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Event-related brain potentials and pupillary responses using a cognitive task in monozygotic twins

Gaudreau, Louise Pauline, Ph.D.

City University of New York, 1991

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Event-related Brain Potentials and Pupillary Responses Using a Cognitive Task in Monozygotic twins

by

Louise L. Gaudreau

A dissertation submitted to the Graduate Faculty in
Psychology in partial fulfillment of the requirements for
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Abstract

EVENT-RELATED BRAIN POTENTIALS AND PUPILLARY RESPONSES USING A COGNITIVE TASK IN MONOZYGOTIC TWINS

by

Louise P. Gaudreau

Advisor: Professor Gad Hakerem

This study recorded pupillary and event-related potential (ERP) responses in seven pairs of monozygotic (MZ) twins under two task conditions. The stimuli in both tasks were four possible combinations of a high (2400 Hz) and low (1700 Hz) tone. Task 1 required the subject to guess whether an equiprobable "same" or "different" pair would be presented; the tone pair then presented provided feedback. In Task 2, the guess was "high" or "low" and the exact order of the tones determined four possible outcomes. A "high" guess followed by a high/high pair was a "win confirmed" while a high/low pair resulted in a "win cancelled". The two main objectives were first to determine if MZ twins exhibited a high degree of similarity on their waveforms and second if intertask differences would emerge. The results for the pupil responses showed no task differences in either overall shape, peak dilation or latency of the waveforms. Visual inspection supports a high degree of similarity in the cotwins. The ERP results contrasted the MZ pairs with mean scores for all possible nontwin pairings for each twin in the sample. Naive judges performed considerably above chance (25%) in matching cotwin waveforms (Task 1 50%; Task 2 61%) using a forced choice technique. Larger correlations for twins than nontwins were statistically significant for the whole waveform, first and second half independently. For both groups Task 1 resulted in larger correlations in the waveforms, especially at Cz and Pz. The component amplitudes for S_1N_1, S_1P_2 and S_2N_1 (S_1/S_2 first/second stimulus of pair) were more similar for twins than nontwins while P3 amplitudes were not. Task 1 produced more similar amplitudes in both groups compared to Task 2. The direct amplitude measurements of the 14 twins showed S_1N_1 and S_2P_3 to be the largest, as anticipated, yet smaller at Fz. The only latency differences were greater similarity for twins than nontwins for S_1N_1 and S_1P_2. The MZ twins were quite similar in their overall response patterns. The ERP waveforms were more sensitive to task differences with Task 1 showing more overall similarity. A substantial familial contribution was postulated to determine functional processes, as well as, the underlying structural units.

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To my very special dear friend and relative, Gisele, there are no words to convey the gratitude I feel for all that you heve done for me and my boys. Finally I thank a very recent new friend Walter for his courage when mine was wavering.

Dedication

This work is dedicated foremost to my husband Albert c. Martinez, who never once doubted the eventual completion of this research or suggested other than forging ahead.

I also dedicate this accomplishment to my parents whose emotional and financial support truly lessened the burden. For their love and dauntless support I thank them sincerely.

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The quest to understand the functions of the brain and its interrelationship with a concept of 'mind' seems to be an enduring human pursuit. Wundt, as the founder of experimental psychology in 1879, chose consciousness as the major topic of investigation. More than a century later psychology is still striving, albeit using other more sophisticated techniques, to understand the cerebral mechanisms underlying indirectly observed human mental activity. Consciousness remains an intuitively experienced state that has defied characterization to date, yet continues to influence much present day theorizing.

History attests to a very long tradition of efforts at localization of function. Phrenology, as utilized by Gall, sought to map human 'faculties' on the scalp. Scalp morphology, a bump or depression, was thought to be indicative of an abundance or lack of some specific faculty. Success at localizing complex mental functions came first with Broca (1861) and later Wernicke (1873), both of whom described specific types of aphasia following circumscribed cortical damage (Luria 1973). Much progress has been made in understanding of nerve cell properties and sensory physiology. Unfortunately, the synthesis of many detailed facts about anatomical, neurochemical and electrophysiological properties of single and groups of cells still

These so-called cognitive or "higher-level" mental activities have again become an intense topic of research in the last two decades. Questions concerning those activities and qualities that make us human are perhaps best answered in the intact functioning brain. Higher mental processes include a host of varied activities: memory, perception, thinking, learning, reasoning, language and understanding. A fruitful approach to the study of such processes has been that of information processing, where the manipulation and storage of informational events is assessed, together with the sensory properties and mere registration of stimuli. According to Lachman, Lachman and Butterfield (1979) "information-processing-oriented cognitive psychologists believe that such collection, storage, interpretation, understanding, and use of environmental or internal information _is_ cognition (p.7)." Toward this end two psychophysiological measures have proven to be valuable indicators of cognitive activity; pupillary motility and cortical evoked potential responses. Event-related brain potentials (ERPS) and task-evoked pupillary responses (TEPRS) (Beatty 1982) are distinctive measurements in that they permit us glimpses into the functioning brain.

Pupillary dilation serves as an index of central nervous system activity which is sensitive to the processing demands (e.g., attention, effort, memory load) acting in concert on the individual at a precise point in time. ERPs are indicative of longer lasting successive changes in brain activity during task performance. Although both measures are sensitive to many informational parameters, they nonetheless manifest a confluence of effects which may not be separable as is possible with simpler systems.

Information Processing - History

Human information processing as an approach to the study of "cognition" has pervaded almost all active research areas within that broad category. The ubiquitous nature of this view of man as an information analyzer and user necessitates a brief historical and current status review since it has shaped not only the research questions asked within this study, but how the answers are sought as well.

Three separate fields of study have contributed and stimulated the development of the information processing paradigm: communication science, computer science and human engineering. Information theory has provided much of the terminology and concepts of human processors and information channels of limited capacity: serial or parallel processing, coding, efficiency, and uncertainty (Attneave 1959). Computer science with its use of programs and control processes (software) led to the application of a computer analogy which delineates human structures (hardware) from their functional organization (Newell and

Simon 1972, 1976). Computer simulation and theories of language and knowledge have opened up a whole new field of "artificial intelligence".

Finally, military problems with man/machine systems, during World War II, instigated the study of skilled performance and human factors engineering. Man was seen as a limited information perceiver, transmitter and decision maker. An information processing paradigm is what has emerged, as that term is defined by Lachman et al., (1979), meaning a common set of ideas or pre-theoretical commitment to concepts which become implicit assumptions.

