the similarity in pattern of spontaneous pupillary oscillations (pupillary unrest) in MZ twins (Lowenstein & Loewenfeld, 1969). Initial pupil diameter and phenylephrine-induced

mydriasis are highly correlated (over .9) in MZ twins and uncorrelated (.09) in DZ twins (Bertler & Smith, 1971a, 1971b).

Average Evoked Potentials in Twins

Average evoked potential studies in twins have focused exclusively on sensory variables. Dustman and Beck (1965) measured the amplitude of the visual evoked response recorded from occipital scalp leads at two arbitrarily selected latencies in MZ and DZ twins and pairs of unrelated persons. Mean intrapair correlations were significantly higher for MZ than for DZ twins (.82 and .58 respectively), with no difference between DZ twins and unrelated persons. In many cases, the MZ intrapair similarity was so striking that correlations between two MZ twins were higher than test-retest correlations for a single subject. The former ranged from .72 to .99 (median = .88) in an earlier study for components in the latency range from 100 to 300 msec, while interindividual correlations for unrelated persons ranged from -.29 to .92 (median = .37) (Beck & Dustman, 1963).

Osborne (1970) also studied the visual evoked response in MZ and DZ twins and age-matched unrelated controls. In an attempt to correlate the entire waveform plots, ordinates were erected at intervals, beginning with stimulus onset, to yield a total of thirty values for each subject. The mean intrapair MZ correlation computed in this way was .77, and the mean DZ correlation .53, values very similar to those reported earlier. While all twins were significantly more highly correlated with their co-twins than with matched controls, the group mean correlations were not significantly different. There was considerable overlap between the MZ and DZ groups (e.g., MZ correlations ranged

from .59 to .88; DZ correlations from -.22 to .86). Again, in some cases, MZ intrapair correlations exceeded interhemispheric correlations for the same individual.

Visual evoked response similarity has also been reported in MZ twins concordant, as well as discordant, for schizophrenia (Buchsbaum, 1970; Cohn, Pollin, Stabenau, & Tupin, 1974).

Extension of the technique of intercorrelating the average evoked potentials of MZ and DZ twins and unrelated persons to other sensory modalities reveals similar trends, though not of the same magnitude. Auditory and visual evoked potential waveforms, for example, were significantly more similar among MZ than DZ twins in one study (Lewis, Dustman, & Beck, 1972), while somatosensory evoked potential waveforms showed only a nonsignificant trend in this direction. A measure of total amplitude change revealed similar relationships.

On the assumption that early and late components of the evoked response reflect different neural processes, Lewis et al. (1972) computed correlations separately for two segments of the total waveform: stimulus onset to 88 msec, and 90 to 300 msec. Both segments were equally similar (or dissimilar) across the three groups of subjects. Amplitude comparisons, however, showed a tendency for the MZ twins to be relatively more similar during the later segment. One of the most striking results of this study is the large variability within groups. Correlations in all three modalities and at all analysis time intervals ranged from negative or essentially zero to .90 or above for MZ and DZ twins as well as unrelated pairs. This may be due at least in part to the wide age range of subjects (4 to 40 years).

Consistent patterns of developmental change in evoked response

have been reported in these three modalities with respect to amplitude and latency of waveform components (Dustman & Beck, 1966; Dustman & Beck, 1969; Schenkenberg & Dustman, 1970). Variability in visual and auditory evoked potentials decreases with age, especially for components of 100 msec or greater latency (Callaway & Halliday, 1973). There is also evidence that these age changes affect overall waveform similarity in twin pairs (Lewis & Beck, 1970). Early components of the visual evoked response increase or remain constant in similarity (depending on electrode location) with increasing age in MZ twins, but decrease in similarity in DZ twins and unrelated persons. Later components show an increase in similarity until late adolescence when recorded from a central placement, and a decrease in similarity when recorded from an occipital lead, but these trends hold regardless of genetic relationship.

Young et al. (1972) recorded auditory evoked responses and reported mean correlations of .76, .55 and .40, respectively, for MZ twins, DZ twins and unrelated persons, for a latency range of 20 to 498 msec after stimulus onset. Analysis over a shorter latency range yielded substantially lower correlations for DZ twins and unrelated persons, but only slightly lower for MZ twins. None of the MZ-DZ differences reached statistical significance, though all were in the direction of greater MZ similarity. Monozygotic twins were significantly more alike than unrelated pairs, while DZ twins were not.

Buchsbaum (1974) found greater similarity among MZ twins in amplitude of three components of the visual evoked response, and also in amplitude change with increasing stimulus intensity. Dizygotic twins showed little or no similarity in these measures. Since positive com-

ponents yielded greater heritability indices than did negative components, Buchsbaum concluded the source of twin similarity is functional neurophysiological, rather than anatomical. Dustman and Beck (1965) had shown earlier that identity of waveforms in twins could not be accounted for by a simple cephalic index of head size.

On the basis of these findings, it seems clearly established that, despite occasional dissimilar pairs of twins or highly similar pairs of unrelated persons, MZ twins are consistently more alike in the visual, auditory and somatosensory evoked responses than any other pairs of individuals. Such similarity may reflect the tendency for MZ twins to share a more identical environment, with more similar life experiences, than DZ twins or unrelated persons, and thus be environmental in nature rather than genetic. This issue of equal degrees of environmental similarity for MZ and DZ twins strikes at a basic assumption of the twin-study method (Vandenberg, 1966). Evidence has been cited that MZ twins are treated more alike, especially by their parents, than are DZ twins (Lilienfeld & Pasamanick, 1955; Smith, 1965). However, there is also evidence that such differential treatment reflects rather than causes greater behavioral similarity in MZ twins (Scarr, 1968). Other investigators deny altogether the possibility that shared postnatal experiences of MZ twins differ qualitatively from those of DZ twins, pointing out that any such critical environmental factors would most likely elevate DZ concordance with respect to that of nontwin siblings (Jablon, Neel, Gershowitz, & Atkinson, 1967).

In the final analysis, it is unlikely that greater EEG similarity in MZ twins is traceable to their more identical environments since it has been observed in MZ twins reared apart (Juel-Nielsen & Harvald,

1958), in older twins leading independent lives for many years (Vogel, 1970) and since patterns of developmental change in EEG activity, themselves, appear to be genetically determined (Lewis & Beck, 1970).

Observed EEG similarity, therefore, most likely reflects a congruence in basic neural processes within the brain. It is not clear from the evidence presently available, however, whether this congruence includes responses to other than the sensory aspects of a stimulus. There are no physiological data with respect to the way MZ twins respond to the meaning or significance of a stimulus in a decision-making task, i.e., how they "cope" with a life situation.

Evoked Potentials and Cognitive Variables

One method of investigating this question involves the variable of stimulus uncertainty, the effects of which have been studied in a number of physiological systems (Sutton, 1968; Levine & Hakerem, 1969; Lovibond, 1969; Pratt, 1970; Higgins, 1971). The effects of stimulus uncertainty on the auditory evoked potential and the pupillary dilation response have been particularly well explored by Sutton and Hakerem and their colleagues (Sutton et al., 1965; Sutton, Tueting, Zubin, & John, 1967; Levine & Hakerem, 1969; Tueting, Sutton, & Zubin, 1971; Friedman et al., 1973).

Their studies have shown that when a subject is uncertain as to which of two or more stimuli are to be presented, a large amplitude positive component is present in the evoked potential, peaking at about 300 msec. When a subject knows in advance which stimulus will occur, this component, termed P300, is absent or greatly reduced in amplitude. The amplitude of P300 is unrelated to the sensory aspects of the stimu-

lus; rather, it is inversely related to the probability of occurrence of an event in a guessing situation, such as that used by Tueting et al. (1971). Their experimental design enabled them to manipulate stimulus uncertainty by varying the probability of occurrence of high and low pitched clicks. The subject was required in the "uncertain" condition to guess in advance what the next stimulus would be; in the "certain" condition, the subject was given this information by the experimenter. The amplitude of P300 was inversely related to the a priori stimulus probabilities in both conditions, but was much larger in the uncertain condition. In addition, P300 amplitude was affected by the subject's guessing behavior, being most strongly related to the relative probability of the outcome of his guess. For example, if he correctly guessed that the high probability stimulus would occur, then P300 amplitude was small, since this is a very likely occurrence. Similarly, P300 amplitude was small when the subject incorrectly guessed the low probability stimulus, since this outcome is also a likely one. When he correctly predicted the low probability stimulus, or failed to guess the high probability stimulus, both relatively unusual outcomes, P300 amplitude was large.

Although the interpretation of P300 as a correlate of the orienting response is consistent with these data (Ritter, Vaughan, & Costa, 1968), the suggestion has been offered that some broader term (perhaps "stimulus salience"), emphasizing information content, would be preferable (Jenness, 1972). The concept of salience, a characteristic attributed to a stimulus by an observer as a consequence of his experience, implies that the late components of the evoked potential represent the subject's attitude toward or assessment of stimulus importance

(Jenness, 1972; John, 1972). Recent evidence supports the interpretation of P300 in terms of post-stimulus decision-making processes rather than nonspecific preparatory alerting (Donchin, Kubovy, Kutas, Johnson, & Herning, 1973; Squires, Hillyard, & Lindsay, 1973; Poon, Thompson, Williams, & Marsh, 1974; Rohrbaugh, Donchin, & Eriksen, 1974).

Pupillary Motility and Cognitive Variables

Pupillary dilation has also been related to the psychological significance of stimuli (Kahneman & Beatty, 1967). The pupillary response to stimulus uncertainty varies with the P300 component of the evoked potential. Using simultaneous recording of average evoked potential and average pupillary responses, Friedman et al. (1973) confirmed that both P300 amplitude and peak pupillary dilation increase as a function of the rareness of an event. Friedman (1972) has also reported individual differences in the degree to which various components of the overall waveform are affected by manipulations of stimulus uncertainty. In some subjects the greatest effect occurred between the first negative and second positive deflections, while in others the second negative to P300 peak was most affected. Of Friedman's eight subjects, two happened to be identical twin girls. Both belonged to the group which showed the greatest effect of stimulus uncertainty prior to P300 and, in fact, generated waveforms which were almost perfectly superimposable under all experimental conditions. These findings suggested that "...the component that is affected is part of one's biological individuality" (Friedman, 1972, p. 94). In addition, Friedman reported greater variability for incorrect than for correct guesses, so that the division of subjects according to the component most affected by un-

certainty held only for "hits." If Friedman's speculations are correct, it should be possible to compare MZ and DZ twins on the basis of pupillary responses and evoked cortical potentials to guessing correctly or incorrectly on high or low probability stimuli, as well as early vs. late components of the waveform.

A variable known to affect evoked potential characteristics is the sex of the subject. Sex differences have been reported in normal as well as psychiatric adult populations for visual and somatosensory evoked responses, with females showing greater amplitude and shorter latency (Shagass & Schwartz, 1965a, 1965b; Shagass & Schwartz, 1966; Shagass, Schwartz, & Straumanis, 1966; Schenkenberg & Dustman, 1970; Buchsbaum & Pfefferbaum, 1971; Schenkenberg, Dustman, & Beck, 1971; Small, Small, & Perez, 1971; Shagass, Overton, & Straumanis, 1972; Buchsbaum, Landau, Murphy, & Goodwin, 1973). Females also demonstrate greater recovery of the visual evoked response to repeated stimuli (Shagass & Schwartz, 1965b; Shagass et al., 1966). Sex differences have been reported in amplitude augmenting to visual stimuli of increasing intensity (Buchsbaum & Pfefferbaum, 1971; Buchsbaum et al., 1973). These sex differences interact with stress and psychiatric diagnosis (Knott, 1971, 1973) and are usually of smaller magnitude in normal subjects (Shagass & Schwartz, 1966; Shagass, 1968; Shagass et al., 1972; Buchsbaum et al., 1973). The magnitude of observed sex differences is small when compared to the more dramatic age changes in cortical potential waveforms (Shagass, 1972, p. 91; Beck & Dustman, 1974). There is some indication of greater individual differences among females than males, which may be related to the effects of hormonal changes associated with the menstrual cycle on EEG activity

(Margerison, Anderson, & Dawson, 1964; Rodin, Grisell, Gudobba, & Zachary, 1965; Vogel, Broverman, & Klaiber, 1971; Klaiber, Broverman, Vogel, Kobayashi, & Moriarty, 1972). Indeed, the difficulty of controlling for effects due to the menstrual cycle led Young et al. (1972) to restrict their EEG study to male twins.

Other Psychophysiological Measures in Twins

In view of the positive evidence of greater MZ similarity yielded thus far by EEG and evoked cortical potential studies, and the long history of twin studies on intelligence, personality and psychopathology, the relative dearth of twin studies focusing on psychophysiological variables is somewhat surprising (Mittler, 1971; Claridge et al., 1973). In general, such studies involve variables in one or more of the following categories: cardiovascular measures, galvanic skin response, respiration, biochemical functioning, perceptual measures.

Cardiovascular measures

Greater MZ similarity in blood pressure has been reported for resting levels in both hypertensives and normotensives (Jost & Sontag, 1944; Osborne, DeGeorge, & Mathers, 1963; Barcal, Simon, & Sova, 1969); for response to pain (Shapiro, Nicotero, Sapira, & Scheib, 1968); and for response to cold (Kryshova, Beliaeva, Dmitrieva, Zhilinskaia, & Pervov, 1962). Negative results for heritability of resting blood pressure have also been reported (Downie, Boyle, Grieg, Buchanan, & Alepa, 1969). Miall and colleagues have emphasized the multifactorial nature of blood pressure determination, in which genetic and environmental factors interact (Miall, Heneage, Khosia, Lovell, & Moore, 1967). Such interaction is clearly indicated by Liljefors and Rahe (1970) in a

study of MZ twins discordant for coronary heart disease (CHD) and discordant as well for life patterns regarding work stress, lack of leisure, home problems and overall dissatisfaction. The psychosocial profiles of CHD patients were more like each other's than each was like his co-twin's. Torgerson and Kringlen (1971) found that while there was less variance in systolic blood pressure within MZ pairs than for unrelated age-matched persons, there was a tendency for elevated blood pressure in the twin characterized by submissiveness, obedience, timidity, shyness and passivity in childhood.

Resting heart rate levels are reported to be more similar in MZ twins (Mathers, Osborne, & DeGeorge, 1961; Block, 1967; Shapiro et al., 1968; Claridge et al., 1973), although there are conflicting findings (Jost & Sontag, 1944). Measures of change in heart rate to stressful or arousing stimuli are more similar in MZ twins, as well (Vandenberg, Clark, & Samuels, 1965; Lader & Wing, 1966; Block, 1967; Shapiro et al., 1968; Claridge et al., 1973).

Galvanic skin response

Greater MZ similarity in resting skin resistance level has been reported by Jost and Sontag (1944), Block (1967), and Claridge et al. (1973). Lader and Wing (1966) found greater MZ similarity in spontaneous fluctuations in skin conductance, and in GSR habituation. Similarity in GSR latency was reported by Rachman (1960). No differences between MZ and DZ twins in GSR similarity to startling stimuli were found by Vandenberg et al. (1965), although these data are considered suspect by the authors, themselves, due to methodological difficulties.

Respiration

Changes in breathing rate in response to unexpected stimuli are

more similar in MZ twins (Vandenberg et al., 1965) but the data on resting breathing rates are conflicting (Jost & Sontag, 1944; Block, 1967).

Overall autonomic activity

Higher average correlations in MZ twins than in sibs for several autonomic variables led Jost and Sontag (1944) to suggest an inherited factor of "autonomic balance." The existence of such a factor has been confirmed by Claridge et al. (1973), who also derived genetically-loaded factors of sympathetic response, EEG activity and skin potential from a battery of perceptual, electrodermal, cardiovascular and EEG measures. Interestingly, though Claridge et al. chose their variables within the general context of the arousal concept, they did not measure pupillary motility, perhaps the single most sensitive measure available of sympathetic arousal (Loewenfeld, 1958). The surprising dearth of research employing pupillary measures of arousal or anxiety has been discussed in a recent review by Janisse (1974).

Biochemical functioning

Greater MZ similarity has been reported for erythrocyte sedimentation rate (Kempthorne & Osborne, 1961), barbiturate sedation threshold (Claridge et al., 1973), behavioral reaction to coffee and alcohol (Abe, 1968) and antipyrine metabolism (Vesell & Page, 1968). No difference between MZ and DZ twin concordance in catecholamine levels before and after presentation of frustrating or painful stimuli was found by Shapiro et al. (1968). Greater similarity in plasma corticosteroids has been reported for female but not male MZ twins (Maxwell, Boyle, Greig, & Buchanan, 1969). Striking intrapair correspondence in urinary corticosteroid excretion was found in male MZ

pairs (Fox, Gifford, Valenstein, & Murawski, 1965), as well as a suggestion that twins who accept their special relationship in a positive, noncompetitive way, excrete higher levels of 17-hydroxycorticosteroids and lower levels of 17-ketosteroids than twins who unrealistically compete or deny all differences.

Perceptual measures

Studies on intrapair differences in the magnitude of visual illusions in twins have been reviewed by Mittler (1971). In general, MZ twins are more alike than DZ twins on measures of the magnitude of the Ponzo and Muller-Lyer illusions (Matheny, 1971), the autokinetic effect and critical flicker fusion (Eysenck & Prell, 1951), the size of afterimages and eidetic imagery (Smith, 1949). Claridge et al. (1973) found greater MZ similarity on measures of spiral aftereffect and two-flash threshold, but the MZ-DZ differences were not statistically significant.

General Summary

The studies reviewed here, measuring autonomic, biochemical and sensory-perceptual functioning, suggest that there is substantial similarity among MZ twins in the responses of several physiological systems to life situations involving cognitive activity or stress. While the overall trend of these studies implies a substantial genetic component, results are sometimes contradictory and frequently difficult to compare due to differences in experimental procedures and statistical treatment, occasional lack of appropriate comparison groups (DZ twins or sibs), and small sample sizes. Use of group means often obscures important differences in distributions, as well as the existence of the potentially valuable discrepant MZ pair. In the seda-

tion threshold study of Claridge et al. (1973), for example, three of eleven MZ pairs were nearly indistinguishable, nine others differed by less than 1 mg/kg, but two showed large differences. Of ten DZ pairs in that study, two were extremely similar, but the remaining eight differed by more than 1 mg/kg. Unfortunately, there was no indication of whether the dissimilar MZ pairs were also dissimilar on other measures.