Theoretical development in information processing has progressed from the initial structural model of a serial, single channel processor to present day views of multiple structures, each with its own capacity, orchestrated by control processes. The earliest model proposed a filter analogy since it became obvious that there is a limit to the amount of information which can be processed simultaneously. Eventually the question became whether information processing is entirely serial, parallel or both. Today the distinctions are made such that systemic or automatic processing is based on structures and requires little effort and may proceed in parallel fashion; on the other hand cognitive or control processing is slow, serial, effortful and requires functional resources. The concepts of capacity, attention and effort play a crucial role in discovering the processing parameters.

Pupil dilation, as a specific instance, reflects not only demands on attention (Lowenstein 1920; Beatty 1977), but quantitative and qualitative aspects of task difficulty (Beatty 1982). Likewise the N1 ERP component has also been associated with attention and vigilance (see Appendix A, p. 135), but as resource or capacity limited automatic processing (Norman and Bobrow 1975; Hillyard and Picton 1977) of meaningful stimuli. A later stage of controlled processing, underlying some sort of decision making, has been identified with the P3 component, though the postulated functional equivalents vary (Ruchkin, Sutton, and Tueting 1975; Donchin 1981; Verleger 1988). A more detailed review of information processing models including the significance of pupil responses and various ERP components is provided in Appendix A.

The processing of informational events invokes cognitive mechanisms, perhaps even motivational and emotional factors, and it is the physiological correlates of these activities which we endeavor to analyze. As in most areas of psychology, we must confront at some point the recurring question of environmental versus genetic influences on these processes. Are our processing resources, both in structure and function, determined more by experience and momentary processing strategies or are they relatively fixed and biologically determined. Perhaps an attempt can be made at an answer by studying monozygotic (MZ) twins which should allow some judgment as to the role of heredity in determining performance on a cognitive task.

The present study anticipates to confirm the existing findings which suggest greater similarity in MZ twins on both pupillary and ERP measures. The questions to be asked next are whether monozygotic (MZ) twins will show much similarity and to the same degree on two cognitive tasks. If MZ twins remain similar under two task conditions, the salience of a genetic component in an aspect of information processing will be strengthened. Measures which do not contain significant genetic components should not produce higher intrapair similarity for MZ twins (Vandenberg 1966a, 1966b). These results would attest to biological constraints on "higher-level" processes thought to be more idiosyncratic.

The pertinent findings in the literature will be reviewed for both pupillary and event-related potential measures, with a preference for cognitive or information processing paradigms. Subsequently, the limited data available within this framework using MZ twins, and other areas of twin research will be reviewed.

Pupil Dilation and Information

Whether the structure of processing resources is envisioned as a single capacity system or parallel multiple resources, pupil dilation has been demonstrated to be an accurate overall measure of cortical activation and a valid tool in the study of information processing. Information in this regard is viewed as a measure of the uncertainty of that event. The amount of information provided is equal to the number of questions which would have to be asked in order to predict that stimulus occurrence; mathematically when the probability of occurrence is reduced by half, information increases by one bit (Keele 1973). Research examining task evoked pupillary responses (TEPRs) to an informational event, in prediction or guessing tasks, has been largely accomplished by Hakerem and his co-workers (Levine 1969; Hakerem 1973, 1974; Bock 1975; Friedman, Hakerem, Sutton, and Fleiss 1973; Steinhauer, Hakerem, and Spring 1979).

Due to methodological concerns, Hakerem and his colleagues have espoused paradigms where only auditory stimuli are presented and the TEPRs (task-evoked pupillary response) and ERPs (event-related brain potential) are recorded in total darkness. Whenever visual stimuli are utilized, extreme care is required to ensure that the total amount of luminance is equated for all experimental conditions. The magnitude of dilation obtained in cognitive tasks is quite small, since there is always the possibility of confounding due to variability in light intensity, auditory stimuli are sometimes preferable. The physical properties (light-dark contrast) of visual stimuli can produce pupillary changes of up to 5% (Woodmansee 1966a, 1966b; Lowenfeld 1966). The essential component in these experimental paradigms is for the subject to predict in advance which of two or three possible stimuli, tones or pairs of tones, will subsequently be presented. Responses to the ensuing stimuli reflect not only perception, but the meaning of that event for the present outcome as well as future predictions. In these instances the experimental stimuli reflect feedback on task performance, an informational event to be processed.

Levine (1969) reported that peak pupil dilation had a latency of 1200 ms following feedback to the subject as to the correctness of his guess. In addition, post-peak constriction was detected to be greater when the guess was incorrect. While difficulty was not a factor in guessing (single, double or triple clicks), as in the work of Kahneman, Beatty or Peavler previously mentioned (see also Appendix A), a motivational factor or continued processing may be plausible assumptions for less constriction with correct guesses. A crucial observation by Levine (1969) was that when no guess was made and no information received, simply reporting the occurring stimulus produced no dilation.

Pupillary responses have been shown to be related to motivational, as well as, informational characteristics. Steinhauer (1981) using a betting task found the amplitude of dilation, following the informational event or feedback, to be greater as the value of the monetary bet increased. Although peak dilation measures did not differ for winning versus losing outcomes, the recovery slope exhibited greater constriction for increasing loss of money and conversely less constriction as the amount of money won increased. The post-peak characteristics of the dilation curve were felt to be possibly indicative of a secondary process rather than merely a return to baseline.

The consequence or task relevance of a stimulus event is established by the prior task instructions, such that the stimulus itself without an assigned task role would not produce pupil dilations. When subjects guess which stimulus will be presented, there is some uncertainty and large dilations are obtained (Friedman et al., 1973; Bock 1975; Steinhauer et. al., 1979). Friedman et al., (1973) used a guessing task where the relative probabilities of two auditory stimuli were varied across blocks (20/80, 40/60, 60/40, 80/20). Peak pupillary dilation was found to be an inverse monotonic function of stimulus probability. The magnitude of dilation decreases as the probability of the event increases or becomes more certain. This finding was more evident for correct guesses while incorrect guesses exhibited a more complicated interaction. An analysis of outcome probabilities (based on joint probabilities of stimulus and guess) (Tueting, Sutton, and Zubin, 1971) demonstrated that the largest dilations ensue for the rarest events. Both low and high probability stimuli gave large dilations depending on the guess; for example, guessing correctly was a rare event for low probability stimuli while guessing incorrectly was a rare event for high probability stimuli. When these data were analyzed for equiprobable stimuli, no differences in pupil dilation amplitude were obtained for correct versus incorrect responses.

Using an oddball paradigm, where the subject is asked to count a rare event (target) imbedded in a series of non-targets, Quiyan, Richer, Wagoner, and Beatty (1985) demonstrated a decrease in the amplitude of pupil dilation as stimulus probability increased from .2 to .5, with a value of .8 showing no further decrease. As the rare stimulus became more frequent or less uncertain the extent of dilation decreased. The most interesting effect was that of larger pupil amplitude during the post-peak period; a slower return to baseline more strongly manifested at the lowest probability levels. Constriction occurred sooner with the higher probability certain events and reached an asymptote for the low probability or rare events. In contradistinction to ERP findings, pupil dilations occurred to nontargets, even though they were reduced in amplitude and had a shorter latency than the target responses.

Prediction of the occurrence of a tone and the role of feedback on pupil size were also investigated by Haughney (1976). All feedback resulted in increased pupil size, however the largest dilations occurred for disconfirming feedback, that is wrong guesses. On the other hand, Beatty and Wagoner (1976) obtained contrary findings also using a signal detection analysis. They discovered that, on signal present trials, large pupillary dilations occurred significantly more often with correct guesses or decisions.

In a study of maintained processing using a general information questionnaire, Headly (1981) described effects of correct versus incorrect answers on the recovery slope. Correct answers resulted in a steeper recovery slope while incorrect answers showed a leveling or asymptote. Headly (1981) concluded that "the pupillometric technique was a sensitive monitor of the evaluation of information ... (p.125)." When answering questions, a wrong answer might lead to continued retrieval attempts (Headly 1981). In a simple guessing task, opposite results displayed more constriction for incorrect guesses (Levine 1969) perhaps due to a motivational factor or a termination of processing, whereas a correct guess engenders continued evaluation.

The absence of an expected stimulus or event can also produce pupil dilation responses. When subjects are asked to guess whether a click will follow an initial stimulus one second later, dilation occurs both to the occurrence or absence of that stimulus (Levine 1969). Furthermore, the "phantom" dilations showed smaller absolute magnitudes and greater post-peak constriction for incorrect responses. Steinhauer (1981) has also elicited emitted pupil dilations with the same post-peak constriction evident for losing outcomes in a betting task and somewhat reduced amplitude of peak dilation. Pupil dilations occurring to stimulus omissions are also sensitive to stimulus probability (Qiyuan et al., 1985). The significance of these emitted pupil responses is in establishing this physiological measure as based on an endogenous rather than exogenous or solely data driven process.

The physiological mechanisms implicated in these consistent patterns of autonomic nervous system activity are not understood at present. Nonetheless, the role of the reticular formation of the brainstem and its function of diffuse generalized activation and inhibition of the cerebral cortex has been more clearly specified (Khomskaia 1982). This non-specific system which also controls wakefulness also participates in attention. A similar organization of nerve structures has been postulated by several researchers (Lindsley 1960; Bloch 1966; Hernandez-Peon

1969): (1) a passive or nonspecific, "general orientation" function operates when new or unexpected stimuli are present, that is sensory and motor systems are facilitated and (2) a specific "steady orientation" system operates when stimulus meaning is already known, to facilitate only afferent paths activated by attention with concurrent immobilization of motor pathways. Beatty (1977) asserted that there were two approaches to study how the brainstem participates with the cortex in the processing of information; pupil dilation measures momentary changes in attention as they occur in varied cognitive tasks while brain wave recordings reflect longer lasting changes in attention. One of the most productive methods of studying attention has been that of electrophysiology and it is to this area of research that we now turn our focus.

Event-Related Potentials

Behavioral analyses of information processing have not unequivocally substantiated the existence of a hierarchy of stages and processes. Event-related brain potentials (ERPs), which reflect the summated and attenuated activity of neuronal units recorded at the scalp, have been a useful source of converging operations. The typology of ERPs is continually being refined and has been largely based on the identification of specific components, that is positive or negative deflections in the waveform.

Component overlap continues to be a most serious problem. Donchin (1979) has thus often warned of the difficulties of reliance on the analysis of component amplitudes and latencies. There is some subjectivity and different methods of analyzing components that are assumed to manifest a sequence of serially activated processes (Donchin, Ritter, and McCallum 1978). The positive and negative shifts in brain electrical activity most probably are not spatially and temporally independent.

Nonetheless, present methodology continues to dissect the ERP waveform based on time-locked significant task events, while component labelling is based on both polarity (i.e., N negative, P positive) and latency. The nature of this enterprise has not been objectively defined, but a number of essential criteria have been enumerated by Sutton and Ruchkin (1984): (1) Latency (2) Polarity (3) Sequence (4) Scalp distribution (5) Relation to physical stimulus parameters (6) Relation to behavior (7) Relation to population variables and state of the organism variables. A brief review of the sequence of components that are consistently obtained under similar functional roles is available in Appendix A (pp.135-142).

ERP components can be further dichotomized as exogenous or stimulus dependent and endogenous or internally determined. A useful classification (Donald 1979) distinguishes: (1) early ERPs (1-70 ms) which are exogenous, show resistance to anesthesia, and sleep, and bear a linear relationship to psychophysical estimates of stimulus intensity (2) intermediate ERPs (70-200 ms) are both exogenous and endogenous, since they vary with stimulus intensity but also with alertness and attention and (3) late ERPs (200-500 ms) which are entirely endogenous and modulated by the amount of attention and a variety of cognitive variables.

Sources and Artifacts in ERPs

ERPs are generally believed to arise from discrete generators of dipolar potential fields with sources in sensory pathways or near primary sensory cortex being responsible for many components (Goff, Allison, and Vaughan 1978). Motor and association cortex are also likely sources of endogenous potentials. Most likely we are appraising the role of multiple, overlapping generators with ERPs. An intestable inference prevails that the negative/positive ERP reflects an excitatory post-synaptic potential (EPSP)/inhibitory post-synaptic potential (IPSP) sequence (Goff et al., 1978). A decrease in cell unit firing results in positive slow potentials with increased firing underlying negative slow potentials (Yingling and Skinner 1975).

Artifacts are an extremely important concern in recording evoked potentials as they can make interpretation of results bewildering. Muscle activity, eyeblinks, tongue and skin potentials can all modify ERPs considerably (Picton and Hink 1974). The utmost care must be exercised in order to eliminate or at least monitor these confounding sources of biopotential activity.