The Present Study

It has been suggested (Osborne, 1970) that additional twin studies utilizing EEG measures represent "overkill" since the greater MZ intrapair similarity is well established. In reality, however, the range of behavioral situations examined thus far has been severely restricted to those requiring little or no utilization of stimulus information by the subject. Unpublished pilot data from MZ twins in a guessing paradigm, i.e., a complex cognitive or "coping" task, suggest that evoked potential waveforms as well as pupillary motility records are so alike as to be nearly superimposable by eye. These findings suggest the need for carefully controlled studies of evoked potential and pupillary similarity in twins performing cognitive tasks. In addition, none of the studies cited before included a group of sibling pairs to provide the DZ-sib comparisons which are necessary to complete the twin-study design. Since DZ twins and sibs are equally alike genetically, one would expect equal similarity in evoked potential and pupillary waveforms in these two groups if the genetic hypothesis is a valid one in this case. If DZ twins prove to be more similar than sibs, the inference may be drawn that environmental factors also contribute to these measures, since DZ twins share a more similar environment than do sibs of different ages.

The present study is designed to extend the twin-study method to include evoked potential and pupillary correlates of decision-making under conditions of varying degrees of predictability of stimulus occurrence. In addition, a major purpose of the present study is to develop a methodology, using recent advances in computer technology, for comparing the waveforms of all subjects with each other. The availability of such a technique would permit derivation of a theoretical or expected value for the baseline similarity in evoked cortical potential waveforms of unrelated persons. The high correlations found by other investigators in unrelated pairs suggest that the value of this baseline is probably high. It is against this baseline that the even greater similarities of genetically-related persons must be weighed.

Specifically, this study was designed to assess the following hypotheses:

a -- Evoked potential and pupillary responses in a decision-making task are more alike among MZ twins than among persons of lesser genetic relationship, i.e., DZ twins, nontwin siblings and unrelated persons. Preliminary research (Hakerem, 1974, personal communication) suggested an affirmative answer. The magnitude of similarity, however, may be expected to be less than that reported for sensory responses since aspects of personality likely to affect decision-making strategies and attitudes show less than perfect heritability (Mittler, 1971).

b -- There are differences in intrapair similarity between early and late waveform components. Early components are considered to represent primarily sensory input, while later components are less related to the physical nature of the stimulus and more to its evalu-

ation in relation to a decision which must be made (Donchin, 1969; Regan, 1972). It is expected that the latter process, reflecting greater individual variability, will yield greater disparity among all subject pairs than will the former. It is however expected that this disparity will not be as marked for MZ twins as for DZ, sib or unrelated pairs, reflecting the operation of genetic factors with respect to complex cortical data processing.

c -- There is a relationship between intrapair waveform similarity and correct vs. incorrect guesses or likely vs. unlikely outcomes. Tueting et al. (1971) have demonstrated the relationship between P300 amplitude and the likeliness or unlikeliness of an event. Friedman (1972) found differences in evoked potential variability between correct and incorrect guesses. Right-wrong differences in pupillary as well as evoked potential activity become more marked when a monetary payoff accompanies correct guesses in a combined guessing-betting paradigm (Hakerem & Steinhauer, 1975). Although differential financial payoffs were not included in the present study, it is nevertheless likely that subjects differentiated outcomes in the light of their own expectations and attitudes regarding their task.

d -- There are sex differences in the degree to which twins are alike on measures of evoked potential and pupillary dilation. Despite the literature on sex differences in evoked cortical potential characteristics already reviewed, only two references could be located to sex differences in auditory evoked responses (Schenkenberg & Dustman, 1970; Schenkenberg et al., 1971) and no data exist on the role of sex differences in long-latency potentials associated with stimulus "salience." In view of the relationship between evoked cortical potentials

and personality variables, or cognitive style (Shagass & Schwartz, 1965a; Buchsbaum & Pfefferbaum, 1971) it seems plausible that males and females may show differing evoked cortical potential characteristics in a task requiring the development of guessing strategy, and involving high and low probability stimuli. The responses of male and female and opposite-sex pairs will be closely examined in an attempt to clarify the relationship between sex of subjects and waveform similarity.

Method

The procedures of the present study were designed to enable comparisons to be made of the similarity of average evoked cortical potential waveforms and pupillary response records obtained during a decision-making task from subjects who varied in their degree of genetic relationship. Simultaneous recordings were made of pupillary response and evoked cortical potentials to the two different auditory stimuli. These patterns were presented in random order but constrained by the requirement that probability of occurrence of each was predetermined. The decision-making task here involved guessing which of the stimuli would occur on each trial.

Subjects

Subjects were 10 pairs of monozyotic twins (4 female, 6 male), 9 pairs of dizygotic twins (5 female, 4 opposite-sex) and 8 pairs of nontwin siblings (4 female, 4 opposite-sex). All were paid for their service as subjects and recruited by advertising in college newspapers. They ranged in age from 14 to 23-1/2 years, with a mean of 19 years for each of the three groups. For the nontwin sibling pairs, the dif-

ference in age ranged from 1 to 5 years, with a mean of 2.8 years.

Zygosity was based on the report of the subjects and further checked by a combination of anthropometric measurements (height, weight, head circumference), judgments of facial similarity based on photographs taken just prior to each experimental session, and a questionnaire designed to elicit information on developmental similarity (see Appendix). The questionnaire was based on those developed by Cederlof and colleagues (Cederlof, Friberg, Johnson, & Kaij, 1961) and Harvald and Hauge (1965). Additional items included eye and hair coloring, patterning and texture, and similarity of size and shape of facial features (Jablon et al., 1967). Similar questionnaires have been used to determine zygosity in genetic studies of schizophrenia and other psychiatric disorders and correlate highly (over .90) with blood-grouping analysis (Nichols, 1965; Creager, 1968). The validity of the questionnaire in the present study is likely to have been increased by the age (young adult) and relative sophistication (all were college or senior high-school students) of the respondents (Harvald & Hauge, 1965; Nichols, 1965).

The initial diagnosis of zygosity was made on the basis of the subjects' own report and degree of facial resemblance. (In no case did these criteria conflict, although there were twins who were unsure of their zygosity.) Subsequent analysis of measurement data showed that all MZ pairs differed by 1-inch or less in height, 10 pounds or less in weight, and 1/2-inch or less in head circumference. The differences in DZ pairs, with one exception, exceeded these values in one or more category. The exceptional DZ pair, although within the limits of the MZ group according to these three criteria, nevertheless differed

markedly in facial appearance, and family history revealed their mother had taken fertility drugs, which increase the frequency of dizygotic twinning. Final confirmation of zygosity was provided by the developmental history questionnaire. All the MZ, but none of the DZ, pairs had been occasionally or frequently mistaken by casual acquaintances or relatives during childhood.

Instrumentation

Experimental environment. Subjects sat in a cubicle which was completely darkened, sound-damped and electrostatically shielded with brass mesh. The experimenter sat directly outside this cubicle, facing a locally-designed control panel. Pupil and EEG data were monitored on-line using a Tektronix four-channel oscilloscope, enabling the experimenter to observe continuously the output of EEG amplifiers, and pupillograph data going on to the tape. The same data coming downstream off the recording heads were fed into a TMC 400A Computer of Average Transients (CAT) for on-line averaging. For purposes of final data analysis, however, averaging was done off-line by a large electronic computer (procedures to be described below).

The control panel consisted of a programming unit which interconnected a series of timers, and generated a trial sequence. A switching unit enabled the experimenter to select either of two stimuli to be presented on a given trial according to one of two predetermined sequences. In one sequence, the more frequent stimulus occurred on 70% of the trials. In the other sequence, the more frequent stimulus occurred on 60% of the trials.

The subject indicated his guess by pressing one of two choice

keys which placed an electronic tagging pulse on the tape, identifying his guess as right or wrong. Each trial sequence could therefore be tagged and identified according to which of the two stimuli had occurred and whether the subject had guessed correctly or incorrectly. This tag was used only for on-line monitoring. For actual data analysis trial outcomes were identified by a different procedure (see Data Retrieval section).

The flow chart in Figure 1 illustrates the components and sequencing of steps in the experiment.

Stimuli. The stimuli employed were actually both double clicks differing only in the duration of the interclick interval. Each click was of 0.1 msec duration, obtained by capacitor discharge, then amplified (amplifier of local design) and attenuated (Hewlett-Packard attenuator Model #350D) to approximately 60 dB above threshold for a normal adult. Clicks were delivered through a speaker 2-1/2 feet above the subject's head. The "single click" stimulus was obtained by setting the interclick interval at 2 msec, this value having been previously established as being below the discrimination threshold for normal adults (Friedman, 1972). The precise value of this threshold, though it varies somewhat from person to person, is generally 8 to 10 msec. In order to insure reliable discrimination of the "single" from the "double" click, as required by the experimental design, the interclick interval for the "double click" stimulus was set at 14 msec. Two pairs of subjects, one DZ and one sib, made occasional errors at this setting, so for them the interclick interval was increased to 16 msec.

Extraneous stimuli were masked by constant noise generated by

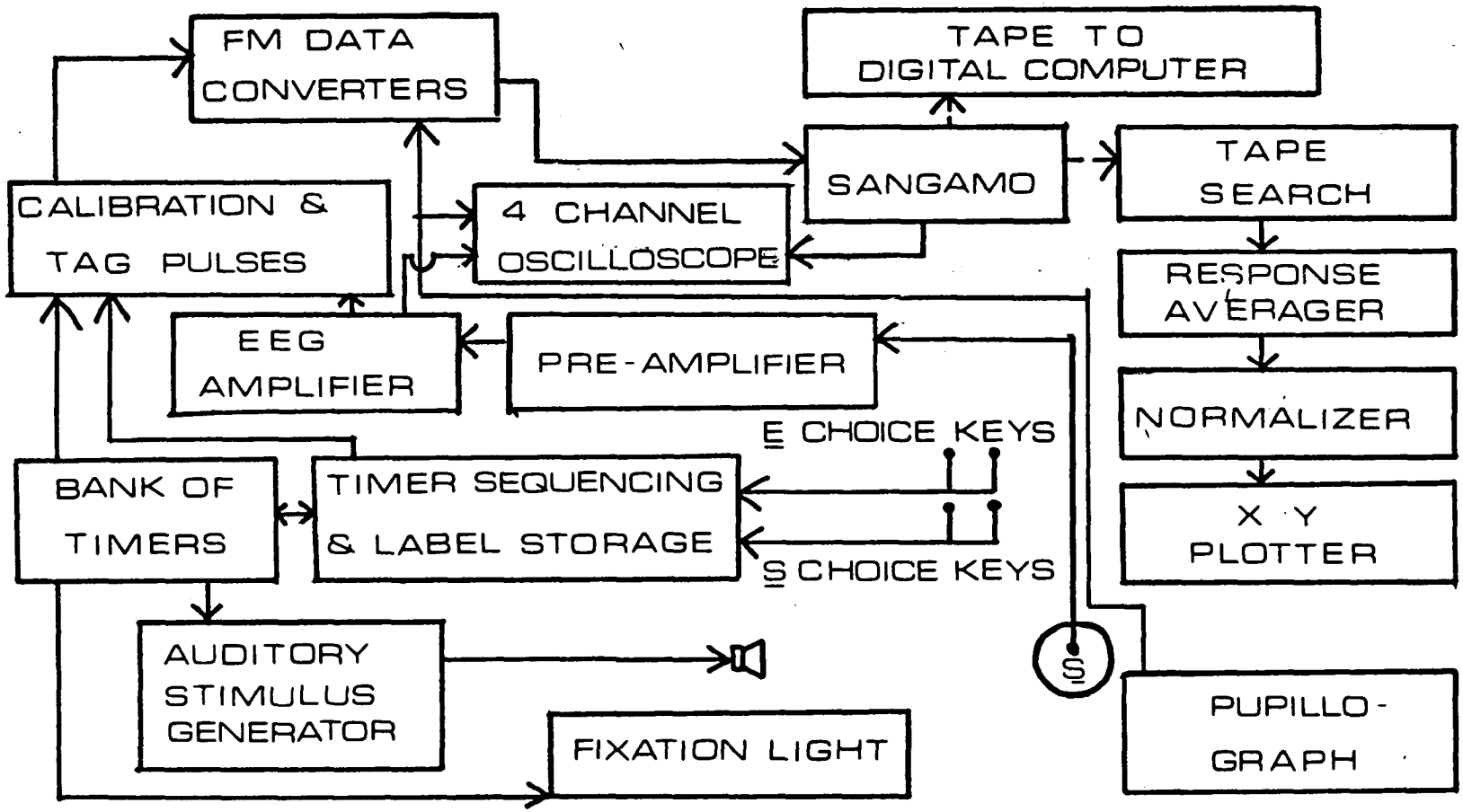

Figure 1. Simplified block diagram of the apparatus used in this study.

air conditioning and exhaust units located in the subject's cubicle. Ambient noise, measured by a Bruel & Kjaer Precision Sound Level Meter (Type 2203) was 65 dB SPL on Scale A.

Two Honeywell Model #7A1HL microswitches served as the subject's choice keys. They were fitted into a plywood strip on which the subject rested his right arm, and were marked by a raised single bar (to indicate the key representing a guess of "single click") and a double bar (to indicate the key representing a guess of "double click"). Thus, the subject could identify the keys by touch. The force necessary to close either switch was approximately 1 oz. through 1 cm.

Pupillary recording. Subjects were seated on a modified dental chair in front of the Lowenstein-Loewenfeld electronic pupillograph (Lowenstein & Loewenfeld, 1968; Hakerem, 1967). The height of the chair was adjusted so that the subject's eyes were at the correct level for recording pupillary activity. To minimize head movements and insure maintenance of focus, the subject's head position was fixed during the trial sequence by a combination forehead rest and bite board. The bite board was made for each subject prior to the experimental session, using Kerr dental compound.

The operation of the Lowenstein-Loewenfeld pupillograph has been described in detail by Hakerem (1967). In brief, the basic principle involves a mechanical infrared light scan directed on to the right eye, which is either reflected by the iris or absorbed by the pupil. The reflection of the scan is directed by a system of lenses to a photomultiplier, yielding a voltage output. The voltage output drops to zero when the scan reaches the pupil edge and is absorbed in the eye. Since the speed of the scan is known, the resulting square

wave has a width which is proportional to the pupil sector. The widest square wave is electronically identified as the pupil diameter.

At the beginning of each trial the data acquisition was interrupted for 240 msec. During this time a pulse was deposited on the tape which was equivalent in voltage to an 8 mm. pupil. The trial identification tag was also deposited on the tape at this time. During this interruption, a waveform envelope was deposited on one channel of the tape. This envelope consisted of a positive-going 200 cycle sine wave and a negative-going 2 msec square wave pulse. This envelope is referred to as the control pulse, and was used in the subsequent analog-to-digital conversion to generate an interrupt pulse in the computer (see Data Retrieval section).

The accuracy of these pupil measurements had been established previously and was rated to be within .01 mm. in an average of 25 trials.

EEG amplification. The evoked cortical potential data were obtained by a Cyber Model #J1 amplifier, which had a bandpass of .02 to 100 Hz. The amplifier gain was calibrated with a sine wave of known voltage at the input, and adjusted at the output to produce a gain of 10,000. The calibration of the amplifier was checked before the experiment began and periodically during the period of data collection.

Here, too, data acquisition was interrupted at the beginning of each trial. A calibration pulse equivalent to 30 μv. of biological signal and the trial identification tag pulse were deposited on the tape at this time.

Electrode placement. EEG was recorded from vertex [CZ, according to the 10-20 system] (Jasper, 1958). Artifact due to eye movement

could be recognized by monitoring the eye picture position on the pupillograph monitor panel. Eye blinks could be seen on one channel of the Tektronix oscilloscope displaying pupil diameter. All trials containing either eye movement or blinks were noted and eliminated from data analysis.

Beckman standard biopotential silver/silver chloride skin electrodes (Model #330421) were used. Before applying Beckman electrode paste and affixing to the scalp with Mallickrodt collodion, the subject's scalp was cleaned with an ether/acetone solution to remove the outer layer of dead epidermis. The reference electrode (Beckman Model #650399) was placed on the right earlobe using a Beckman adhesive collar. A ground electrode was place on the subject's neck and also fixed in place by an adhesive collar. All electrical resistances were checked before the subject was seated in the recording cubicle. When the resistances were greater than 10,000 ohms the electrode was re-applied using the same procedure until the resistance was lowered to the acceptable range. The subject was then seated, the pupillograph focused, and the electrode leads attached to a small pre-amplifier unit located on the back of the chair. Subjects remained seated in the cubicle for a 15-minute dark-adaptation period prior to any data recording.

Procedure

The procedure followed that of Friedman (1972) and Friedman et al. (1973). By allowing the subject to prepare himself for a trial and to self-initiate the sequence when ready, it was possible to reduce the troublesome blinking problem which often plagues pupillary research. The subject assumed the ready position (forehead against headrest,

teeth in bite board) and looked toward two alternating red lights presented at optical infinity. The beginning of a trial was signalled to the subject by stopping the alternation of the lights and leaving one light, the fixation light, steady. The subject then had three seconds (termed the "window") during which he could initiate a trial sequence by pressing one of the choice keys and thereby registering his guess for that trial. If he felt the urge to blink at that moment, or felt that he was not ready, he simply did not press. At the end of the window, if he had failed to press, the experimenter could recycle the trial by triggering the fixation light once again. Subjects were encouraged to deliberately blink during the intertrial interval. Friedman (1972) has reported this procedure reduces unusable trials due to blinking to 1% of the total. This may be due largely to the fact that Friedman's subjects were highly selected (i.e., "good" subjects for pupil research). There appears to be widespread variability in the degree to which individuals can inhibit blinking for more than a few seconds, and those individuals who may be characterized as "blinkers" are clearly inappropriate subjects for pupillary research. However, since the focus of the present study was on twins, "blinkers" who happened to be twins could not be rejected out of hand. Therefore, the percentage of "bad trials" which had to be rejected in the present experiment varies from subject to subject, and often far exceeded 1%. An extensive training period, during which the subject receives immediate feedback by being told whether he blinked on each trial, might have been helpful, but the nature of the present study, necessitating both members of a pair to be tested on the same day, reduced the training period to 15 minutes.

Trial procedure. The trial procedure is diagrammed in Figure 2. The subject always initiated the trial sequence by pressing one of the choice keys during the three second window. His press activated the timers which controlled the deposition on tape of the trial identification tags and calibration pulses previously described. The stimulus, either a "double" or a "single" click, was delivered 1.7 seconds after recording began, and either confirmed or disconfirmed the subject's guess. Sampling time, during which EEG and pupillary recordings were made, lasted for 4 seconds after trial onset (the press), and its end was signalled by resumption of the alternation of the fixation lights (which had remained steady during sampling time). The subject could now come out of his bite board position and relax until the next window, which began 8 seconds later. To insure maximum attentiveness, to the task during the trial and correct identification of stimuli, the subject was required to report at the end of each trial whether his guess had been correct or incorrect.

The intertrial interval was set at 8 seconds to give the subject sufficient time to make his verbal report and resume his position in time for the next window. The subject could register his guess and thereby initiate a trial at any time during the 3 second "window." Thus, the minimum interstimulus interval was 12 seconds. This time interval insures that no confounding effects due to recovery processes in the vertex auditory evoked potential would occur (Davis, Mast, Yoshie, & Zerlin, 1966).

Probability programs. Two probability programs were used for each subject, constructed with the use of a random number table. The programs were 70% double - 30% single, and 60% double - 40% single.

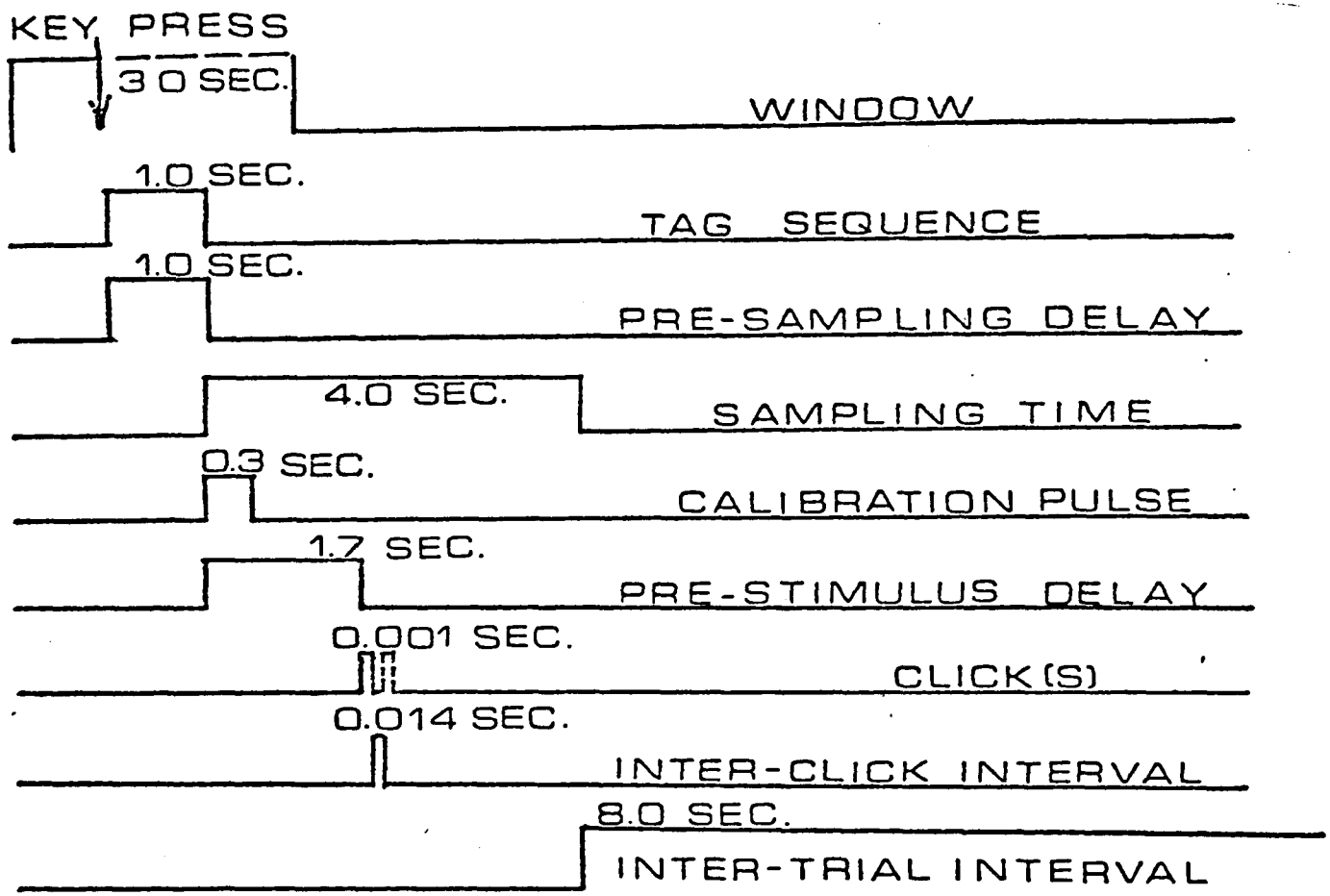

Figure 2. Sequence of events in a trial, beginning with self-initiation by subject's key press.

For half the pairs, the 70-30 program preceded the 60-40 (A order); for the other half, the sequence was reversed (B order). Both members of a twin or sibling pair received the same order. Each subject received a total of 525 trials, divided into blocks of 25 trials each, separated by one minute rest periods, and into two half sessions, each lasting approximately two hours. The half-time break allowed the first member of a pair to leave the recording chamber while his or her sib entered. Since one member of the pair was always being tested while the other rested, no communication between them was possible until the end of the experimental session. Subjects completed the twin zygosity questionnaire during this rest period.

Each sequence of uncertain trials was preceded by a single block of certain trials of the same probability program. Thus, each subject received 100 certain trials, 250 uncertain trials under the 70-30 program and 175 uncertain trials under the 60-40 program.

Instructions. Instructions were read to each subject before the first half-session. At the beginning of the second half-session the subject was simply reminded of the probabilities involved. The instructions were as follows:

> This experiment is designed to measure the electrical activity of your brain and the changes in your pupil under different conditions. There will be two sessions of approximately two hours each, separated by a two hour rest. In addition, there will be briefer rest periods within each session. You will be presented with two different stimuli. One will be a single click (demonstrate) and the other will be a double click (demonstrate).

(At this point, the subject was given a random sequence of single and double clicks, and required to demonstrate his ability to differentiate them consistently.)

Both types of click will be presented in groups of trials, or blocks, of about 6 minutes in length. There will be a rest of one minute between blocks.

For each session, there will be two different probability conditions. This means that one type of click will occur more frequently than the other. Under Condition I, the double click will occur 70% of the time and the single click 30% of the time. Under Condition II, the double click will occur 60% of the time and the single click 40%. Remember that these frequencies have been generated by computer and will be exact only in the long run, not necessarily for each block. I will tell you which probability condition obtains first, and when we switch to the other.

Each condition will begin with one block of Certain trials. This means that I will tell you in advance, through the intercom, whether a double or single click will be presented. You will then press the appropriate key (demonstrate). A little less than 2 seconds after you press, the stimulus will be presented and you will hear it. Then you will be presented with several blocks of Uncertain trials. On these trials, I will not tell you what the next stimulus will be. Instead, you will guess, and indicate your guess by pressing the appropriate key. Then you will hear the stimulus presented and you will discover whether your guess was correct or incorrect. After the trial is over, I want you to tell me whether you guessed right or wrong. At the end of each block I will tell you how many you guessed right or wrong.

After the fixation light becomes steady, you must go into position in the bite board and fixate the light. You will have three seconds within which to do this and to press one of the choice keys indicating your guess. Press lightly, using only your index finger. After you press, it is essential that you not move for 4 seconds because it is during this period that your brain and pupillary activity are being recorded. Moving includes blinking, moving your eyes or head, moving your body, gasping or coughing, and coming out of the bite board too soon. If you feel you are going to blink or you have to move, do not press the key. If you fail to press the key, the fixation lights will begin to alternate again. Simply wait until it steadies and then you may press.

Because of the way the experiment is set up, I would rather have you miss the steady signal light and wait for another one than to have you press before you are ready and waste the trial. The end of the trial is

> indicated to you by the fixation light: it will remain steady during the 4 secons of recording and then begin to alternate again. The blinking light tells you the trial is over. You may then come out of position and report to me whether you guessed right or wrong. Please do not count stimuli at any time.

Data Retrieval, Averaging and Analysis

Data acquisition was monitored on-line. Selected trials were averaged on-line (CAT) and visually inspected to insure the quality of the records. Analysis of the data was carried out on a XDS Sigma 6 and 7 computer. Several programs were written for this purpose.

Analog-to-digital conversion. Program 1 was designed to accomplish conversion of the tape recorded analog data to digital form. For this purpose, the analog tapes were read into the computer system from a Honeywell tape deck (Model 3600). The control channel of the analog tape was fed through a circuit designed to recognize the control envelope at the start of a trial. The recognition of this envelope triggered the conversion process during which samples of the data in the form of voltages were taken at 10 msec intervals (real time) and converted into digital numbers. These numbers were outputted on a digital tape. Four hundred samples were taken from each trial. The pulse from the recognition circuit and the analog data were monitored during the digitalization process on a dual-beam oscilloscope. Since pupillary and EEG data were recorded on independent channels, the conversion process had to be repeated for each channel of analog information. A later version of this program permits multiplexing of six channels. At the end of the digitalization, data output was in the form of a series of positive integers representing voltages of

EEG activity or mm. of pupillary diameter. Procedures were incorporated in the program to confirm the presence of a calibration pulse before each trial and thus insure that data and not noise had triggered the computer.

Scaling of digital data. Program 2 was called the scaling program. At the beginning of every trial a calibration voltage had been deposited on the tape equal to 8 mm. of pupillary diameter on the pupil channel and 30 microvolts of EEG activity on the second data channel. Each digital data point could thus be scaled to a numerical value representing actual pupillary diameter in mm. and actual EEG signal in microvolts, by comparison with the calibration pulse. For each digitalized trial, two points in the calibration pulse, i and j, were chosen to determine the scaling factor. Point i was chosen so that X_i (digitalized) corresponded to 0 μv. (or 0 mm.) and point j so that X_j (digitalized) corresponded to -30 μv. (or 8 mm.). All other data points, X_k, were scaled proportionally to these two points using the equation:

$$X_k(\text{scaled}) = \frac{X_k(\text{digitalized}) - X_i(\text{digitalized})}{X_j(\text{digitalized}) - X_i(\text{digitalized})} \times [-30\ \mu\text{v.}]\ (\text{or } 8\ \text{mm.})$$

The output of Program 2 consisted of a listing of scaled trials in sequential order. The trials were then numerically coded to indicate the experimental contingency for each trial.

Coding of trials. Program 3 was designed to group trials together according to experimental condition. Using the digits from 0 to 9, each trial could be identified according to ten possible experimental conditions and trial outcomes, with 0 reserved for "bad"

trials (such as those on which blinks and other events rendered the trial useless). Zero-coded trials were eliminated from further data analysis. Trial codes were keypunched behind the trial sequence numbers on a prepunched deck. The keypunched deck was then reordered and repunched by Program 3, grouping the trial numbers by experimental condition.

Data reduction. Program 4 yielded at each of 400 data points descriptive measures for each of five groups of trials for each subject. Trials were grouped by combining the two probability programs so that all trials which had the same outcome constituted a group. Thus, the five groups were: certain, single right, single wrong, double right, and double wrong. The descriptive measures were: mean, median, quartile 1, quartile 3, semi-interquartile range, mean-median difference, standard deviation, skewness and kurtosis, and rise-flat-fall (indicating the percentage of trials on which the waveform was rising, falling or flat at each sampling point, which is useful in helping to determine component peaks) (Prichep, 1974). These descriptive measures were outputted in printed as well as punched form. Graphic plots of mean, median, standard deviation, skewness and kurtosis for each trial group for each subject were generated by a Calcomp plotter.

Master tapes. Program 5 accomplished the creation of two master tapes, one for pupil and one for evoked cortical potential, containing means and standard deviations for each trial condition for all subjects, within a designated epoch. These tapes were created from the punched output of Program 4. These master tapes then were the data base for the comparison of all possible pairs of subjects in the sample.

A later version of Program 4, not used here, deposited all outputs on a disc pack master file for storage and further analysis, superseding Program 5.

Early and late segments. The primary purpose of data analysis was to evaluate the degree of similarity between any two subjects of evoked potential and pupillary correlates of the decision-making process. For this reason, no attempt was made to identify and measure EEG and pupillary components, per se. Instead, measures were used which would take into account the overall waveform characteristics of each individual. It has been speculated that early and late evoked potential components represent distinct neural processes. The early components have been associated with a largely sensory response system, while the later components, including P300, seem to be more related to attention and cognitive processes. Recent evidence on these points has already been cited. Therefore each waveform, was divided into two segments, called "early" and "late." The break point between the two segments was determined independently for each waveform, and corresponded to the halfway point between the first negative (latency approximately 100 msec) and second positive (latency approximately 200 msec) deflections. Previous work cited indicated that components earlier than P300 could also be affected by manipulations of stimulus probability. The early segment began at stimulus onset. The late segment ended at the point where EEG activity returned to pre-stimulus baseline, approximately 2 seconds later. Figure 3 illustrates the break point between early and late segments in relation to total sampling time.

Measures of similarity. Program 6 yielded separate 54 x 54 correlation matrices (Pearson product-moment r), in which the evoked

potential data from each subject was correlated with data from every other subject, separately for the early and late segments. Each experimental condition was separately analyzed, so that these matrices were generated for each of the five groups of trials. Program 6 also yielded a 54 x 54 correlation matrix for overall pupillary activity for each condition.

Program 7 generated a statistic referred to as a "distance function." Visual examination of graphic plots revealed several instances in which observably different waveforms yielded high correlations despite substantial amplitude discrepancy. Lewis et al. (1972) in their study of evoked potential similarity in twins, included a measure of total voltage change as well as the Pearson r. Vaughan (1974) has pointed out the inappropriateness of relying solely on correlational measures to evaluate waveform similarity since voltages at adjacent points are not independent. It was therefore decided to include an additional measure of waveform similarity in the present study, the distance function (Fleiss, 1975, personal communication), which represents the mean of the distribution of amplitude differences between any two records superimposed at stimulus onset and scaled to the same baseline. The twenty data points prior to stimulus onset were averaged to determine baseline for each record. The difference between the baseline values for any two waveforms then became a scaling constant which was subtracted from (or added to) each data point of one of the waveforms within the designated epoch. The absolute value of the differences between the scaled data points of the two waveforms was then computed, and averaged over the number of points in the epoch, yielding a mean distance between the two.

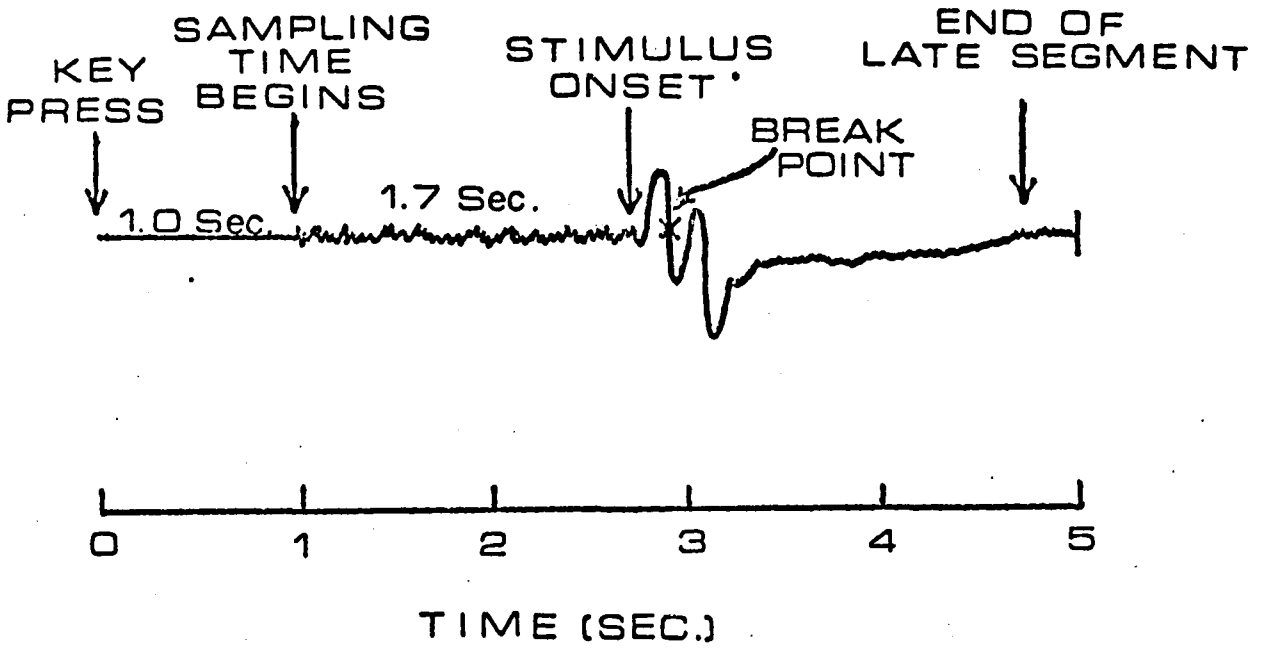

Figure 3. Break point between early and late segments of the evoked potential in relation to total sampling time. *Early segment begins at stimulus onset.

Visual inspection of data. It has been observed that mere "eyeballing" of pupillary and evoked potential waveforms, while yielding no quantitative measure of similarity, may nevertheless constitute a valuable method of gauging overall similarity or dissimilarity (Hakerem, 1975, personal communication). It was eyeballing which led to the discovery that the correlation coefficient alone might yield spuriously high (in cases of amplitude differences) as well as spuriously low (in cases of latency differences) values. For this reason it was decided to include a judgment analysis, in which naive and experienced judges examined all waveform plots for each group of subjects (MZ, DZ and sibs) for each experimental condition, in an attempt to correctly identify the related pairs. The plots of all 20 MZ twins for a given experimental condition were placed on a large surface, and judges were told to select pairs based on their impression of overall waveform similarity within the same epoch selected for statistical analysis. The same procedure was followed for each experimental condition, and then repeated using the plots of all 18 DZ twins.

Results

This study was designed to investigate the role of familial and genetic factors in determining waveform similarity of the average evoked cortical potential and the pupillary dilation response in a cognitive task in monozygotic and dizygotic twins, siblings and unrelated adults. A guessing paradigm was used in which subjects tried to correctly anticipate the occurrence of a specific stimulus pattern. Comparisons were made under five experimental conditions, one of certainty on the part of the subject, and four of uncertainty. The four

uncertain conditions were: a correct guess of single ("single right"), an incorrect guess of single ("single wrong"), a correct guess of double ("double right") and an incorrect guess of double ("double wrong").

Overview of Measures and Comparisons

Two measures of overall waveform similarity were used, the Pearson product-moment correlation coefficient (hereafter referred to as r) and the distance function previously described (hereafter referred to as D). The statistic r was not employed in the traditional sense of percent variance explained by the relationship between two variables, but rather as an index of similarity between two records. Both measures were analyzed separately for males and females for the early and late segments of the vertex evoked potential. This overall approach was used in preference to the usual component-by-component amplitude analysis in order to approximate more closely the translation into quantitative terms of the qualitative impression of waveform similarity obtained by visual inspection.