ERPs and Stimulus Information

The significance and role of a stimulus depends on the task to be performed and this is manipulated by instructions or by altering the frequency of stimulus occurrence. The work of Sutton and his colleagues (Sutton, Braren, Zubin, and John 1965), on the discovery of P3 and its sensitivity to uncertainty, was the beginning of much research using the concept of information transmission, the resolution of uncertainty (Sutton 1969).

Manipulation of relative probabilities of classes of stimuli has distinctive effects on certain components of evoked or emitted cortical responses. The modality specific N1 is insensitive to stimulus probability while the N2, also modality specific, shows an inverse relationship between amplitude and probability. The rarest stimulus change or deviation produces the largest N2 amplitude. Both P3 and slow wave (SW), the late positive complex, display the greatest amplitudes with task relevant, uncertain or low probability events.

A number of studies, using a guessing task, have further illustrated that the a priori probability of an event is only effective through its impact on subjective probability. Tueting, Sutton and Zubin (1971) were the first to interpret this finding which they labelled 'outcome probability'; the combined effect of a priori stimulus probability and the specific guess made. When a series of stimuli are presented, there is a consequence of the immediately preceding stimulus on the subject's guess, which along with a priori probability determines the operative subjective probability of the next stimulus (Squires, Wickens, Squires N., and Donchin 1976; Duncan-Johnson and Donchin 1977).

Donchin and his group adopted the term "expectancy" formally defined as a function of a priori probability and the operation of an exponentially decaying short-term memory, incorporated with the tendency of individuals to expect the continuation of a series of stimulus alternations. The consideration of 'subject option', the choice whether to follow instructions or use an unexpected strategy, must also be included in the assessment of decision making tasks (Sutton 1969).

The P3 has been characterized as a concomitant of 'strategic information processing', that is as a by-product of 'context updating' (Donchin et al., 1978). It operates in the evaluation of ongoing strategies using feedback information in preparation for subsequent trials. The latency of P3 depends on the time necessary to identify and assess task relevant or important information. Verleger (1988) in an extensive review has disputed this characterization and suggested instead that P3 reflects 'context closure' rather than context updating in an effort to decrease its dependence on direct memory processes. Needless to say this brings us no closer in resolving the theoretical issues as any theory is to date only a post-hoc attempt to account for empirical results. Context closure rather than a new interpretation is similar to Sutton's resolution of uncertainty notion (Sutton et al., 1965), a point in time where some decision is reached.

When guessing or detection paradigms are utilized, it is the feedback value of the stimulus which is reflected in the ERPs. The amplitude of P3 increases directly with the amount of information received in guessing paradigms (Hillyard, Squires, Bauer, and Lindsay 1971; Tueting, Sutton, and Zubin 1971; Ruchkin et. al., 1975; Donchin, Tueting, Ritter, Kutas, and Heffley 1975). Large amplitude CNVs and P3s arise under uncertain conditions, with no CNV and small P3s when there is complete certainty (Tueting et al., 1971; Friedman 1972; Bock 1975). Using a sentence completion task, words which delivered information increased P3 latency as opposed to uninformative stimuli (Friedman, Simson, Ritter, and Rapin 1975).

According to information theory, the amount of information received is equal to the information provided (directly related to a priori stimulus uncertainty), minus information loss (directly related to a posteriori uncertainty of having correctly perceived stimulus) (Shannon and Weaver 1949). This information loss has been labelled 'equivocation' by Ruchkin and Sutton (1978). As equivocation increases, detection confidence decreases thus P3 amplitude decreases.

Variations in the difficulty of a task usually result in a graded P3 that can not be solely reflective of fluctuations in arousal (Benson and Teas 1972). The latency of N2, a decision process related to sensory discrimination, and P3 increased from an easy to hard discrimination (Ritter, Simson, Vaughan, and Friedman 1979). This was also confirmed using click stimuli at two levels of difficulty, where N2 and P3 showed much longer latencies (Towey, Rist, Hakerem, Ruchkin, and Sutton 1980). P3 amplitude decreased with the more difficult task as predicted by equivocation (Ruchkin et. al., 1978). A more difficult discrimination results in greater a posteriori uncertainty as to the correctness of the detection.

Correct or wrong decisions in either detect or guess situations have not generated consistent and reliable findings. Initially, Sutton (Sutton et al., 1965) recorded larger amplitude P3s for wrong guesses, but this was not replicated in a later study. Instead P3 amplitude was largest for low outcome probability, that is, a correct guess on low probability stimuli or wrong guess on high probability stimuli (Tueting et al., 1971). Friedman et al. (1973) confirmed these results by demonstrating that P3 amplitude, as well as other components, was an inverse monotonic function of outcome probability.

A much more recent study further supports an interaction of stimulus sequence and prediction. Correct and wrong guesses elicited larger P3bs when followed by a prediction that the next trial would be different (Munson, Ruchkin, Ritter, Sutton, and Squires N. 1984). Being correct for discontinuation, that is alternation, produced large P3bs, while being correct for stimulus continuation, that is repetition, produced small P3bs. For wrong predictions, large P3bs ensued regardless of whether they were of continuations or discontinuations (Munson et al., 1984).

Squires, Hillyard and Lindsay (1973) used an intensity discrimination task and discovered that disconfirming feedback produced larger amplitude P3s than confirming feedback. This would support Sutton (Sutton et al., 1965), something about being wrong augments the P3 component, be it due to salience, motivational factors or the need for more context updating when a wrong decision is made. The evidence, however, is far from clear as emitted P3s were found to be larger for losing outcomes, in a betting game, while evoked P3s showed opposite results being larger for winning outcomes. Since the ERP data were only consistent within a session in this previous study, generalizations are premature.

The difficulty in trying to categorize and understand almost every aspect of human functioning is augmented by the reality of individual differences. Interindividual variations in certain processes can sometimes provide insights, but often only complicates the existing problems. The magnitude of this variance is modulated by the complex interaction of genetic and environmental factors. The classical twin study, using monozygotic (MZ) and dizygotic (DZ) twins, has provided many answers in certain areas of research. In this study MZ twins were used to evaluate the degree of similarity displayed on both pupil and ERP measures. This will allow some estimation of the range of variability possible in a cognitive processing task as opposed to the more common studies on elementary sensory processing similarities.

Behavior Genetics

The controversy over which is more salient, nature or nurture, in specific aspects of behavior continues in many areas. The idea that behavioral traits may be genetically determined arouses strong negative reactions in those who abhor the concept of a 'biological determinism', but as Rose (1987) put it "no dimension of behavior is immune to the effects of genetic expression." The major goals of modern behavior genetics are to evaluate the degree of genetic predisposition for specific behavioral phenotypes, and to evaluate as well the mechanisms whereby environmental variables interact with the genetic programs. A wide variety of traits and predispositions have been found, in the last two decades especially, to depend largely on heredity: activity level, alcoholism, anxiety, criminality, dominance, extraversion, political attitudes, schizophrenia and values (Rushton 1987). However, some necessary environmental conditions may still be required to bring out these potentials.

The twin study method presupposes that MZ and DZ twins have experienced equally variable environments. Critics of this method have continually pointed out that MZ twins have more similar environments. That is, their experiences and others' responses to them are more uniform, than for DZ pairs, due to their greater genetic similarity. Vandenberg and Wilson (1979) failed to find an effect of the MZ twin situation on cognitive variables, as measured by a number of standardized mental abilities tests. Likewise, an extensive study has assessed the relative effects of perceived and actual genetic similarity on cognitive, personality and physical measures (Scarr and Carter-Saltzman 1979). When an error in presumed zygosity had been made, both by the co-twins and their parents, this failed to significantly bias the degree of observed intrapair similarity on the measures.

The study of MZ twins, therefore, provides an appropriate methodology for the explorative study of the genetic contribution in a cognitive task.

The influence of genetics on general intelligence has been largely accepted as incontrovertible. A recent comprehensive review (Bouchard and McGue 1981) of family studies on intelligence reports the following interstudy mean IQ correlations: MZ pairs reared together (.86), MZ pairs reared apart (.72), DZ pairs reared together (.60), siblings reared together (.47), siblings reared apart (.24), parent-offspring (.42) and cousins (.15). The pattern was consistent with both polygenic determination and the salience of environmental factors. More specific cognitive functioning such as divergent thinking (e.g., word association) and conceptual ability (e.g., card sorting), though somewhat more similar for MZ twins, were overshadowed by general intelligence correlations between the pairs (Canter 1973).

This genetic basis for intelligence, as defined by a number of tasks, has led to an interest in developmental behavior genetics. Wilson (1978, 1983) has reported on a large longitudinal sample (N=500) where MZ twins became more similar in mental development with age from 3 months to 6 years, while DZ twins became less concordant over time (MZ/6yrs .85, DZ/6 yrs .63). Monozygotic twins exhibited a parallel course of accelerations and lags in mental development. Genetic programming, maturation and the environment are postulated by Wilson (1978) to work together toward achieving a specific end point in a dynamic process he called 'epigenesis'. A genetic schedule for brain development, though modified by environmental factors, must provide for functional in addition to structural organization because the former depends on the latter. Cowan (1979) asserts that the brain definitively becomes wired in an explicit manner during development. Sperry (1961) has offered the suggestion that embryonic growth and differentiation are sufficient as mechanisms to explain how intricate nerve pathways can be inherited and organized. Migration of neurons and their subsequent differentiation into functional systems appears to be an extremely orderly and genetically programmed process which takes place prenatally. Consequently, environmental factors and cognitive control processes may be operating within a structural organization which is relatively fixed early in life.

Most of the connections between nerve cells and their operation are genetically determined and specified in advance. Neural pathways are formed by very specific neuron circuits, however, these appear to maintain some degree of plasticity even in adult brains (Baltes and Willis 1982). Research in the field of aging has shown that not only recovery of function can occur, but also functional reorganization through elaboration of dendritic trees (Buell and Coleman 1979). Synaptic interconnections can be increased in an adaptive manner when neurons die or are damaged (Brody 1982).

Experience has also long been known to alter neural brain organization (Hubel and Wiesel 1959; Held and Hein 1963; Dru, Walker, and Walker 1975) in a number of animal species. In conclusion, it is perhaps best to view genetically determined brain structures as the background upon which normal development and experience are allowed to further sculpt functional processes. The lack of perfect MZ twin correlations in any number of research areas would also seem to support this contention. In light of these facts there is therefore more certainty of genetic predominance when MZ twins do perform very similarly.

Another prodigious area of research in twins has been that of personality. The first large scale study of personality characteristics found median heritability estimates of .50, based on 514 pairs of MZ and 336 pairs of DZ twins (Loehlin and Nichols 1976). No effect of shared environment could be documented as far as personality and interests were concerned. The most recent and detailed conclusions in the area of personality are from Bouchard's ongoing Minnesota Twin Study. The overall heritability of all personality traits measured was .50 (range .39 -.58), with median correlations of .49 for MZ twins reared apart, .52 for MZ twins reared together, and .23 for DZ twins reared together (Tellegen, Lykken, Bouchard, Wilcox, et al., 1988). These findings have been analyzed as signifying that the common environment contributed very little to the similarity between the twins reared together Tellegen et al., 1988; Plomin and Daniels 1987). Vandenberg (1984) analogously concluded, after a long career in twin research, that the assumption that common environments contribute to the similarity in the abilities of MZ and DZ twins is untenable.

MZ Twins and Autonomic Variables

A mixture of results, showing at times more or no greater similarity in MZ twins, have been obtained for more objective physiological variables. An hereditary component accounts for similarities in heart rate (HR) and breathing rate following stressful or arousing stimuli (i.e., unexpected light flash or noise) (Vandenberg, Clark and Samuels 1965; Block 1967; Claridge, Cantor, and Hume 1973). Resting HR levels are also reported to be more similar in MZ twins (Shapiro, Nicotero, Sapira, and Scheib 1968; Block 1967). A more recent study, measuring HR in a resting situation, an auditory selective attention task, and a test of specific cognitive abilities, concluded that genetics did not play an important role (Boomsma, Dorret, and Plomin 1986). A higher concordance in MZ twins for blood pressure changes following surprise by a light or bell has also been described (Kryshova, Beliaeva, Dmitrieva, Zhilinskaia, and Pervov, 1962).