Since sex differences in pupillary activity have not been reported (Lidsky, Hakerem, & Sutton, 1971; Young, 1975; Loewenfeld, 1975, personal communication), and since the present data indicated such differences to be very small and non-significant, pupillary responses were analyzed irrespective of sex.

Comparisons of the r and D measures of similarity among pairs of subjects varying in degree of genetic relationship from identity (MZ twins) to zero (unrelated persons) were carried out by a series of analyses of variance for a "split-plot" design with repeated measures (Winer, 1962).

All correlation coefficients were transformed by the Fisher Z method before statistical analysis. Since the distance function showed a tendency for larger variances to accompany larger means, a logarithmic transform was performed on these data prior to analysis of variance. The means and standard deviations reported in Tables 1-19, however, represent the raw, untransformed data.

Hypotheses tested. Two basic hypotheses were tested for each set of analyses: (1) biologically related persons show more similar pupillary records and evoked potential waveforms than do unrelated persons under the experimental conditions described above (familial hypothesis); (2) monozygotic twins show more similar pupillary records and evoked potential waveforms than do persons of lesser degrees of genetic relatedness (genetic hypothesis). The familial hypothesis was tested by combining the data for all pairs of biologically related subjects (MZ, DZ and sib pairs) and comparing this "related" group to the unrelated pairs of subjects. The method of obtaining the sample of unrelated pairs will be clarified in a later section. A further test of the importance of familial factors was performed by combining MZ and DZ twin pairs and comparing the "twin" group to nontwin siblings. The purpose of this analysis was to examine the possible role of the special psychological closeness of the twin relationship (Mittler, 1971, p. 29-44) in determining waveform similarity. The genetic hypothesis was tested by comparing the four separate groups of subject pairs with one another, and also by comparing MZ twin pairs to the combined group of DZ twin and sibling pairs, who are of the same degree of genetic relationship. The comparisons by which each of these hypotheses were tested can be summarized as follows:

Familial #1: (MZ + DZ + sib) vs. (unrelated)

Familial #2: (MZ + DZ) vs. (sib)

Genetic #1: (MZ) vs. (DZ) vs. (sib) vs. (unrelated)

Genetic #2: (MZ) vs. (DZ + sib)

Experimental conditions. Initial analyses revealed a variable pattern of significant differences among the five experimental conditions (see Table 1). That the experimental conditions may not always be combined is suggested on a common sense level by the fact that these five outcomes probably have very different psychological values for the subject. Since the "single" click was always a relatively rare event compared to the "double" click, a correct guess of "single" cannot be assumed to be the cognitive equivalent of a correct guess of "double." For this reason it would not be appropriate to combine all correct guesses, and all incorrect guesses.

A logically more defensible approach might be to combine the "likely" and "unlikely" outcomes. For example, a guess of "single" was most likely to have been incorrect, since relatively few single clicks were presented. The category "single wrong," therefore, may be considered in some sense equivalent to the category "double right," also a likely outcome. By the same reasoning, the categories of "single right" and "double wrong" may be considered equally unlikely to occur. Such an approach, however, would require combining together correct and incorrect guesses. This is questionable procedure in the light of previous studies reporting different relationships between stimulus probability and amplitude of late components of the evoked potential for correct and incorrect guesses (Tueting, et al., 1971; Friedman et al., 1973). Pupillary activity also differentiates between right and wrong responses (Kahneman & Beatty, 1967; Hakerem &

Table 1: Patterns of significant differences among experimental conditions in terms of degree of similarity of paired waveforms. Conditions which do not differ significantly from each other are enclosed within parentheses. Conditions are listed in order of decreasing similarity of waveforms.

	E V O K E D P O T E N T I A L	
	Early segment	Late segment
Males		
Pearson r	Double Right	Double Right
	(Certain; Single Right; Single Wrong; Double Wrong)	(Certain; Single Right; Double Wrong)
		Single Wrong
Distance Function	(Certain; Single Right; Single Wrong; Double Right)	Certain
	Double Wrong	(Single Right; Single Wrong; Double Right; Double Wrong)
Females		
Pearson r	(Single Wrong; Double Wrong)	(Certain; Double Right)
	(Certain; Double Right)	Single Right
	Single Right	(Single Wrong; Double Wrong)
Distance Function	(Certain; Single Wrong)	Certain
	Double Right	(Single Wrong; Double Right)
	Double Wrong	(Single Right; Double Wrong)
	Single Right	
	P U P I L	
Pearson r	(Single Right; Single Wrong; Double Right; Double Wrong)	
	Certain	
Distance Function	(Certain; Single Wrong; Double Right)	
	(Single Right; Double Wrong)	

Steinhauer, 1975). In addition, the psychological consequences of guessing incorrectly are probably not the same as those of guessing correctly, even though no differential monetary payoffs were involved in the present study. For these reasons, the basic analyses were carried out without combining any of the five levels of the factor of experimental condition. Comparisons between likely and unlikely outcomes are justifiable, however, whenever analysis of variance indicated no significant differences between single wrong and double right (likely outcomes), or between single right and double wrong (unlikely outcomes).

Opposite sex pairs. Previously reported evoked potential data suggest that evoked response waveform differences between males and females, although smaller in normal than psychiatric populations, and smaller in magnitude than age differences, might nevertheless obscure the genetic variable if opposite sex DZ pairs were included with same sex pairs in the analysis (see Method section for references). It is also true, as Meehl (1972) has argued, that ignoring data generated by opposite sex DZ pairs overlooks a valuable source of information bearing upon the importance of environmental factors. The results for opposite sex pairs are, therefore, reported separately.

Guessing behavior. Post-experimental debriefing of each subject included a short interview designed to elucidate the guessing strategies, if any, developed during the course of the session. The guessing behavior of each subject was also analyzed to determine whether similarities in the approach to the task related in any way to similarities in evoked response or pupillary waveform.

Population Baselines

Prior to evaluating differences in waveform similarity between MZ and DZ pairs, it was essential to establish the baseline level of similarity which could be expected in the population of unrelated same sex persons. The value of this baseline probably exceeds a zero level of similarity by a considerable degree, since all subjects a) were humans, b) came from a limited range of age and educational backgrounds, and c) were all performing the same highly-structured cognitive task during recording.

The calculation of population baselines was made possible by the master tapes created by Program 5 (see Method section). A program directed the computer to average the r and D measures for all possible paired combinations of unrelated same sex and unrelated opposite sex subjects, separately for pupil and for both segments of the evoked potential. Related pairs of subjects were excluded from these averages.

The baseline values thus calculated constitute a comparison level against which the relatively greater similarity of related pairs may be evaluated. However, the baseline values were computed by considering each subject many times, since each was paired with all other same sex subjects to whom he or she was unrelated. Practically, this technique solved the problem of constructing a large population of pairs from a relatively small sample of subjects, but statistically, it created a more difficult problem in terms of the appropriate number of degrees of freedom to be used in the analysis of variance.

For this reason, two separate samples of unrelated pairs, ten male and seventeen female, were created by randomly pairing each subject with a same sex subject to whom he or she was not related. The re-

presentativeness of these samples was assured by comparing them to the baseline population values (see Tables 2-6) for unrelated pairs, from which they do not differ, and the 10- and 17-pair samples were then used in all analyses of variance.

Table 2 shows the population baselines for the pupillary dilation response. The least similarity, measured by r, occurs for both males and females under the certain condition. Visual inspection of the waveforms shows that little, if any, dilation occurs when the subject has advance knowledge of the stimulus to be presented. Baseline similarities in the four guessing conditions range between .5 and .7.

Table 3 shows the baseline D measure for the pupillary dilation response. For this measure the smaller it is, the larger the similarity. However, since this measure involves superimposition of paired waveforms at the point of origin of the dilation (approximately 600 msec after stimulus onset), less distance between waveforms should be expected where the dilation is smaller, namely in the certain condition. The data confirm this expectation, with distances of .02 mm. in the certain condition, increasing to a maximum of .09 mm. in the single wrong condition, with most values in the neighborhood of .03 mm.

Tables 4 and 5 give the population baseline similarities for the early and late segments of the evoked potential, as measured by r. A tendency for males to be more alike than females is apparent in the later segment, since the values of r for males are higher in the later than in the earlier segment.

Tables 6 and 7, which show the population baselines for the D measure for the early and late segments of the evoked potential, show that all values of D are larger in the late segment. These results

Table 2: Population baselines for pupillary dilation response, Pearson r (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	.42	.61	.69	.62	.69
	s	(.35)	(.26)	(.28)	(.30)	(.22)
Female-female (n = 516)	$\bar{X}$	.39	.48	.64	.68	.67
	s	(.39)	(.35)	(.27)	(.26)	(.26)
Male-female (n = 652)	$\bar{X}$	.42	.53	.67	.65	.69
	s	(.37)	(.33)	(.27)	(.29)	(.24)
Unrelated (n = 26)	$\bar{X}$	.40	.55	.64	.66	.70
	s	(.38)	(.41)	(.28)	(.27)	(.20)

Table 3: Population baselines for pupillary dilation response, Distance Function (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	.025	.036	.032	.029	.035
	s	(.013)	(.016)	(.017)	(.018)	(.018)
Female-female (n = 516)	$\bar{X}$	.021	.035	.092	.024	.030
	s	(.012)	(.021)	(.253)	(.015)	(.015)
Male-female (n = 652)	$\bar{X}$	.022	.035	.062	.026	.031
	s	(.013)	(.018)	(.185)	(.016)	(.016)
Unrelated (n = 26)	$\bar{X}$	.022	.034	.070	.025	.030
	s	(.012)	(.016)	(.025)	(.014)	(.014)

Table 4: Population baselines for the early segment of the evoked response, Pearson r (evoked response measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	.39	.49	.51	.60	.49
	s	(.50)	(.35)	(.38)	(.36)	(.42)
Female-female (n = 548)	$\bar{X}$	.63	.59	.65	.70	.66
	s	(.27)	(.26)	(.24)	(.24)	(.23)
Male-female (n = 672)	$\bar{X}$	.49	.55	.56	.65	.58
	s	(.41)	(.31)	(.31)	(.30)	(.35)
Unrelated male (n = 10)	$\bar{X}$	.34	.48	.47	.57	.43
	s	(.51)	(.36)	(.41)	(.39)	(.49)
Unrelated female (n = 17)	$\bar{X}$	.66	.56	.74	.70	.67
	s	(.25)	(.29)	(.13)	(.17)	(.22)

Table 5: Population baselines for the late segment of the evoked response, Pearson r (evoked response measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	.73	.59	.47	.68	.59
	s	(.11)	(.20)	(.31)	(.17)	(.22)
Female-female (n = 548)	$\bar{X}$	.70	.43	.35	.65	.39
	s	(.17)	(.35)	(.38)	(.24)	(.37)
Male-female (n = 672)	$\bar{X}$	.72	.51	.42	.68	.47
	s	(.14)	(.31)	(.35)	(.21)	(.35)
Unrelated male (n = 10)	$\bar{X}$	.72	.65	.48	.70	.62
	s	(.11)	(.12)	(.29)	(.15)	(.24)
Unrelated female (n = 17)	$\bar{X}$	.70	.49	.33	.66	.36
	s	(.18)	(.26)	(.45)	(.21)	(.41)

Table 6: Population baselines for the early segment of the evoked response, Distance Function (evoked response measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	3.605	3.925	3.773	3.515	4.500
	s	(1.615)	(1.869)	(1.524)	(1.772)	(2.163)
Female-female (n = 548)	$\bar{X}$	3.233	4.260	3.286	3.469	4.009
	s	(1.073)	(1.513)	(1.177)	(1.269)	(1.649)
Male-female (n = 672)	$\bar{X}$	3.423	4.086	3.535	3.468	4.197
	s	(1.377)	(1.652)	(1.385)	(1.555)	(1.985)
Unrelated male (n = 10)	$\bar{X}$	3.541	3.940	3.717	3.648	4.677
	s	(1.609)	(1.836)	(1.511)	(1.391)	(2.103)
Unrelated female (n = 17)	$\bar{X}$	3.032	3.130	4.769	3.737	4.258
	s	(1.237)	(1.014)	(1.467)	(1.027)	(1.489)

Table 7: Population baselines for the late segment of the evoked response, Distance Function (evoked response measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
Male-male (n = 184)	$\bar{X}$	3.355	6.178	5.985	5.161	5.944
	s	(1.500)	(3.073)	(2.497)	(2.327)	(2.724)
Female-female (n = 548)	$\bar{X}$	4.136	7.180	6.033	4.933	6.569
	s	(1.641)	(3.076)	(2.598)	(2.083)	(2.712)
Male-female (n = 672)	$\bar{X}$	3.718	6.691	5.884	5.149	6.407
	s	(1.453)	(3.063)	(2.607)	(2.287)	(2.773)
Unrelated male (n = 10)	$\bar{X}$	3.487	6.587	6.340	5.570	6.343
	s	(1.410)	(2.839)	(2.346)	(2.441)	(2.762)
Unrelated female (n = 17)	$\bar{X}$	4.107	7.091	5.810	4.953	6.630
	s	(1.990)	(3.747)	(2.876)	(2.291)	(2.534)

also confirm the trend towards greater similarity among males than females in the late components. This result is in accord with the finding that female MZ pairs are less alike than male MZ pairs, especially for late components, and will be discussed more fully in later sections.

The results will be presented in terms of the hypotheses described above, first for the pupil data and then for the evoked potential.

Pupil Analysis

Familial and genetic hypotheses. Table 8 shows the mean Pearson r for the samples of MZ, DZ, sibling and unrelated pairs, for each experimental condition. Little difference among the samples exists for the certain condition, in which little pupillary dilation occurs. With one exception, however, the MZ pairs have the highest correlations on the guessing conditions. The unrelated pairs are least alike on the single wrong condition, but are more alike than either DZ twins or siblings on the other three guessing conditions. The magnitudes of these differences are not large, and none reach statistical significance. Genetic hypothesis #1, therefore, was not confirmed. Combining the samples into all-related or all-twin groups to make the comparisons outlined earlier in this section failed to confirm either familial or genetic hypothesis, but the trends are in the predicted direction.

Further analysis using a combination of all guessing conditions into a global category of "uncertain" failed to reveal any significant familial or genetic group differences.

Table 9 shows the mean D measure for the same samples. Again,

Table 8: Mean Pearson r for the pupillary dilation response (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ (n = 10)	$\bar{X}$	.46	.77	.81	.74	.80	.78
	s	(.27)	(.16)	(.11)	(.18)	(.18)	(.13)
DZ (n = 9)	$\bar{X}$	.48	.65	.69	.82	.64	.70
	s	(.24)	(.16)	(.12)	(.12)	(.27)	(.16)
Sib (n = 8)	$\bar{X}$	.47	.43	.76	.65	.75	.65
	s	(.12)	(.35)	(.15)	(.24)	(.21)	(.29)
Related (MZ + DZ + Sib) (n = 27)	$\bar{X}$	.47	.67	.77	.74	.78	.74
	s	(.24)	(.25)	(.13)	(.19)	(.20)	(.19)
Unrelated (n = 27)	$\bar{X}$	.40	.55	.64	.66	.70	.64
	s	(.38)	(.41)	(.28)	(.27)	(.20)	(.29)

Table 9: Mean Distance Function for the pupillary dilation response (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ (n = 10)	$\bar{X}$	.0168	.0203	.0186	.0186	.0213	.0197
	s	(.0083)	(.0122)	(.0105)	(.0140)	(.0132)	(.0110)
DZ (n = 9)	$\bar{X}$	.0222	.0306	.0247	.0109	.0244	.0226
	s	(.0117)	(.0195)	(.0126)	(.0047)	(.0093)	(.0171)
Sib (n = 8)	$\bar{X}$	.0152	.0279	.0196	.0201	.0187	.0215
	s	(.0035)	(.0126)	(.0061)	(.0093)	(.0095)	(.0094)
Related (MZ + DZ + Sib) (n = 27)	$\bar{X}$	.0176	.0242	.0202	.0173	.0214	.0332
	s	(.0079)	(.0179)	(.0099)	(.0109)	(.0115)	(.0125)
Unrelated (n = 27)	$\bar{X}$	.0217	.0343	.0706	.0252	.0299	.0640
	s	(.0116)	(.0159)	(.0249)	(.0140)	(.0144)	(.0173)

the MZ pairs have the lowest mean distances in three of the four guessing conditions. Unrelated pairs are the least alike in all guessing conditions. Sibs, however, are more similar than DZ twins in three of the four. Familial hypothesis #1, stating that related pairs are more alike than unrelated pairs, was confirmed ($F = 8.073$, $p < .01$). None of the other three hypotheses were confirmed. Further analysis, in which experimental conditions were combined (see section on Experimental Conditions for the rationale underlying these combinations) also confirmed familial hypothesis #1, but none of the other three hypotheses.

Experimental conditions. The factor of experimental conditions yielded a significant F ratio for both measures of similarity ($F = 11.47$, $p < .005$ for r; $F = 7.117$, $p < .005$ for D). The Scheffe test for multiple comparisons (Winer, 1962) yielded a different pattern of significant differences among the five experimental conditions for the two measures, however. When similarity was assessed by Pearson r, the certain condition was significantly different from all other conditions. These latter, however, were not significantly different from one another, indicating that subject pairs were more alike on the guessing conditions than they were on the certain condition.

When similarity was measured using D, the pattern of significant differences among conditions was as follows: the distances between paired waveforms of all subjects in the certain, single wrong and double right conditions were not significantly different from each other, but were different from the distances in the single right and double wrong conditions. This pattern corresponds to the distinction between likely and unlikely outcomes previously discussed, and shows

that smaller D values are associated with more likely events.

There were no significant interactions between subject group and experimental conditions in any pupil analysis.

Evoked Potential Analysis

In all analyses of evoked potential data, male and female pairs are considered separately. For females, all four hypotheses were tested. For males, only familial hypothesis #1 could be tested.

Early segment: Familial and genetic hypotheses. Table 10 shows the mean Pearson r for the early segment of the evoked potential for male and female pairs varying in degree of genetic relationship. For females, it can be seen that MZ pairs did not always have higher correlations than DZ pairs; nor were unrelated female pairs always less alike than related pairs. Analysis of variance did not confirm any of the four hypotheses. For males, MZ pairs were more similar than unrelated pairs, confirming familial hypothesis #1 ($F = 6.04$, $p < .05$).