Osborne, DeGeorge and Mathers (1963) found significant differences for casual blood pressure in MZ compared to the more similar DZ twins. Blood pressure readings in a study of 39 pairs of MZ and 51 pairs of DZ twins revealed very small intrapair similarities (Barcal, Simon, and Sova 1969). Similarly a lack of greater intrapair correlation for MZ twins for casual blood pressure was also obtained in another study (Downie, Boyle, Greig, Buchanan, and Alepa 1969). Arterial blood pressure is determined in large part by cardiac function, metabolic tissue requirements and renal function rather than neurogenic influences (Herd, 1978). This could account for the similarities obtained in some twin studies when physiological factors predominate. Yet, coping styles and personality characteristics have also been found to have a direct effect on blood pressure (Gentry, Chesney, Gary, Hall, and Harburg 1982) and might lead to absence of strong correlations on some blood pressure measures.

Greater similarity for skin conductance level (GSR) at rest (Block 1967; Claridge et al., 1973), in spontaneous changes and in habituation (Lader and Wing 1966) have been demonstrated in MZ twins. On the other hand, Rust (1984) in evaluating 15 electrodermal characteristics discovered large significant genetic effects in basal conductance, spontaneous response rate and amplitude, but not with stimulus change or habituation scores.

Surprisingly almost no research has been done on the pupillary response even though it is the best single indicator of sympathetic activation (Lowenfeld 1958). Similar patterns of pupillary unrest have been noted in MZ twins (Lowenstein and Lowenfeld 1969). In Hakerem's laboratory, Bock (1975) established that pupillary waveforms, in a guessing task, were often superimposable in MZ twins. In her study greater similarity for related persons (MZ, DZ, siblings) in comparison to unrelated persons was the only statistically significant finding. This is possibly due to the difficulty of quantifying a continuous waveform.

Autonomic variables have not overall supported strong hereditary influences. The autonomic nervous system is an extremely complex regulatory mechanism subject to influences from the central nervous system and the endocrine system and these in turn interact with specific organ structures in intricate feedback loops. There are in these physiological systems a myriad of locations where external and internal variability may be introduced. Furthermore, the specific task and situation are critical in determining response parameters in the central and autonomic nervous systems. The mixed results are not then entirely unexpected.

MZ Twins and EEG

Recordings of brain activity at rest (EEG) clearly substantiate the greater similarities between MZ twins. More than forty years ago, Lenox, Gibbs, and Gibbs (1945) showed that brain wave pattern was an hereditary trait. Even MZ twins raised apart show high EEG correspondence (Juel-Nielsen and Harvald 1958). The pattern and amount of alpha activity (8-13 Hz) within the EEG is also very similar in MZ twins, with a mean correlation of .52 for MZ compared to .29 for DZ twins and -.02 for unrelated persons (Young, Lader, and Fenton 1972). Osborne (1970) obtained mean alpha correlation values of .60 and .12 for MZ and DZ twins, respectively.

There is a difficulty posed by the lack of an appropriate statistic to quantify the similarity between two EEG records and many studies have relied on visual inspection of the whole EEG. Consequently, there is much variability and subjectivity in similarity judgments of whole waveforms. With the use of spectrum analysis (EEG voltage with respect to frequency), MZ twins show striking similarities while DZ twins are no more alike than unrelated individuals (Lykken, Tellegen, and Thorkelson 1974; Lykken, Tellegen, and Iacono 1982). The alpha rhythm in particular was strongly correlated for MZ twins (.82) and essentially zero for DZ twins (-.20) (Lykken et al., 1974).

Monozygotic Twins and ERPs

An important characteristic of ERPs is the wide range of variability in amplitude and waveform manifested between individuals. Therefore finding highly similar waveforms in MZ, in contrast to DZ twins, strongly suggests genetic heritability. An anatomical, structural basis, or a physiological, functional one, may singly or both underlie MZ twin similarities.

The visual evoked potential (EP) to light stimuli resulted in intrapair waveform correlations that were always much larger for MZ than DZ twins (Dustman and Beck 1963; MZ median *r*=.88, DZ median *r*=.37; Dustman and Beck 1965; MZ mean *r*=.82, DZ mean *r*=.58, unrelated mean *r*=.61). The similarity of cotwins for one session in this study sometimes exceeded that of repeated sessions for the same twin. Osborne (1970) found mean intrapair correlations of .77 for MZ, .53 for DZ and .12 for unrelated individuals on visual EPs, but the MZ/DZ group differences were not statistically significant. Auditory EPs provided mean correlations of .76, .55, and .40 for MZ twins, DZ twins and unrelated persons, respectively (Young et al., 1972). Statistically again the MZ correlation was not significantly different from that of the DZ twins, yet upon visual inspection of the waveforms, the higher degree of resemblance within MZ twin pairs was clearly apparent.

Callaway and Halliday (1973) described a decrease in variability with age for auditory and visual EPs, especially for components of 100 ms or greater latency. In MZ twins, overall waveform similarity increased with age for visual EPs, while similarity decreased for DZ twins and unrelated persons (Lewis and Beck 1970). Moreover, MZ twins exhibited a tendency for greater similarity in the later segment (90-300 ms) of the waveform; early segment correlations of .69, .44 and .32 for MZ, DZ and unrelated, respectively, compared to .82, .73 and .61, respectively, for the late segment (Lewis, Dustman, and Beck 1972).

Interestingly, other research has shown that the early more sensory aspects of the ERP displayed more similarity in all individuals than the later segment which was subject to greater individual variation (Donchin and Lindsley 1969; Regan 1972). The variety of paradigms examined appraised mostly sensory dimensions of a stimulus and not its significance, relevance or information value. Moreover, the designation of late segment starting at 90 ms includes what have been considered early or intermediate components (up to 150-200 ms) by others (Donald 1979; Bock 1975).

A study by Surwillo (1980) found more similarity in the earlier or exogenous components (P1, N1, P2) for all subjects. In an auditory stimulus discrimination task, the latency of exogenous components was similar for MZ twins and matched controls; by contrast the latency of endogenous components (N2, P3) was very much alike only for MZ twins (Surwillo 1980). Endogenous potentials are presumed to reflect a person's intentions, strategies or decisions, that is psychological and personality variables. One other study confirmed and extended these conclusions using a very similar simple auditory discrimination task with MZ twins (Polich and Burns 1987). The amplitudes and latencies for N1, P2, N2 and P3 were significantly correlated (except N1 latency) whereas this effect was not evident for the control unrelated pairs. Therefore both early (N1, P2) and late (N2, P3) components have been found to be more similar in MZ twins. The authors concluded that morphological waveform similarities most likely stem from identical neurophysiological structure rather than cognitive background or strategies as the task required relatively low level cognitive processes.

Bock (1975) provides the only twin study that evaluates cognitive components of the ERP waveform, using a guessing task. Related individuals (MZ, DZ, siblings) as a group provided significantly larger similarity scores than the unrelated group, and though MZ twins usually exhibited greater similarity the trend was not statistically significant. MZ and DZ twins were more alike for the late segment (150-1800 ms) than the early segment, especially for the more likely outcomes. Overall, greater similarities occur with high probability outcomes (e.g., correct guess for high probability stimulus) (Bock 1975). A new finding in this study was that of a sex difference such that female MZ pairs were less alike than males for the late segment in particular.

Recent studies by Russian investigators using a variety of conditions suggests the importance of the stimuli employed. A large genotypic contribution was evident for responses to light flashes, symmetric geometric figures, random shapes, and checkerboards in MZ and DZ twins (Ivoshima 1983). The intrapair resemblance in waveform amplitude and temporal parameters was maximal at occipital sites for the preceding stimuli, but was not obvious for the word house, while the image of a house did elicit similarities in twins (Maryutina and Ivoshima 1984).

Generalizations are not possible at this time since there is a paucity of research with MZ twins within an information processing framework. There is strong evidence, however, that the sensory characteristics of a stimulus result in near identical ERP components in MZ twins (Dustman et al., 1963, 1965; Buchsbaum 1974). The sensory physiological mechanisms, since genetically determined allow us to predict the occurrence of a narrow range of response waveforms.

In contrast, cognitive ERPs must be assessed at a higher level of abstraction. In fact, a major question to be answered in this study pertains to whether genetics can be presumed to largely influence the configuration of ERPs during a cognitive task. The stimuli in such instances are not merely detected and identified, but they convey information based on rules which have been stored in long-term memory. Once identified the significance of the particular stimulus in short-term memory is evaluated using information retrieved from long-term memory, which includes the value or salience of that outcome for the individual at that time (e.g., win/lose, correct/wrong). Furthermore, anticipation of the next condition and performance on the overall task induce the formation of strategies, which may belie personality characteristics or cognitive style.

Sutton (1977) focused on the concept of salience or meaning of the information received by the subject. He pointed out that 'subject option' must be considered in any task. Due to certain personality characteristics some individuals may focus more on either being wrong or right in devising a guessing strategy (Sutton, Tueting, Hammer and Hakerem 1978). ERPs recorded during an information processing task reflect the functions of the brain. Though no specific component-process correlations have been established, the early stages of decision making have been implicated, especially with P3 amplitude, rather than the final deliberate phase of analysis (Ruchkin and Sutton 1978) (see Appendix A, p. 145).

This study entails the recording of both pupillary and ERP responses in MZ twins to auditory stimuli which serve as feedback in two guessing tasks. In the first task one of two equiprobable guesses is made (same or different) and the ensuing tone pair provides the feedback. Only a relative discrimination between the tones in each pair is necessary, though some memory component may play a part in choosing the next guess following a series of outcomes. Since each subject is encouraged to maximize correct guesses, some strategy must be employed to both tally the outcomes and decide on the next guess. There are some findings which show that repetition of stimuli is the expectancy rather than alternation (Squires et al., 1973). The guess outcome is also an interacting variable as subjects often change their guess following a correct outcome.

The second task uses the same pairs of tones except that there are four categories of possible results for each guess (high or low). The specific combination of tones is crucial and provides an additional cognitive operation, prior to determining a correct or wrong outcome, that depends on the rules stored in memory. The strategies for both tasks will be examined with a brief questionnaire. Using two tasks may allow more certainty, or an additional degree of freedom in judging the genetic dependence in this type of cognitive processing.

The use of MZ twins will allow some interpretation to be made on the importance of inherited characteristics in cognitive or decision making tasks. ERPs reveal the concomitants of brain processes and it is the degree of hard-wiring or anatomical and physiological constraints on higher level conceptual information processing that we are attempting to evaluate. The initial prediction is that more similar waveforms will be obtained in MZ twins compared to unrelated control pairs.

A second question to be answered concerns between task differences for both MZ twins and controls. One additional bit of information was added to the second task, by using four outcome categories, some conclusion on the sensitivity of both pupil and ERP components to task instructions may then be possible. In addition, the subjective conclusions of the twins about the tasks will be recorded in a brief questionnaire.

The Present Study

The design of this study consists of two tasks, both requiring the processing of information. The first is a prediction task on which MZ twins are expected to show much similarity on the evoked potential and pupil measures. The prediction or guess involves one of two choices with the subject knowing that the probability of all stimulus pairs (four combinations) are roughly equivalent. The instructions suggest that some sort of strategy for keeping track of guesses and outcomes may prove helpful in maximizing the number of correct guesses.

The second task contains the same stimuli pairs but prediction strategies may be more variable since there are four outcomes or ways to be both correct and wrong rather than two. The guess is again one of two possibilities, however the outcome may be from one of four categories; two each indicating a correct or wrong guess (see Appendix B). Comparisons will be made to assess if MZ twins also show greater similarities than nontwins and if overall task effects occur based on differing instructions.

Specific changes or differences between tasks are expected in the pupil and ERP waveforms which may allow discussion of the degree of sensitivity to task demands. The utilization of additional processing resources has been reliably and repeatedly measured by pupil functions. The slope and magnitude of dilation would be greater and the recovery slope would be less steep or asymptotic if additional resources are necessary for task performance. The ERPs to the tone pairs in both tasks should consist of N1-P2 components, with the first stimulus of the pair followed by a CNV in anticipation of the second tone which resolves the outcome of the trial. A P3 component to the second stimulus may also vary in magnitude and/or latency depending on the task. The first stimulus of the pair provides only half of the necessary information on the trial outcome therefore with repetition (140 trials) the presence of any P3 component is expected to disappear or be drastically reduced.

Method

Subjects

The subjects used in this study were seven pairs of monozygotic (MZ) twins. Their age ranged from 18-25 years with a mean of 19.2 years. They were solicited largely from Queens College through advertisements. All volunteers were paid an average of $10/hour. The original goal was to study ten pairs of MZ twins, however due to equipment malfunction and change to a new updated digital system only seven pairs were available under the same experimental paradigm.