Table 11 shows the mean distance measure for the same waveforms. For female subjects, the distance measure shows a significant trend for related pairs to be more alike than unrelated pairs, thus confirming familial hypothesis #1 ($F = 5.96$, $p < .05$). None of the other three hypotheses were confirmed. For males, MZ pairs were significantly more alike than unrelated pairs ($F = 11.01$, $p < .01$).

Early segment: Experimental conditions. The factor of experimental conditions yielded a complex and variable pattern which differed for males and females, and for the r and D measures.

For females, highest correlations occurred on both wrong conditions, which did not differ significantly from each other. Inter-

Table 10: Mean Pearson r for early segment of the evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ male (n = 6)	$\bar{X}$	.78	.75	.68	.89	.86	.80
	s	(.12)	(.21)	(.30)	(.06)	(.05)	(.15)
Unrelated male (n = 10)	$\bar{X}$	.34	.48	.47	.57	.43	.48
	s	(.51)	(.36)	(.41)	(.39)	(.49)	(.41)
MZ female (n = 4)	$\bar{X}$	.76	.60	.72	.82	.67	.70
	s	(.14)	(.20)	(.13)	(.11)	(.09)	(.13)
DZ female (n = 5)	$\bar{X}$	.61	.71	.71	.80	.81	.76
	s	(.48)	(.17)	(.19)	(.17)	(.16)	(.18)
Sib female (n = 4)	$\bar{X}$	.65	.83	.77	.77	.71	.77
	s	(.25)	(.12)	(.13)	(.12)	(.21)	(.15)
Related female (MZ + DZ + Sib)	$\bar{X}$	.67	.72	.73	.80	.74	.75
	s	(.36)	(.19)	(.16)	(.14)	(.18)	(.17)
Unrelated female (n = 17)	$\bar{X}$	.66	.56	.74	.70	.67	.67
	s	(.25)	(.29)	(.13)	(.17)	(.22)	(.20)

Table 11: Mean Distance Function for early segment of evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ male (n = 6)	$\bar{X}$	1.870	2.212	2.425	1.760	2.504	2.225
	s	(.248)	(.718)	(.873	(.344)	(.459)	(.599)
Unrelated male (n = 10)	$\bar{X}$	3.541	3.940	3.717	3.648	4.677	3.928
	s	(1.609)	(1.836)	(1.511)	(1.391)	(2.103)	(1.832)
MZ female (n = 4)	$\bar{X}$	3.150	3.475	2.797	2.474	2.837	2.947
	s	(1.413)	(.382)	(.462)	(.814)	(.392)	(.513)
DZ female (n = 5)	$\bar{X}$	2.548	3.610	2.334	2.755	2.610	2.7714
	s	(.755)	(1.909)	(.734)	(.618)	(.563)	(.956)
Sib female (n = 4)	$\bar{X}$	2.625	4.043	2.193	3.106	4.436	3.2806
	s	(.808)	(1.711)	(.980)	(.615)	(2.012)	(1.683)
Related female (MZ + DZ + Sib)	$\bar{X}$	2.757	3.701	2.432	2.776	3.241	3.037
	s	(1.093)	(1.612)	(.826)	(.756)	(1.492)	(1.171)
Unrelated female (n = 17)	$\bar{X}$	3.032	3.130	4.769	3.737	4.258	3.973
	s	(1.237)	(1.014)	(1.467)	(1.027)	(1.489)	(1.249)

mediate values of r occurred on the certain and double right conditions, which did not differ significantly from each other, but did differ from the wrongs. Female pairs were least alike on the single right condition, which differed significantly from all the others. The D measure for females showed that distances in all experimental conditions differed significantly from each other except for certain and single wrong, which yielded the smallest distances.

For males, the highest correlations occurred on the double right condition. None of the other conditions differed significantly from each other. The greatest distances occurred for males on the double wrong condition. There were no other significant differences.

Early segment: Interactions. There were no significant interactions for males. There was a significant interaction between genetic relationship and experimental conditions for females when similarity was measured by Pearson r, ($F = 4.3$, $p < .05$). The interaction was accounted for by the fact that unrelated and twin pairs were least alike, while sibling pairs were most alike in the single right condition.

Late segment: Familial and genetic hypotheses. Table 12 shows the mean Pearson r for the late segment of the evoked potential. The previously established trend for male MZ pairs to be most similar on all experimental conditions is clearly evident in these data, but MZ and DZ female pairs hardly differ. Unrelated pairs are less alike on the late segment than they were for earlier components.

Analysis of variance confirms familial hypothesis #1 for both males ($F = 13.22$, $p < .01$) and females ($F = 5.69$, $p < .05$). None of the other three hypotheses were confirmed for females.

Table 12: Mean Pearson r for late segment of evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ male (n = 6)	$\bar{X}$	.85	.80	.83	.91	.86	.85
	s	(.03)	(.09)	(.07)	(.08)	(.07)	(.07)
Unrelated male (n = 10)	$\bar{X}$	.72	.65	.48	.70	.62	.58
	s	(.11)	(.12)	(.29)	(.15)	(.24)	(.23)
MZ female (n = 4)	$\bar{X}$	.86	.61	.63	.89	.56	.67
	s	(.04)	(.35)	(.23)	(.09)	(.27)	(.23)
DZ female (n = 5)	$\bar{X}$	.83	.63	.63	.82	.71	.70
	s	(.06)	(.27)	(.23)	(.04)	(.12)	(.20)
Sib female (n = 4)	$\bar{X}$	.63	.50	.43	.72	.41	.45
	s	(.28)	(.16)	(.24)	(.19)	(.30)	(.33)
Related female (MZ + DZ + Sib)	$\bar{X}$	.78	.59	.57	.81	.58	.64
	s	(.19)	(.29)	(.26)	(.14)	(.25)	(.23)
Unrelated female (n = 17)	$\bar{X}$	.70	.49	.33	.66	.36	.46
	s	(.18)	(.26)	(.45)	(.21)	(.41)	(.33)

Table 13 shows the mean distance function for the same waveforms. Distances are generally greater for all groups than in the early segment, but male MZ pairs are still the most similar. Familial hypothesis #1 for males was confirmed ($F = 9.3$, $p < .01$). Female MZ pairs are more alike than either DZ or sibling pairs on all experimental conditions, and all are more alike than are unrelated pairs. Although these trends are in the direction predicted by the familial and genetic hypotheses, none could be confirmed by analysis of variance. Supplementary analyses in which experimental conditions were combined, also failed to confirm any of the four hypotheses.

Late segment: Experimental conditions. As was the case for the early segment of the evoked potential, a different pattern of significant differences among experimental conditions emerges for males and females, and for the r and D measures.

For females, the highest correlations occurred in the certain and double right conditions, which did not differ significantly. The single right condition yielded intermediate values of r, and the two wrong conditions yielded the lowest. The groupings of experimental conditions are thus the same as those for females in the early segment, but the similarity of female pairs on these groupings is reversed.

For males, the highest correlations are found in the double right condition, which parallels the findings for the early segment. Significantly lower correlations occurred in certain, single right and double wrong conditions, which did not differ from each other. The lowest correlations were found in the single wrong condition.

When similarity is assessed by the distance function, females

Table 13: Mean Distance Function for late segment of evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS					
		Certain	Single Right	Single Wrong	Double Right	Double Wrong	All uncertain
MZ male (n = 6)	$\bar{X}$	2.157	3.705	3.131	3.244	4.020	3.525
	s	(.500)	(1.847)	(2.153)	(2.503)	(2.707)	(2.303)
Unrelated male (n = 10)	$\bar{X}$	3.487	6.587	6.340	5.570	6.343	5.817
	s	(1.410)	(2.839)	(2.346)	(2.441)	(2.762)	(2.655)
MZ female (n = 4)	$\bar{X}$	2.678	5.391	3.017	2.334	5.000	3.935
	s	(.638)	(1.631)	(.454)	(.514)	(1.619)	(1.055)
DZ female (n = 5)	$\bar{X}$	4.181	5.980	4.112	5.107	5.581	5.195
	s	(1.682	(2.171)	(1.901)	(2.196)	(2.580)	(2.332)
Sib female (n = 4)	$\bar{X}$	4.645	5.955	3.638	3.385	7.502	5.120
	s	(1.541)	(2.628)	(1.278)	(.392)	(1.963)	(2.455)
Related female (MZ + DZ + Sib)	$\bar{X}$	3.861	5.791	3.629	3.724	5.993	4.784
	s	(1.679)	(2.286)	(1.530)	(1.904)	(2.467)	(2.046)
Unrelated female (n = 17)	$\bar{X}$	4.107	7.091	5.810	4.953	6.630	6.121
	s	(1.990)	(3.747)	(2.876)	(2.291)	(2.534)	(2.862)

are most alike on the certain condition. Greater distances are found for single wrong and double right, which do not differ significantly from each other, and the largest distances are yielded by single right and double wrong. This grouping corresponds to the likely-unlikely distinction discussed earlier.

For males, the distances are smallest on the certain condition. None of the guessing conditions differed significantly from each other.

There were no significant interactions for the late segment.

A general summary of the evoked potential results in terms of hypotheses tested and confirmed will be found in Table 14. The pattern of significant differences among experimental conditions is summarized in Table 1.

Guessing Behavior

In the course of post-experiment debriefing, each subject was routinely questioned about his or her guessing strategy. All subjects reported that they had developed a strategy governing their pattern of guesses but females more often than males tended to express doubts that the stimulus probabilities were, in reality, those indicated by the experimenter. It was, therefore, decided to determine whether the pattern of single and double guesses of each subject matched the actual stimulus probabilities, and whether there was any difference between males and females in probability-matching.

The mean proportion of single and double guesses by male and female subjects on the 70/30 and 60/40 probability program is as follows:

Table 14: Summary of significant findings with respect to familial and genetic hypotheses

EVOKED POTENTIAL		
	Early Segment	Late Segment
Males Pearson r	Familial #1 $p < .05$	Familial #1 $p < .01$
Distance Function	Familial #1 $p < .01$	Familial #1 $p < .01$
Females Pearson r	All hypotheses n.s.	Familial #1 $p < .05$
Distance Function	Familial #1 $p < .05$	All hypotheses n.s.

PUPIL	
Pearson r	All hypotheses n.s.
Distance Function	Familial #1, $p < .01$

	70/30		60/40	
	Double	Single	Double	Single
Mean proportion (male)	.73	.27	.64	.36
Mean proportion (female)	.79	.21	.71	.29

It can be seen that all subjects were conservative in their willingness to guess that the relatively infrequent single click would occur, but that females were more conservative in this respect than males.

No subject adopted a consistent tendency toward maximizing correct guesses by completely avoiding the single guess throughout the experiment.

In order to determine if females were significantly more conservative with respect to the single guess than were males, the mean proportion of single and double guesses was calculated for the entire sample of subjects from same sex pairs, for each probability program:

	70/30	60/40
Mean proportion single	.23	.31
Mean proportion double	.77	.69

Males and females were then categorized as being above or below the mean proportion of single guesses for the total sample, and compared on each probability program by means of chi-square. For both programs, females were the more conservative guessers, i.e., they were more likely to have guessed single on a smaller proportion of trials than the average for the entire sample (60/40:$\chi^2 = 3.04$, $.05 < p < .10$;

70/30:$\chi^2 = 2.99$, $.05 < p < .10$). These results are in accord with the report of most female subjects that fewer single clicks were actually presented than the probabilities indicated. These results further suggest that males and females differ in their approach to the guessing task, and the strategies they develop, with males better able to match their pattern of guesses to the actual probabilities of stimulus occurrence. There were no group differences in guessing behavior as a function of degree of genetic relationship.

Opposite Sex Pairs

Tables 15 and 16 show the mean Pearson r and D values, respectively, for opposite sex pairs of DZ twins, siblings and unrelated persons for the pupillary dilation response.

Tables 17 and 18 give the mean Pearson r and D, respectively, for the same groups of subjects, for the early segment of the evoked response, while Tables 19 and 20 give these values for the late segment.

It can be seen from these results that opposite sex DZ pairs are generally more similar than unrelated opposite sex pairs in pupillary activity, but that opposite sex sibling pairs often are less similar than unrelated pairs. With respect to early segments of the evoked potential, the trend for DZ twins to be more similar in comparison with unrelated pairs is somewhat greater than that for siblings, but reversals do occur in some of the experimental conditions. While the D measure shows unrelated pairs to be substantially (although not significantly less alike than sibling pairs, this relationship is reversed when similarity is measured by Pearson r. The data for later segments of the evoked response likewise fail to reveal clear familial trends.

Table 15: Mean Pearson r for opposite sex pairs in the pupillary dilation response (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
DZ (n = 4)	$\bar{X}$	.56	.83	.74	.87	.84
	s	(.23)	(.10)	(.15)	(.11)	(.13)
Sib (n = 4)	$\bar{X}$	.60	.48	.53	.65	.68
	s	(.21)	(.36)	(.28)	(.31)	(.15)
Unrelated (n = 27)	$\bar{X}$	.40	.63	.65	.69	.70
	s	(.41)	(.33)	(.29)	(.28)	(.21)

Table 16: Mean Distance Function for opposite sex pairs in the pupillary dilation response (pupil diameters measured in mm.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
DZ (n = 4)	$\bar{X}$	.0305	.0347	.0399	.0359	.0386
	s	(.0097)	(.0171)	(.0141)	(.0216)	(.0234)
Sib (n = 4)	$\bar{X}$	.0297	.0486	.0392	.0295	.0442
	s	(.0184)	(.0276)	(.0067)	(.0193)	(.0208)
Unrelated (n = 27)	$\bar{X}$	.0242	.0297	.0828	.0242	.0288
	s	(.0149)	(.0156)	(.0236)	(.0189)	(.0160)

Table 17: Mean Pearson r for opposite sex pairs for the early segment of the evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
DZ (n = 4)	$\bar{X}$	.68	.72	.72	.69	.66
	s	(.23)	(.22)	(.21)	(.22)	(.20)
Sib (n = 4)	$\bar{X}$	.12	.27	.24	.58	.27
	s	(.38)	(.30)	(.33)	(.21)	(.44)
Unrelated (n = 27)	$\bar{X}$	.54	.61	.64	.69	.59
	s	(.37)	(.25)	(.24)	(.22)	(.35)

Table 18: Mean Distance Function for opposite sex pairs for the early segment of the evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
DZ (n = 4)	$\bar{X}$	3.478	3.512	3.943	3.749	3.815
	s	(1.285)	(.601)	(1.666)	(1.156)	(2.022)
Sib (n = 4)	$\bar{X}$	3.262	4.089	3.029	3.012	4.586
	s	(1.124)	(.965)	(.542)	(1.115)	(1.825)
Unrelated (n = 27)	$\bar{X}$	3.296	4.373	3.694	3.663	4.667
	s	(1.054)	(1.876)	(1.534)	(1.833)	(2.370)

Table 19: Mean Pearson r for opposite sex pairs for the late segment of the evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Right	Double Wrong
DZ (n = 4)	$\bar{X}$	.82	.42	.41	.57	.50
	s	(.06)	(.31)	(.31)	(.13)	(.32)
Sib (n = 4)	$\bar{X}$	.72	.66	.37	.71	.44
	s	(.18)	(.18)	(.35)	(.20)	(.51)
Unrelated (n = 27)	$\bar{X}$	.69	.50	.39	.66	.45
	s	(.18)	(.28)	(.36)	(.21)	(.35)

Table 20: Mean Distance Function for opposite sex pairs for the late segment of the evoked potential (evoked potential measured in μv.)

GROUP		EXPERIMENTAL CONDITIONS				
		Certain	Single Right	Single Wrong	Double Single	Double Wrong
DZ (n = 4)	$\bar{X}$	3.158	6.906	5.675	5.248	5.047
	s	(1.376)	(2.660)	(2.522)	(1.884)	(.835)
Sib (n = 4)	$\bar{X}$	3.660	7.250	7.077	4.838	7.756
	s	(.697)	(.830)	(2.723)	(1.617)	(3.896)
Unrelated (n = 27)	$\bar{X}$	3.606	6.558	5.170	4.529	5.680
	s	(1.586)	(3.244)	(2.669)	(2.097)	(1.805)

Tests of familial hypothesis #1 for opposite sex pairs were carried out in all cases which had yielded significant F-ratios for same sex pairs, namely the pupil analysis using D, and the late segment evoked potential analysis using r.

In all opposite sex analyses, the familial hypothesis was tested by combining DZ and sibling pairs into a related group, and comparing them to the sample of opposite sex unrelated pairs.

In no analysis were the opposite sex related pairs significantly more alike than opposite sex unrelated pairs. This finding suggests that, in the analysis of same sex pairs, it was the MZ pairs who probably contributed most to the greater similarity of related pairs.

Visual Inspection Analysis

Two persons experienced with evoked response data, and two persons unfamiliar with such waveforms, were asked to select the related pairs of subjects on the basis of overall similarity, by visual inspection.

One experienced and one naive judge were able to correctly match six of the ten MZ pairs, and five of the ten MZ pairs, respectively, on the basis of waveforms generated during uncertainty. The other two judges were not able to exceed four of ten accurate matches. None of the judges was able to match accurately more than two of the nine DZ pairs, under any guessing condition. All judges were less accurate when matching waveforms generated under the certain condition. One judge correctly matched three of ten MZ certain waveforms, while no judge could exceed one of nine correct DZ matches.

Comparison of the most accurate performance using the uncertain MZ waveforms with that for the DZ waveforms yields a marginally signi-

ficant value of chi-square ($\chi^2 = 2.28$, $.05 < p < .10$), indicating that matching by visual impression of similarity tended to be more accurate for MZ than for DZ twin pairs.

General Summary of Principal Findings

The principal finding of the present investigation is the fact that biologically related persons are more similar than unrelated persons in their pupillary and evoked cortical responses to a cognitive task. It has previously been shown that this is true with respect to sensory stimulation and brain activity. The present study has extended the finding that familial factors are significant determinants of waveform similarity to the pupillary dilation response, and to those aspects of brain and pupillary activity which correlate with information processing and decision making.

The role of genetic factors in determining waveform similarity in such tasks has received some support from the directional trends of pupil and evoked response data, and from the results of the visual inspection analysis, though this evidence is not conclusive.

In addition, the present study has shown that evoked response waveform similarity in biologically related as well as unrelated persons is complicated by a sex difference between males and females, with females generally showing less similarity than males of equal genetic relatedness, especially for the late segment. This finding has not been reported previously.

The sex differences in waveform similarity are paralleled by differences in guessing strategy, with males better able to match their guesses to the actual probability program than females.

The degree to which waveforms resemble each other depends in large measure on how similarity is quantified, with Pearson r and D indexing different aspects of waveform congruence. The issue of quantifying waveform similarity will be considered in greater detail in a later section. The greater accuracy of matching MZ than DZ pairs by naive and experienced judges in the present study confirms the value of visual inspection as a useful adjunct to statistical analysis.

The experimental conditions -- one certain and four uncertain -- differ from each other in terms of the extent of waveform similarity in a complex manner. For the pupillary dilation response, the previously reported difference (Friedman, 1972) between certain and uncertain conditions is confirmed, but the D measure is sensitive as well to a further distinction between the likely and unlikely outcomes of guessing conditions. For the evoked potential, Pearson r reveals a complex and not readily interpretable pattern of differences in similarity among all conditions. The distance function for the late components, however, suggests a certain-uncertain distinction for male pairs, and a certain-likely-unlikely pattern for females. In all cases, it is the likelier event which yields the greater similarity.

Discussion

One of the major implications of the findings reviewed in the preceding section is that the similarity in brain and pupillary activity of biologically related persons is not simply a function of the registration of sensory events, but extends as well to the central nervous system processing and evaluation of those events.

Pilot data had shown clearly that evoked cortical potential wave-

forms and pupillary records in MZ twins were superimposable in a simpler guessing paradigm with only one uncertain condition. The present study was designed to show this effect in many experimental conditions. In addition, the first two pilot subjects were females, and their data indicated no necessity to restrict the sample to male twins.

Since the present study is the first report of average evoked potentials in twins performing a decision-making task, it may be instructive at this point to compare these results with those of earlier sensory evoked potential studies in twins.

Table 21 shows the intrapair correlations for MZ and DZ twins, and unrelated pairs where available, in six studies using visual, auditory and somatosensory stimuli. Although none is strictly comparable to the present study, since subjects were drawn from a wider age range and attentional factors were less uniform due to the absence of a task, two studies (Lewis et al., 1972; Young et al., 1972) report similarity in auditory evoked potentials of approximately equal magnitude to those reported here in the certain condition (probably the most analogous experimental condition in the guessing paradigm). Both studies similarly found significant differences only when comparing MZ to unrelated pairs, although the MZ-DZ trend was in the predicted direction. The present findings are parallel in this regard. These results suggest that brain activity in MZ twins is equally as congruent whether that activity reflects the reception of sensory input or a decision-making process.

Greater variability from one study to another can be seen with respect to the correlation among DZ and unrelated pairs. (Non-twin siblings have not previously been studied.) Auditory evoked poten-

Table 21: Intrapair correlations for MZ and DZ twins in previous EEG and sensory evoked potential studies.

AUTHOR	TYPE OF MEASURE	MZ	DZ	UR
Dustman & Beck, 1965	Visual evoked potential (amplitude at 250 & 400 msec)	.82	.58	.61
Osborne, 1970	Alpha	.60	.12	
	Beta	.30	.08	
	Theta	.20	.46	
	Visual evoked potential	.77	.53	.12
Lewis, Dustman, & Beck, 1972	Visual EP (early segment)	.69	.44	.32
	Visual EP (Late segment)	.82	.73	.61
	Auditory EP (early segment)	.85	.75	.56
	Auditory EP (Late segment)	.78	.66	.43
	Somatosensory (early segment)	.50	.48	.43
	Somatosensory (Late segment)	.66	.59	.45
Young, Lader, & Fenton, 1972	Alpha	.52	.29	-.02
	Beta	.90	.56	.05
	Delta	.24	.31	.34
	Theta	.66	.34	.07
	Auditory evoked potential	.71	.39	.07
Lykken et al., 1974	Alpha	.82	-.20	
	Beta	.82	.15	
	Delta	.76	-.01	
	Theta	.86	-.03	
Buchsbaum, 1974	Visual evoked potential	.4 - .6	0 - .57	

tial similarity in DZ twins ranges from a high of .75 for early components in one study to a low of .39 for components up to 300 msec latency in another. The range for unrelated pairs is even greater: .56 to .07. Still greater variability in DZ and unrelated pairs may be seen with respect to the visual evoked potential and to various frequency bands of the EEG. The near zero correlation in DZ pairs is most marked in the studies of Lykken et al. (1974) and Buchsbaum (1974). Buchsbaum's correlations are, in general, lower than those reported herein. Although Buchsbaum compared amplitudes of selected components rather than overall waveform shapes, it is still difficult to reconcile the meager resemblance between DZ twins with either a genetic or a nongenetic familial rationale (Lykken et al., 1974).

In the present study, correlations for DZ twins, siblings and unrelated pairs were .61, .65 and .66 respectively, for the early components, and .83, .63 and .70, respectively, for later components. A major factor accounting for the higher DZ and unrelated pair correlations in the present study is probably the experimental task, itself, and the requirement which it imposed on all subjects for sustained attention and evaluation of a series of stimulus events. Even without the requirements of such a task, it may be speculated, MZ twins can be expected to approach any experimental situation similarly; hence, the high correlation obtained for MZ pairs in all previous studies. However, DZ and unrelated pairs may be expected to differ more markedly in the absence of explicit instructions. The highly structured task used in the present study may have increased the similarity obtained in DZ and unrelated pairs by reducing individual fluctuations in attentiveness, motivation, apprehensiveness, expec-

tancy and other psychological factors known to affect the evoked potential. Imposing greater task structure has been reported to eliminate group differences by increasing interindividual similarity. Shagass (unpublished paper) studied eye movement patterns in schizophrenics and normals, and found that the highly significant differences between these groups in following a swinging pendulum were greatly reduced by increasing task structure.

Attentional, motivational and other psychological factors have been found to affect primarily components exceeding 100 msec in latency, which would correspond roughly to the late segment analyzed in the present study. Specifically, late positive components have been related to attention (Picton & Hillyard, 1974); difficulty of discrimination (Jenness, 1972); task relevance (Donchin & Cohen, 1967); uncertainty, unpredictability or low probability of stimulus occurrence (Sutton et al., 1965; Sutton et al., 1967; Ritter et al., 1968; Smith, Donchin, Cohen, & Starr, 1970; Tueting et al., 1971; Roth, 1973; Ruchkin & Sutton, 1973); detection of signals (Ritter & Vaughan, 1969; Picton & Hillyard, 1974); vigilance in a decision-making situation (Satterfield, 1965; Spong, Haider, & Lindsley, 1965; Eason, Harter, & White, 1969; Picton & Low, 1971); and disconfirming feedback (Sutton et al., 1965; Squires et al., 1973).

A common element in these varied paradigms, as well as the present study, is the fact that subjects were required to attend to a stimulus whose occurrence or omission conveyed task-relevant information. In this sense, the late segment analyzed in the present study may be said to reflect cognitive activity, in respect of which MZ twins resemble each other equally as much as they do in the noncognitive

situations studied earlier.

Although the late segment mean correlations for MZ twins in the certain condition (.85 for male pairs, .86 for female pairs) are as high or higher than those reported previously by any investigator of average evoked potentials in twins in any modality, it is the uncertain conditions which provide the best indicator of the degree to which MZ twins' decision-making processes coincide, at least as assessed by vertex and pupillary recordings. In addition, it may be inquired whether the twin similarity is as marked in the late segment of the evoked potential, which presumably reflects complex processing of the informational properties of the stimulus.

Before these questions can be answered, however, another major implication of the present study must be considered, namely, that the degree of waveform similarity depends largely on the means used to assess it. Pearson r indicates that twins are more alike in the late segment, especially for the most likely outcomes (certain and double right), while siblings and unrelated females are more alike on the early segment. The distance function, however, reveals that all pairs, regardless of genetic relationship, are less alike on the late segment. This is due to the statistical nature of these two measures. Since the early segment begins at the point of superimposition, the distance between any two waveforms necessarily starts at zero. The early component is shorter in duration, however, generally including only one negative-positive sequence (few subjects showed a clearly definable initial positive defection), and thereby may yield lower values of r than the longer late segment, due to a curtailment of range phenomenon.

This clearly illustrates the basic difficulty of statistical comparison of waveform similarity. Two approaches are available, one largely qualitative and the other quantitative; these approaches would be expected to be complementary rather than mutually exclusive.

The initial evaluation of similarity in our pilot data was made by visual inspection (Bock & Hakerem, 1975), which, in many cases, made possible the accurate classification of twins by zygosity, as later confirmed by the techniques already described (see Method section). The visual inspection analysis also showed that judges were more accurate in matching MZ pairs on the basis of overall waveform similarity than they were in matching DZ pairs. The quantitative technique most frequently used in comparing twin waveforms has been the Pearson r.

While a convenient rough index of similarity as thus employed, the Pearson r is, strictly speaking, inappropriate for this purpose from a statistical point of view. The lack of independence between measures taken at successive time points in an average evoked response makes it difficult to determine the appropriate number of degrees of freedom. The significance of the difference between a single obtained value of r and a hypothesized (population) value of zero, therefore, cannot be determined with known probability of error. The proportion of variance accounted for by the correlation likewise cannot be accurately determined in this context (Donchin, 1969; Vaughan, 1974).

Nevertheless, the Pearson r does provide a quantitative indicator of the degree to which positive- and negative-going processes appear at the same time in a pair of waveforms. Figure 4 illustrates such a pair, in which r = .92. This figure also depicts a serious weak-

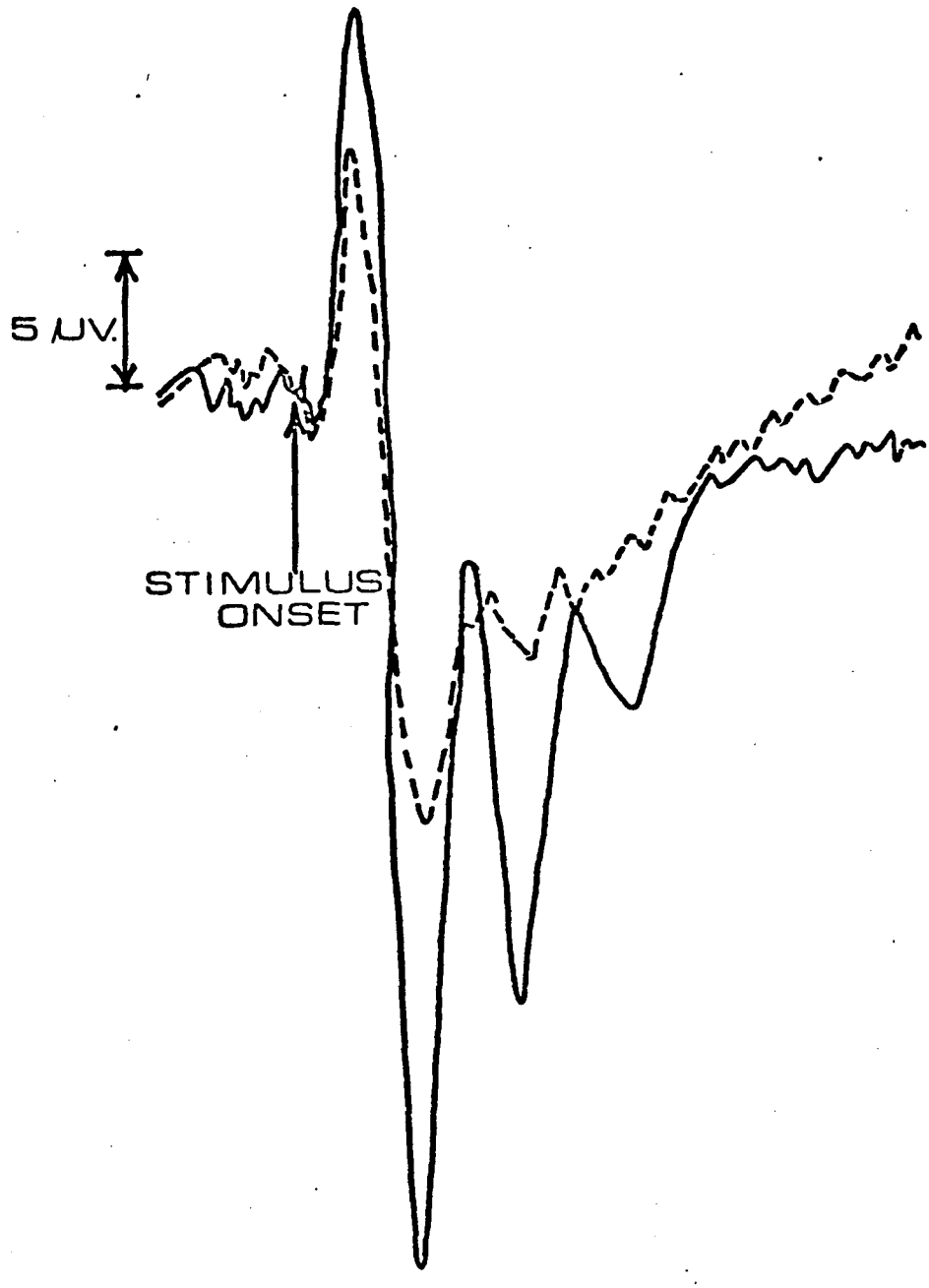

Figure 4. Superimposed waveforms for a pair of female siblings, illustrating difference between aspects of similarity indexed by Pearson r and D. (r = .92; D = 4.0).

ness of Pearson r as an index of similarity, namely its tendency to give misleadingly high values, compared to eyeballing, when the simultaneous positive- and negative-going processes differ widely in amplitude.

It was this finding which led to the development of the distance function (D) for evaluating waveform similarity in the present study. Inspection of Figure 4 reveals that, despite the high value of r, the two waveforms are relatively far apart at the points where components peak and during the entire latter portion of the curve. It is precisely this aspect of similarity, or lack of it, which the D measure quantifies. For this pair of female siblings, D = 4.0, compared to a mean for that group of 3.38.

That D is not a total solution to the problem of quantification, however, is shown by Figure 5. This pair of male MZ twins correlate a relatively low .7 with each other, and their mean distance is equal to 3.5, above the mean for their group, despite the highly unusual and characteristic W-shaped waveform which they share. In this pair of subjects, the statistics are complicated by temporal differences in the waveform patterns. That the waveforms generated by this pair are highly similar to the eye is indicated by the fact that they were correctly matched by all four judges.

A closer agreement between statistical and visual impression of similarity in this case and others might have been achieved by independent determination of the most appropriate superimposition point for each pair of waveforms to be compared, rather than superimposing all at stimulus onset. Such a procedure, however, would not have been possible with available computer software and would, in any case, have

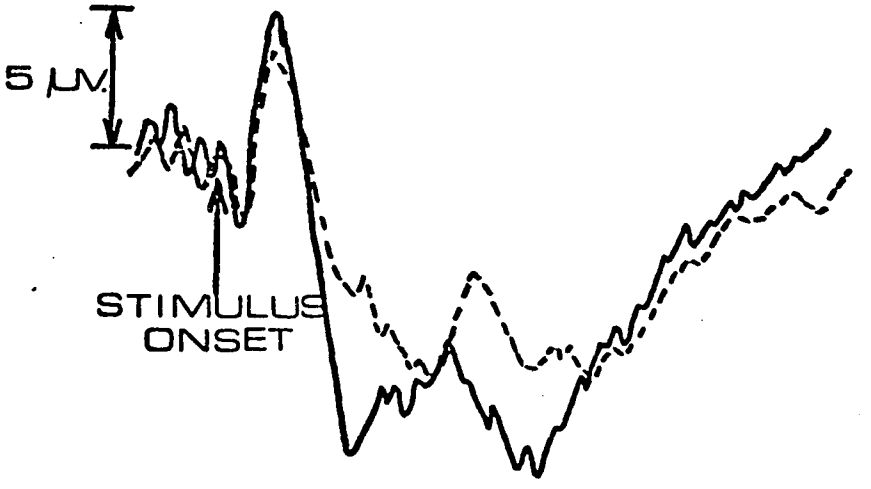

Figure 5. Superimposed waveforms for a pair of male MZ twins, illustrating similarity in overall shape not fully reflected in either r or D. (r = .7; D = 3.5).

been subject to systematic bias since the experimenter might have chosen the superimposition points so as to maximize differences in all but MZ pairs.

An alternative quantitative approach might be to forego the overall waveform comparison in favor of component-by-component amplitude or latency comparisons. Such an approach has been used by others (Dustman & Beck, 1965; Buchsbaum, 1974). Quantification of overall similarity was preferred in the present study since the objective was to approximate statistically the visual impression of similarity obtained by eyeballing, in which one considers the overall waveform shape. It is interesting to note, however, that in a recent use of component amplitude analysis, Buchsbaum (1974) found differential heritability for positive and negative components. This was not due to lower MZ correlations in the less heritable negative components, but rather to higher values for the DZ pairs, thus reducing the size of the MZ-DZ difference.

With respect to the average pupillary dilation response, Pearson r is inappropriate in a strictly statistical sense for the same reason as with evoked potential data, namely the lack of sequential independence of data points. With pupillary data, however, the fact that only one process -- dilation -- is occurring, rather than a series of biphasic processes, as in the evoked response, suggests that even as a rough index of similarity, Pearson r is inadequate. The D measure is probably the more appropriate for analyzing pupillary waveforms.

In general, one can still concur with Vaughan's (1969) comment that "Although visual inspection is subject to interpretive error when it constitutes the sole basis for conclusions, there is not as yet a

practical alternative possessing its power and flexibility in detecting regularities in complex configural data," especially if one substitutes the word "similarities" in the final phase.

As one investigator concluded (Premack, 1975), in quite a different context, "the statistical analysis and what the eye can see are in general agreement, although the eye makes a stronger interpretation than the statistics confirm."

Examination of the pupillary and evoked potential data for the guessing conditions shows that similarity decreases as uncertainty increases (see Tables 6, 7, 8, 9, 11 and 13). The more likely an event, such as correctly-predicted high probability stimulus, or an incorrectly-predicted low probability stimulus, the greater the resemblance in all pairs. This may be accounted for in part by the greater number of trials comprising the individual averaged evoked responses in the likely conditions. However, no averaged waveform contained fewer than 50 trials. The tendency for similarity to decrease with uncertainty is most marked for the late segment of the evoked potential. This would be expected on the basis of the studies already cited showing that later components of the evoked potential are more sensitive to manipulation of the probability of events than are earlier components. The introduction of requirements to attend, to cognitively process, and to make a decision regarding stimulus input apparently introduces additional elements of individuality into the waveform, but it does not diminish the degree to which MZ twins resemble one another. In fact, it may even be said to increase the difference between MZ and DZ twins in terms of intrapair similarity. The distance function data in the present study indicate that in all experimental conditions, the

difference in magnitude of similarity between MZ and DZ twins is greater for the late segment of the evoked potential than for the earlier segment. Thus, while all pairs of waveforms are more distant in the late than in the early segment, this trend is less marked for MZ twins. This finding supports the interpretation that MZ twins are relatively more alike than any other pairs of individuals, especially on aspects of brain activity known to be associated with cognitive functioning.

Although pupillary measurements have traditionally been a preferred index of arousal or affect, due to the sympathetically-derived dilation response, more recent evidence suggests that pupillary motility reflects cognitive involvement as well (Goldwater, 1972; Janisse, 1974).

One of the earliest reports relating pupillary dilation to cognitive activity was that of Hess and Polt (1964) in which dilation increased with increasingly difficult mental arithmetic problems. Dilation to correctly detected threshold light flashes, but not to blank trials, missed flashes or trials in which no discrimination was required, was reported by Hakerem and Sutton (1966). The critical factor in their study appeared to be the informational property of a stimulus when its detection had some significance for the subject. Further developments of the relationship between pupil dilation and the information conveyed by stimulus occurrence or nonoccurrence in the guessing and betting paradigms have been reported by Friedman et al. (1973) and Hakerem and Steinhauer (1975), and referred to in an earlier section.

Kahneman and his colleagues (Kahneman & Beatty, 1967; Kahneman, Tursky, Shapiro, & Crider, 1969; Johnson, 1971) have offered the con-

cept of "processing load" to indicate that pupillary dilation increases as a function of the information processing requirements imposed on a subject by virtue of the task he must perform using the stimulus input. Evidence supporting the concept of processing load has been obtained from studies using a wide variety of cognitive tasks, such as pitch discrimination (Kahneman & Beatty, 1967), paired associates learning (Kahneman & Peavler, 1969), digit transformations (Kahneman, Beatty, & Pollack, 1967; Kahneman et al., 1969), short-term memory (Kahneman & Beatty, 1966; Johnson, 1971), and long-term memory (Peavler, 1974).

Poock (1973) required subjects to process information at varying rates of speed, including rates above and below their capacity, and found a *nonmonotonic* relationship to pupil dilation, with increasing dilation replaced by constriction after the overload point was reached.

In the light of this evidence, therefore, the significantly greater similarity in pupil activity among biologically-related persons in the present study may be seen as an indication of the importance of familial determinants of cognitive activity. The nonsigificant trend towards greater similarity of MZ than DZ twins is suggestive that an important source of these familial factors is genetic.

Finally, in assessing the implications of the results of the present study, consideration must be given to the difference in degree of evoked potential waveform similarity between male and female pairs. Population baseline figures suggest that while unrelated female pairs are no less alike than unrelated male pairs in the early segment of the evoked potential, they are considerably less similar on the late segment. This relationship holds for certain as well as uncertain conditions. Male MZ pairs in the present sample are generally more

similar than female MZ pairs on early as well as late segments, except that the distance function shows this relationship reversed for the likely outcomes on the late segment.

Males, therefore, are more alike than females, regardless of genetic relationship, especially with respect to those late components most likely to be associated with cognitive activity, and on those trials resulting in the least probable event.

Several factors may contribute to the greater degree of between-person variability in females (females in the present study did not show increased within person variability). No attempt was made in the present study to control for menstrual cycle differences, either between or within female pairs. Buchsbaum, Henkin, and Christiansen (1974), reviewing male-female amplitude differences and comparing normal to XO chromosome females, concluded that neither gonadal steroid secretion, circulating level of female hormones or anatomical cranial differences, could completely account for sex differences in the evoked potential. Since the waveforms of XO females in their study were most like those of female children aged six through nine years in terms of amplitude, latency and stability, they concluded that hormonal activity may be related more to age changes in the evoked potential than to sex differences. These authors offered the suggestion that male-female differences may be more apparent than real, if there is greater time-locking of neural events to the stimulus in women. Their data on split-half stability of waveforms, however, do not indicate any sex differences, nor do within-person variability data in the present study.

Since the present study involved a cognitive task, and since male

and female subjects differed in guessing behavior and strategy as well as degree of similarity on unlikely vs. likely outcomes, it may be speculated that these data reflect basic sex differences in coping behavior.

In support of this view may be cited the subjects' own post-experimental interviews, which confirm the actual guessing behavior data: females were less successful than males in establishing a probability-matching strategy and were more likely to fall back upon the notion that particular sequences of single and double clicks would be repeated. Not surprisingly, females tended more often than males to doubt that the stimulus presentation coincided with the stated probability program, or that the experimenter was accurately tabulating trial outcomes (the number of right and wrong trials was reported to each subject after each block). If males were more uniformly likely to adopt similar probability-matching strategies, while females pursued more idiosyncratic approahces to the task, the results might be expected to show, as they do, greater waveform similarity for male pairs.

All subjects were articulate, of above-average intelligence and clearly understood the nature of their task, yet males and females differed in their approaches to the experimental situation in a manner that may have affected waveform similarity. Sex differences in problem-solving with respect to a quantitative task may conceivably arise during the developmental process of sex-role conditioning. Although a recent review of the literature on sex differences in psychological functioning suggests that many of the behaviors thought to differentiate between males and females do so artifactually due to

methodological weakness (Maccoby & Jacklin, 1974), nevertheless real differences do exist in terms of sex roles and parental-societal expectancies of appropriate sex-typed behavior (Unger & Denmark, 1975, p. 219-228). It is likely that some of these differences may influence the sort of cognitive strategies tapped by the probability guessing paradigm.

One of the most amply-substantiated sex differences in cognition, at least in terms of correlational evidence, is the finding of female superiority in verbal skills during the early childhood years, contrasted with a more lasting male superiority in numerical and spatial problems (Oetzel, 1966), despite considerable overlap between male and female performance distributions. Perhaps more to the point in the present context is the difference in cognitive styles or strategies employed by males and females in quantitative problem-solving situations, which persist even when subjects are matched for quantitative SAT scores (Maier & Casselman, 1970). Greater conservatism in judgment and risk-taking behavior, similar to that found in the present study, has been reported by Kass (1964) and Wallach and Kogan (1959), both studies involving probability choices.

Still unresolved, however, is the controversy over whether these differences are biologically or culturally based. Broverman, Klaiber, Kobayashi, and Vogel (1968) cite evidence supporting the view that males are better than females at tasks requiring inhibition of responses to more obvious stimuli in favor of responses to less obvious stimuli, and that this superiority stems directly from sex differences in hormonally-based autonomic tuning. The notion bears a prima facie resemblance to the high and low probability stimuli used in the pre-

sent study, and could explain the sex differences in guessing behavior, but could not easily accommodate the lack of sex differences in pupillary motility. A hormonal explanation would also have difficulty accounting for the fact that cognitive differences between males and females appear in the preschool years when gonadal hormone activity is minimal. A recent review of studies on impulsivity and lack of inhibition in a variety of contexts carried out in the past ten years reveals no support for the Broverman hypothesis (Maccoby & Jacklin, 1974, p. 100-101).

Sherman (1967) accounted for sex differences in another context in terms of differential opportunity to learn skills. The fact that sex differences in cognitive style persist when quantitative skills are equated (Maier & Casselman, 1970), however, suggest that prior task-experience may not be the whole answer. Other factors which may be involved include sex-role expectations and stereotyping (Maccoby, 1966), reinforcement and social interaction in school (Pederson, Shinedling, & Johnson, 1968; Shinedling & Pederson, 1970), and in experimental situations (Hoffman & Maier, 1966).

It has also been suggested that problem-solving in difficult tasks is hindered by the generally higher test anxiety levels reported in female subjects (Russell & Sarason, 1965), and that this factor, coupled with cultural expectations, could account for the bulk of observed male-female differences in cognition. In the present study, there was no indication of greater anxiety among female subjects, either in terms of subjective impression, self-report, or greater pupillary dilation.

It should be stressed, however, that "differences" in the present

study is not meant to imply "inferiority" of female performance, but merely an alternative and less consistent approach to problem-solving strategy in the probability-guessing task.

If females are less likely than males, by virtue of their physiology or acculturation, to develop a consistent probability-matching strategy, then to the extent that the evoked potential is sensitive to such cognitive factors, it may be expected to reflect less similarity among female pairs. Since the differential similarity of male and female pairs was not apparent in the pupillary response, it may be assumed that the measures of pupillary waveform similarity used in the present study are not sensitive to these cognitive factors.

In any event, the less consistent approach to strategy employed by females in the probability-guessing task, coupled with the indeterminate variability introduced by uncontrolled hormonal factors suggests that the role of genetic relationship in determining evoked potential similarity in a cognitive task would be best clarified by restricting the sample to male subjects only.

As has been mentioned earlier, the present sample was not so restricted because pilot data on female MZ pairs yielded identical waveforms. In retrospect, an additional refinement which should be considered in future research is the use of trained rather than naive subjects. The pilot MZ subjects, who were females, were highly trained in the experimental procedures. This may account for their greater waveform similarity than the MZ females used in the present study. Many trials were excluded from averaging in the present study due to blinking, movement artifact and failure of the subject to quickly adapt to the rhythm of the trial sequence. A larger number of averageable

trials could be obtained within a reasonable length experimental session if subjects had sufficient training prior to the collection of actual data. Such a design would involve repeated visits to the laboratory and testing of only one member of a twin pair per day, however, so that controls would have to be introduced to avoid verbal communication of strategies between twins or siblings in the interim.

Summary of Conclusions

The present study has demonstrated strongly and for the first time that biologically-related persons are more alike in terms of cortical and pupillary concomitants of cognitive activity than are unrelated persons. That this similarity is due largely to genetic factors is suggested by the fact that male MZ twins show the greatest congruence on all experimental conditions as assessed by Pearson r and by D, and by the greater accuracy of judges in matching MZ pairs by visual inspection. When MZ twins were perforce excluded from the analysis of familial factors by focusing on opposite sex pairs of DZ twins and siblings, no significant evidence was found for greater similarity among related subjects. The magnitudes of MZ twin correlations in the present study are comparable to those reported earlier in studies where there were no cognitive tasks, while the present values for DZ twins and unrelated pairs are generally higher than previously reported.

It may be concluded from these findings that psychological factors affecting waveform similarity vary more between members of DZ and unrelated pairs than MZ pairs unless constrained by the requirements and structure of the experiment.

No clear evidence for greater similarity of DZ than sib pairs was obtained. A greater similarity of DZ pairs might have been expected if environmental factors contributed significantly to the waveform congruence measures used. The failure to find even a consistent nonsignificant trend in this direction across experimental conditions further strengthens the hypothesis that genetic factors are probably responsible for the familial trends obtained.

All subjects, regardless of degree of relationship, are more alike on early than late segments of the evoked potential, and on trials where the outcome was a more likely event, although these conclusions are complicated by problems of a statistical nature.

The unexpected finding that waveforms of females are, in general, less alike than those of males, regardless of genetic relationship, coupled with the sex differences in guessing behavior, leads to two conclusions: strategy formation, or approach to the guessing task, is more uniformly probability-based among male subjects; and, since males are also more alike in their waveforms it may be concluded that these pupillary and brain recordings are accurately reflecting the neural substrate of complex cognitive activity.

These findings suggest, therefore, that genetic factors may serve to pre-program the neuronal circuitry involved in higher mental activity, leading to greater similarities in all levels of information processing in biologically related persons. This similarity may then interact with environmentally based congruence in cognitive style among persons sharing relevant social backgrounds and cultural experiences, to produce the observed similarities in pupillary and evoked potential waveforms.

Appendix: Zygosity Questionnaire

Completed by _____ Date _____

1. As very young children were you and your twin mistaken for each other?

	Never	Rarely	Occasionally	Frequently
By your mother?				
By your father?				
By other relatives				

2. Now, are you and your twin mistaken for each other?

	Never	Rarely	Occasionally	Frequently
By your mother?				
By your father?				
By other relatives?				
By teachers?				
By close friends?				
By casual acquaintances?				

3. Do you think you and your twin are identical or fraternal?

Identical_____ Fraternal_____

6. Why do you think so?

7. Which twin was born first?_____ By how long?_____

8. Indicate birth weights of yourself_____

your twin_____

9. Describe differences between yourself and your twin physically (strength, health, etc.) while you were growing up.

10. Describe any other differences between yourself and your twin (emotionally, personality, likes and dislikes, etc.).

References

Abe, K. Reaction to coffee and alcohol in monozygotic twins. Journal of Psychosomatic Research, 1968, 12, 199-203.

Barcal, R., Simon, J., & Sova, J. Blood pressure in twins. Lancet, 1969, i, 1321.

Beck, E. C. & Dustman, R. E. Long term stability of visually evoked potentials in man. Science, 1963, 142, 1480-1481.

Beck, E. C. & Dustman, R. E. Changes in evoked responses during maturation and aging in man and macaque. Paper presented at 82nd Annual Convention, American Psychological Association, New Orleans, 1974.

Bertler, A. & Smith, S. E. Pupil diameters and the action of phenylephrine in twins. Clinical Science, 1971, 40, 10-11P. (a)

Bertler, A. & Smith, S. E. Genetic influences in drug responses of the eye and heart. Clinical Science, 1971, 40, 403-410. (b)

Block, J. D. Monozygotic twin similarity in multiple psychophysiologic parameters and measures. Recent Advances in Biological Psychiatry, 1967, 9, 105-118.

Bock, F. A. & Hakerem, G. Pupillary and evoked potential similarity in monozygotic and dizygotic twins and siblings. Paper presented at 9th International Pupil Colloquium, Iowa City, 1975.

Broverman, D. M., Klaiber, E. L., Kobayashi, Y., & Vogel, W. Roles of activiation and inhibition in sex differences in cognitive abilities. Psychological Review, 1968, 75, 23-50.

Buchsbaum, M. Average evoked response: techniques and applications. Schizophrenia Bulletin, 1970, #3, 10-18.

Buchsbaum, M. Average evoked response and stimulus intensity in identical and fraternal twins. Physiological Psychology, 1974, 2, 365-370.

Buchsbaum, M. & Pfefferbaum, A. Individual differences in stimulus intensity response. Psychophysiology, 1971, 8, 600-611.

Buchsbaum, M., Landau, S., Murphy, D., & Goodwin, F. Average evoked response in bipolar and unipolar affective disorders - relationship to sex, age of onset and MAO. Biological Psychiatry, 1973, 7, 199-212.

Buchsbaum, M., Henkin, R. I., & Christiansen, R. L. Age and sex differences in averaged evoked responses in a normal population, with observations in patients with gonadal dysgenesis. Electroencephalography & Clinical Neurophysiology, 1974, 37, 137-144.

Callaway, E. & Halliday, R. A. Evoked potential variability: effects of age, amplitude and methods of measurement. Electroencephalography & Clinical Neurophysiology, 1973, 34, 125-133.

Cederlof, R., Friberg, L., Johnson, E., & Kaij, L. Studies in similarity diagnosis in twins with the aid of mailed questionnaires. Acta Genetica, 1961, 11, 338-362.

Claridge, G., Canter, S., & Hume, W. I. Personality differences and biological variation: a study of twins. Oxford: Pergamon Press, 1973.

Clarke, L. G. & Harding, G. F. A. Comparisons of mono- and dizygotic twins with respect to some features of the electroencephalogram. Proceedings of the Electrophysiological Technology Association, 1969, 16, 94-101.

Cohn, R., Pollin, W., Stabenau, J., & Tupin, J. A neurological and electrical study of identical twins. Electroencephalography & Clinical Neurophysiology, 1974, 37, 209.

Creager, J. A. Errors in zygosity determination and their effects on heritability indices. Proceedings, 76th Annual Convention, American Psychological Association, 1968, 179.

Davis, H., Mast, T., Yoshie, N., & Zerlin, S. The slow responses of the human cortex to auditory stimuli: recovery process. Electroencephalography & Clinical Neurophysiology, 1966, 21, 105-113.

Donchin, E. Data analysis techniques in average evoked potential research. In E. Donchin & D. B. Lindsley (Eds.), Average evoked potentials: methods, results and evaluations. NASA SP-191, 1969.

Donchin, E. & Cohen, M. D. Average evoked potentials and intramodality selective attention. Electroencephalography & Clinical Neurophysiology, 1967, 22, 537-546.

Donchin, E., Kubovy, M., Kutas, M., Johnson, R., & Herning, R. I. Graded changes in evoked response (P300) amplitude as a function of cognitive activity. Perception & Psychophysics, 1973, 14, 319-324.

Downie, W. W., Boyle, J. A., Grieg, W. R., Buchanan, W. W., & Alepa, F. P. Relative roles of genetic and environmental factors in control of blood pressure in normotensive subjects. British Heart Journal, 1969, 31, 21-25.

Dumermuth, G. Variance spectra of electroencephalograms in twins. In P. Kellaway & I. Petersen (Eds.), Clinical electroencephalography of children. New York: Grune & Stratton, 1968.

Dustman, R. E. & Beck, E. C. The visually evoked potential in twins. Electroencephalography & Clinical Neurophysiology, 1965, 19, 570-575.

Dustman, R. E. & Beck, E. C. Visually evoked potentials: amplitude changes with age. Science, 1966, 151, 1013-1015.

Dustman, R. E. & Beck, E. C. Effects of maturation and aging on the waveform of the visually evoked potential. Electroencephalography & Clinical Neurophysiology, 1969, 26, 2-11.

Eason, R. G., Harter, M. R., & White, C. T. Effects of attention and arousal on visually evoked cortical potentials and reaction time in man. Physiology & Behavior, 1969, 4, 283-289.

Erlenmeyer-Kimling, L. & Jarvik, L. F. Genetics and intelligence: a review. Science, 1963, 142, 1477-1479.

Eysenck, H. J. & Prell, D. B. The inheritance of neuroticism. Journal of Mental Science, 1951, 97, 447-465.

Fox, H. M., Gifford, S., Valenstein, A. F., & Murawski, B. J. Psychophysiology of monozygotic male twins. Archives of General Psychiatry, 1965, 12, 490-500.

Friedman, D. The effects of stimulus uncertainty on the pupillary dilation response and the vertex evoked potential in man. Unpublished doctoral dissertation, City University of New York, 1972.

Friedman, D., Hakerem, G., Sutton, S., & Fleiss, J. L. Effect of stimulus uncertainty on the pupillary dilation response and the vertex evoked potential. Electroencephalography & Clinical Neurophysiology, 1973, 34, 475-484.

Goldwater, B. C. Psychological significance of pupillary movements. Psychological Bulletin, 1972, 77, 340-355.

Gottesman, I. I. & Shields, J. Schizophrenia and genetics: a twin study vantage point. New York: Academic Press, 1972.

Hakerem, G. Pupillography. In P. Venables & I. Martin (Eds.), A manual of psychophysiological methods. Amsterdam: North Holland Publishing Company, 1967.

Hakerem, G. & Sutton, S. Pupillary response at visual threshold. Nature, 1966, 212, 485-486.

Hakerem, G. & Steinhauer, S. Winning and losing as expressed by pupillary motility and evoked cortical potentials. Paper presented at the Ninth International Pupil Colloquium, Iowa City, 1975.

Harvald, B. & Hauge, M. Hereditary factors elucidated by twin studies. In J. V. Neel, M. W. Shaw, & W. J. Schull (Eds.), Genetics and the epidemiology of chronic disease. Washington, D. C.: USPHS Publication #1163, 1965.

Hess, E. H. & Polt, J. M. Pupil size in relation to mental activity during simple problem-solving. Science, 1964, 143, 1190-1192.

Higgins, J. D. Set and uncertainty as factors influencing anticipatory cardiovascular responding in humans. Journal of Comparative & Physiological Psychology, 1971, 74, 272-283.

Hoffman, L. E. & Maier, N. R. Social factors influencing problem-solving in women. Journal of Personality & Social Psychology, 1966, 4, 382-390.

Jablon, S., Neel, J. V., Gershowitz, H., & Atkinson, G. F. The NAS-NRC twin panel: methods of construction of the panel, zygosity diagnosis and proposed use. American Journal of Human Genetics, 1967, 19, 133-161.

Janisse, M. P. (Ed.) Pupillary dynamics and behavior. New York: Plenum Press, 1974. Pp. 154-157.

Jasper, H. H. The ten twenty electrode system of the international federation. Electroencephalography & Clinical Neurophysiology, 1958, 10, 371-375.

Jenness, D. Auditory evoked-response differentiation with discrimination learning in humans. Journal of Comparative and Physiological Psychology, 1972, 80, 75-90.

John, E. R. Switchboard versus statistical theories of learning and memory. Science, 1972, 177, 850-864.

Johnson, D. A. Pupillary responses during a short-term memory task: cognitive processing, arousal or both. Journal of Experimental Psychology, 1971, 90, 311-318.

Jost, H. & Sontag, L. W. The genetic factor in autonomic nervous system function. Psychosomatic Medicine, 1944, 6, 308-310.

Juel-Nielsen, N. & Harvald, B. The electroencephalogram in uniovular twins brought up apart. Acta Genetica (Basel), 1958, 8, 57-64.

Kahneman, D. L. & Beatty, J. Pupil diameter and load on memory. Science, 1966, 154, 1583-1585.

Kahneman, D. L. & Beatty, J. Pupillary responses in a pitch-discrimination task. Perception & Psychophysics, 1967, 2, 101-105.

Kahneman, D. L. & Peavler, W. S. Incentive effect and pupillary changes in association learning. Journal of Experimental Psychology, 1969, 79, 312-318.

Kahneman, D. L., Tursky, B., Shapiro, D., & Crider, A. Pupillary, heartrate and skin resistance changes during a mental task. Journal of Experimental Psychology, 1969, 79, 164-179.

Kahneman, D. L., Beatty, J., & Pollack, I. Perceptual deficit during a mental task. Science, 1967, 157, 218-219.

Kass, N. Risk in decision making as a function of age, sex and probability preference. Child Development, 1964, 35, 577-582.

Kempthorne, O. & Osborne, R. H. The interpretation of twin data. American Journal of Human Genetics, 1961, 13, 320-339.

Klaiber, E. L., Broverman, D. M., Vogel, W., Kobayashi, Y., & Moriarty, D. Effects of estrogen therapy on plasma MAO activity and EEG driving responses of depressed women. American Journal of Psychiatry, 1972, 128, 1492-1498.

Knott, J. R., Peters, J. F., Cohen, S. I., VanVeen, W., & Miller, L. H. Sex, stress and the contingent negative variation. Electroencephalography & Clinical Neurophysiology, 1971, 31, 104.

Knott, J. R. & Peters, J. F. Sex, stress and interstimulus interval. In W. C. McCallum & J. R. Knott (Eds.), Event-related potentials of the brain: their relations to behavior. Amsterdam: Elsevier, 1973.

Kryshova, N. A., Beliaeva, Z. V., Dmitrieva, A. F., Zhilinskaia, M. A., & Pervov, L. G. Investigation of the higher nervous activity and of certain vegetative features in twins. Soviet Psychology & Psychiatry, 1962, 1, 36-41.

Lader, M. H. & Wing, L. Physiological measures, sedative drugs and morbid anxiety. Oxford: Oxford University Press, 1966.

Lennox, L. G., Gibbs, E. L., & Gibbs, F. A. The brain-wave pattern, an hereditary trait. Journal of Heredity, 1945, 36, 233-243.

Levine, S. & Hakerem, G. Pupillary dilation as a function of stimulus uncertainty. Paper presented at the 40th Annual Meeting of the Eastern Psychological Association, Washington, D. C., 1969.

Lewis, E. G. & Beck, E. C. Cerebral evoked response similarity in MZ, DZ and unrelated individuals. Proceedings, 78th Annual Convention, American Psychological Association, 1970, 181.

Lewis, E. G., Dustman, R. E., & Beck, E. C. Evoked response similarity in monozygotic, dizygotic and unrelated individuals: a comparative study. Electroencephalography & Clinical Neurophysiology, 1972, 23, 309-316.

Lidsky, A., Hakerem, G., & Sutton, S. Pupillary reactions to single light pulses in psychiatric patients and normals. Journal of Nervous & Mental Disease, 1971, 153, 286-291.

Lilienfeld, A. & Pasamanick, B. A study of the variations in the frequency of twin births by race and socioeconomic status. American Journal of Human Genetics, 1955, 7, 204-217.

Liljefors, I. & Rahe, R. H. An identical twin study of psychosocial factors in coronary heart disease in Sweden. Psychosomatic Medicine, 1970, 32, 523-542.

Loewenfeld, I. E. Mechanisms of reflex dilation of the pupil: historical review and experimental analysis. Documenta Ophthalmologica, 1958, 12, 185-448.

Lowenstein, O. & Loewenfeld, I. E. The pupil. In H. Davson (Ed.), The eye, Vol. 3. New York: Academic Press, 1969. P. 277.

Lowenstein, O. & Loewenfeld, I. E. Electronic pupillography. Archives of Ophthalmology, 1958, 59, 352-363.

Lovibond, S. H. Habituation of the orienting response to multiple stimulus sequences. Psychophysiology, 1969, 5, 435-439.

Lykken, D. T., Tellegen, A., & Thorkelson, K. Genetic determination of EEG frequency spectra. Biological Psychology, 1974, 1, 245-259.

Maccoby, E. E. Sex differences in intellectual functioning. In E. E. Maccoby (Ed.), The development of sex differences. Stanford, California: Stanford University Press, 1966.

Maccoby, E. E. & Jacklin, C. N. The psychology of sex differences. Stanford, California: Stanford University Press, 1974.

Maier, N. R. F. & Casselman, G. C. The SAT as a measure of problem-solving ability in males and females. Psychological Reports, 1970, 26, 927-939.

Margerison, J. H., Anderson, W. McC., & Dawson, J. Plasma sodium and the EEG during the menstrual cycle of normal human females. Electroencephalography & Clinical Neurophysiology, 1964, 17, 540-544.

Mathers, J. A. L., Osborne, R. H., & DeGeorge, F. V. Studies of blood pressure, heartrate and the electrocardiogram in adult twins. American Heart Journal, 1961, 62, 634-642.

Matheny, A. P. Genetic determinants of the Ponzo illusion. Psychonomic Science, 1971, 24, 155-156.

Maxwell, J. D., Boyle, J. A., Greig, W. R., & Buchanan, W. W. Plasma corticosteroids in healthy twin pairs. Journal of Medical Genetics, 1969, 6, 294-297.

Meehl, P. E. A critical afterword. In I. I. Gottesman & J. Shields, Schizophrenia and genetics. New York: Academic Press, 1972.

Miall, W. E., Heneage, P., Khosia, T., Lovell, H., & Moore, F. Factors influencing the degree of resemblance in arterial pressure in close relatives. Clinical Science, 1967, 33, 271-283.

Mittler, P. The study of twins. London: Penguin, 1971.

Nichols, R. C. The National Merit twin study. In S. G. Vandenberg (Ed.), Methods and goals in human behavior genetics. New York: Academic Press, 1965.

Oetzel, R. M. Annotated bibliography. In E. E. Maccoby (Ed.), The development of sex differences. Stanford, California: Stanford University Press, 1966.

Osborne, R. H., DeGeorge, F. V., & Mathers, J. A. L. The variability of blood pressure: basal and causal measurements in adult twins. American Heart Journal, 1963, 66, 176-183.

Osborne, R. T. Heritability estimates for the visual evoked response. Life Sciences, 1970, 9, 481-490.

Osborne, R. T. & Gregor, A. J. The heritability of visualization, perceptual speed and spatial orientation. Perceptual & Motor Skills, 1966, 23, 379-390.

Osborne, R. T., Gregor, A. J., & Miele, F. Heritability of numerical facility. Perceptual & Motor Skills, 1967, 24, 659-666.

Peavler, W. S. Pupil size, information overload and performance differences. Journal of Physiology, 1974, 11, 559-566.

Pedersen, D. M., Shinedling, M. M., & Johnson, D. L. Effect of sex of examiner and subject on children's quantitative test performance. Journal of Personality & Social Psychology, 1968, 10, 251-254.

Picton, T. W. & Low, M. D. The CNV and semantic content of stimuli in the experimental paradigm: effects of feedback. Electroencephalography & Clinical Neurophysiology, 1971, 31, 451-456.

Picton, T. W. & Hillyard, S. A. Human auditory evoked potential. II: Effects of attention. Electroencephalography & Clinical Neurophysiology, 1974, 36, 191-199.

Pollin, W. & Stabenau, J. R. Biological, psychological and historical differences in a series of monozygotic twins discordant for schizophrenia. In D. Rosenthal & S. S. Kety (Eds.), The transmission of schizophrenia. Oxford: Pergamon Press, 1968.

Pollin, W., Stabenau, J. R., Mosher, L., & Tupin, J. Life history differences in identical twins discordant for schizophrenia. American Journal of Orthopsychiatry, 1966, 36, 492-509.

Poock, G. K. Information processing vs. pupil diameter. Perceptual & Motor Skills, 1973, 37, 1000-1002.

Poon, L., Thompson, L., Williams, R., & Marsh, G. The effects of learning on average evoked potentials. Psychophysiology, 1974, 11, 233.

Pratt, R. W. Cognitive processing of uncertainty: its effect on pupillary dilation and preference ratings. Perception & Psychophysics, 1970, 8, 193-198.

Premack, D. Putting a face together. Science, 1975, 188, 228-236.

Prichep, L. S. Attention and the auditory evoked potential in hyperkinetic children treated with methylphenidate and in normal children. Unpublished doctoral dissertation, City University of New York, 1974.

Rachman, S. Galvanic skin response in identical twins. Psychological Reports, 1960, 6, 298.

Regan, D. Evoked potentials in psychology, sensory physiology and clinical medicine. London: Chapman & Hall, 1972.

Ritter, W. & Vaughan, H. G., Jr. Averaged evoked responses in vigilance and discrimination: a reassessment. Science, 1969, 164, 326-328.

Ritter, W., Vaughan, H. G., Jr., & Costa, L. D. Orienting and habituation to auditory stimuli: a study of short-term changes in average evoked responses. Electroencephalography & Clinical Neurophysiology, 1968, 25, 550-556.

Rodin, E. A., Grisell, J. L., Gudobba, R. D., & Zachary, G. Relationship of EEG background rhythms to photic evoked responses. Electroencephalography & Clinical Neurophysiology, 1965, 19, 301-304.

Rohrbaugh, J. W., Donchin, E., & Eriksen, C. W. Decision making and the P300 component of the cortical evoked response. Perception & Psychophysics, 1974, 15, 368-374.

Roth, W. T. Auditory evoked responses to unpredictable stimuli. Psychophysiology, 1973, 10, 125-138.

Ruchkin, D. S. & Sutton, S. Visual evoked and emitted potentials and stimulus significance. Bulletin of Psychonomic Society, 1973, 2, 144-146.

Russell, D. G. & Sarason, I. G. Test anxiety, sex and experimental conditions in relation to anagram solution. Journal of Personality & Social Psychology, 1965, 1, 493-496.

Satterfield, J. H. Evoked cortical response enhancement and attention in man: a study of responses to auditory and shock stimuli. Electroencephalography & Clinical Neurophysiology, 1965, 19, 470-475.

Scarr, S. Environmental bias in twin studies. In S. G. Vandenberg (Ed.), Progress in human behavior genetics. Baltimore: Johns Hopkins University Press, 1968.

Schenkenberg, T. & Dustman, R. E. Visual, auditory and somatosensory evoked response changes related to age, hemisphere and sex. Proceedings, 78th Annual Convention, American Psychological Association, 1970, 183-184.

Schenkenberg, T., Dustman, R. E., & Beck, E. C. Changes in evoked responses related to age, hemisphere and sex. Electroencephalography & Clinical Neurophysiology, 1971, 30, 163-164.

Shagass, C. Averaged somatosensory evoked responses in various psychiatric disorders. Recent Advances in Biological Psychiatry, 1968, 10, 205-219.

Shagass, C. Evoked brain potentials in psychiatry. New York: Plenum Press, 1972. Pp. 87-105.

Shagass, C. & Schwartz, M. Age, personality and somatosensory cerebral evoked responses. Science, 1965, 148, 1359-1361. (a)

Shagass, C. & Schwartz, M. Visual cerebral evoked response characteristics in a psychiatric population. American Journal of Psychiatry, 1965, 121, 979-987. (b)

Shagass, C. & Schwartz, M. Somatosensory cerebral evoked responses in psychotic depression. British Journal of Psychiatry, 1966, 112, 799-807.

Shagass, C., Schwartz, M., & Straumanis, J. J. Subject factors related to variability of averaged evoked responses. Electroencephalography & Clinical Neurophysiology, 1966, 20, 93-98.

Shagass, C., Overton, D. A., & Straumanis, J. J. Sex differences in somatosensory evoked responses related to psychiatric illness. Biological Psychiatry, 1972, 5, 295-309.

Shapiro, A. P., Nicotero, J., Sapira, J., & Scheib, E. T. Analysis of the variability of blood pressure, pulse rate and catecholamine responsivity in identical and fraternal twins. Psychosomatic Medicine, 1968, 30, 506-520.

Sherman, J. A. Problem of sex differences in space perception and aspects of intellectual functioning. Psychological Review, 1967, 74, 290-299.

Shinedling, M. M. & Pedersen, D. M. Effects of sex of teacher and student on children's gain in quantitative and verbal performance. Journal of Psychology, 1970, 76, 79-84.

Small, J. G., Small, I. F., & Perez, H. C. EEG, evoked potential and CNV with lithium in manic-depressive disease. Biological Psychiatry, 1971, 3, 47.

Smith, D. B. D., Donchin, E., Cohen, L., & Starr, A. Auditory averaged evoked potentials in man during selective binaural listening. Electroencephalography & Clinical Neurophysiology, 1970, 28, 146-152.

Smith, G. Psychological studies in twin differences. Lund, Sweden: Gleerup, 1949.

Smith, R. T. A comparison of socioenvironmental factors in monozygotic and dizygotic twins, testing an assumption. In S. G. Vandenberg (Ed.), Methods and goals in human behavior genetics. New York: Academic Press, 1965.

Spong, P., Haider, M., & Lindsley, D. B. Selective attentiveness and cortical evoked responses to visual and auditory stimuli. Science, 1965, 148, 395-397.

Squires, K. C., Hillyard, S. A., & Lindsay, P. H. Cortical potentials evoked by confirming and disconfirming feedback following an auditory discrimination. Perception & Psychophysics, 1973, 13, 25-31.

Sutton, S. Recent eddies in brain currents. Bulletin of Atomic Scientists, 1968, 24, 23-27.

Sutton, S., Braren, M., Zubin, J., & John, E. R. Evoked potential correlates of stimulus uncertainty. Science, 1965, 150, 1187-1188.

Sutton, S., Tueting, P., Zubin, J., & John, E. R. Information delivery and the sensory evoked potential. Science, 1967, 155, 1436-1439.

Torgerson, S. & Kinglen, E. Blood pressure and personality. A study of the relationship between intrapair differences in systolic blood pressure and personality in MZ twins. Journal of Psychosomatic Research, 1971, 15, 183-191.

Tueting, P., Sutton, S., & Zubin, J. Quantitative evoked potential correlates of the probability of events. Psychophysiology, 1971, 7, 385-394.

Unger, R. K. & Denmark, F. L. (Eds.) Woman: dependent or independent variable. New York: Psychological Dimensions, 1975. Pp. 219-228.

Vandenberg, S. G. Multivariate analysis of twin differences. In S. G. Vandenberg (Ed.), Methods and goals in human behavior genetics. New York: Academic Press, 1965.

Vandenberg, S. G. Contributions of twin research to psychology. Psychological Bulletin, 1966, 66, 327-352.

Vandenberg, S. G. Hereditary factors in psychological variables in man, with special emphasis on cognition. In J. N. Sphuler (Ed.), Genetic diversity and human behavior. Chicago: Aldine, 1967. (a)

Vandenberg, S. G. Hereditary factors in normal personality traits (as measured by inventories). Recent Advances in Biological Psychiatry, 1967, 9, 65-104. (b)

Vandenberg, S. G., Clark, P. J., & Samuels, I. Psychophysiological reactions of twins: hereditary factors in galvanic skin resistance, heartbeat and breathing rates. Eugenics Quarterly, 1965, 12, 7-10.

Vaughan, H. G., Jr. The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D. B. Lindsley (Eds.), Average evoked potentials: methods, results and evaluations. NASA SP-191, 1969, 45-94.

Vaughan, H. G., Jr. The analysis of scalp-recorded brain potentials. In R. F. Thompson & M. M. Patterson (Eds.), Bioelectric recording techniques. Part B: Electroencephalography and human brain potentials. New York: Academic Press, 1974.

Vesell, E. S. & Page, J. G. Genetic control of drug levels in man: antipyrine. Science, 1968, 161, 72-73.

Vogel, F. The genetic basis of the normal human electroencephalogram (EEG). Humangenetik, 1970, 10, 91-114.

Vogel, W., Broverman, D. M., & Klaiber, E. L. EEG responses in regularly menstruating women and in amenorrheic women treated with ovarian hormones. Science, 1971, 172, 388-391.

Wallach, M. A. & Kogan, N. Sex differences and judgment process. Journal of Personality, 1959, 27, 555-564.

Winer, B. J. Statistical principles in experimental design. New York: McGraw-Hill, 1962. P. 191.

Young, F. A. The pupil and refractive errors. Paper presented at the Ninth International Pupil Colloquium, Iowa City, 1975.

Young, J. P. R., Lader, M. H., & Fenton, G. W. A twin study of the genetic influences on the electroencephalogram. Journal of Medical Genetics, 1972, 9, 13-16.