Zygosity. The determination of zygosity was established on the basis of four criteria. The subject's own report (also asked to verify with mother) and the degree of facial resemblance was noted. The major attributes evaluated were hair and eye color, shape and size of facial features and skin patterning and texture. Furthermore, anthropometric measures (height, weight, head circumference), whose accuracy combined with other indicators are fairly high, were used (Bock 1975; Jablon, Neel, Gershowitz, and Atkinson 1967). According to Bock's criteria differences in weight had to be within ten pounds, height within an inch and head circumference within a half inch. No pairs recruited had to be eliminated based on this evidence. The last source of confirmation was a developmental questionnaire, part of a larger one designed by

Cederlof, Friberg, Johnson, and Kaij (1961), which has a correlation of more than .90 with blood sample groupings for determination of zygosity (see Appendix B). Two questions are largely responsible for that correlation; positive results to being confused by parents and others, as well as the assertion that the twins see themselves "as alike as two peas in a pod". All twin pairs reported: being mixed up as children, being "as alike as two peas in a pod", having to use some sign in order to be differentiated. Successful results on all criteria was the basis for inclusion in this study.

Apparatus

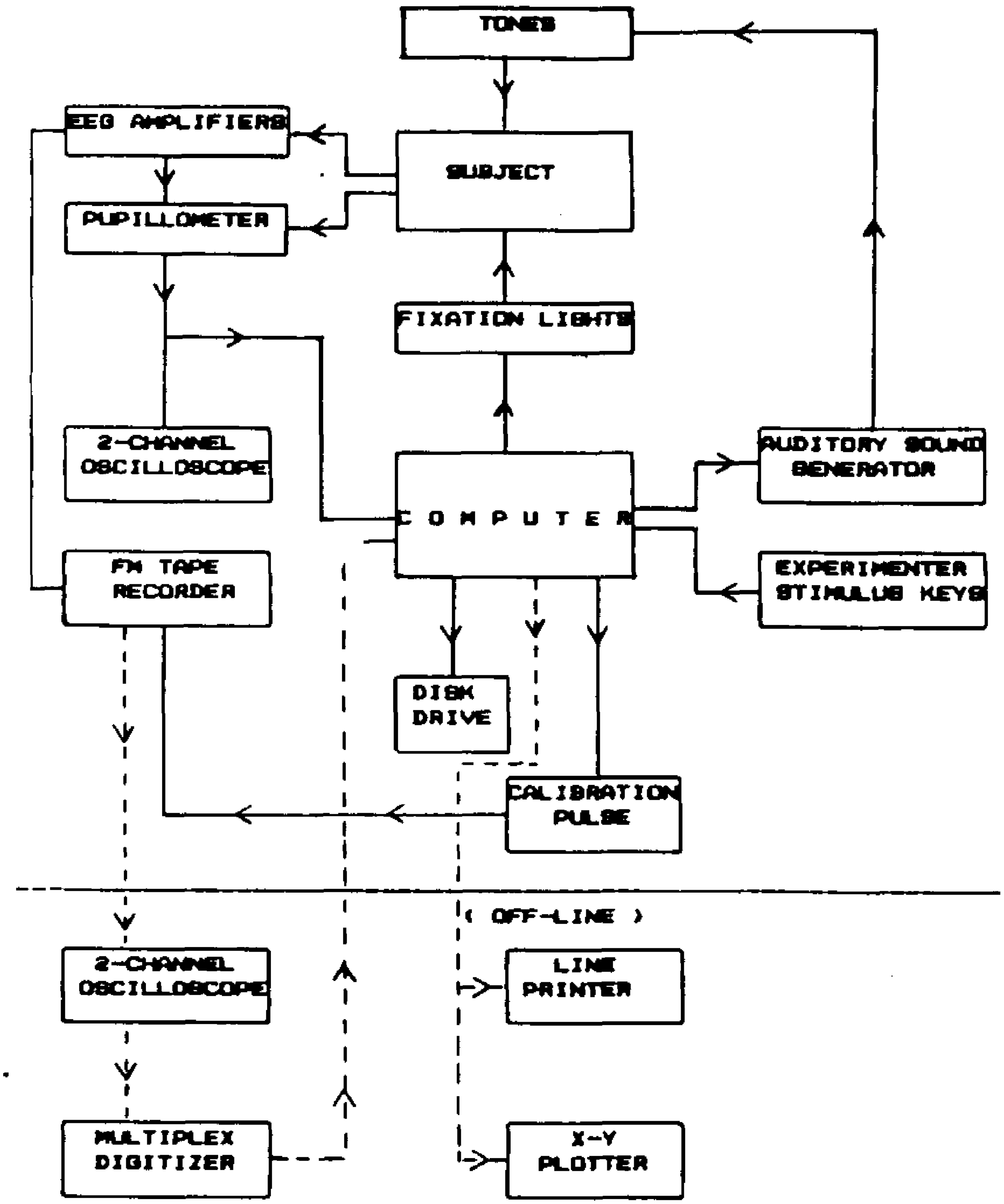
The study was run using a Heathkit H8/H89 microcomputer which controlled the presentation of stimuli and the recording of data. The pupil and EEG measures were monitored on line with a Tektronix 2 channel oscilloscope. One channel was used to scrutinize the pupil continuously while the other was used to multiplex the four EEG channels. The pupil data was stored on floppy disks after each block of 35 trials, while the EEG was recorded in analog form on magnetic tape (Sangamo 3500/ 7 channels). The subject's predictions or "guesses" were entered into the computer by the experimenter where they initiated each trial and allowed for its coding according to outcome, either correct or incorrect. The ERP waveforms were tagged at the start of each trial by a 500 ms, 4 volt square pulse deposited on one channel of the FM tape recorder; each electrode placement (Fz, Cz, Pz, Oz) also had a specific recording channel (see Figure 1).

Stimuli. Two auditory stimuli, a 2400 Hz and a 1700 Hz tone, were presented at 70db above threshold (a.l.) through a speaker located two and a half feet above the subject's head. The tones were rectangular pulses of 120 ms duration with an interstimulus interval of 1300 ms and were always heard in pairs in all possible combinations. A demonstration program was run prior to the testing session to insure perfect discrimination of the high and low tone, followed by an average of ten practice trials.

Procedure

All experimental sessions were conducted with the subject alone in a completely dark room with communication through an intercom system. The first task was always completed first and the second task following on another day. Since the same stimuli are used and instructions alone determine the task, a confounding between tasks is therefore avoided by proceeding from the first, two outcome task, to the second, four outcome task, as instructions can not be taken back or ignored with certainty once elaborated.

<u>Figure 1</u>. Block diagram of experimental apparatus.


TONES
EEG AMPLIFIERS
SUBJECT
PUPILLOMETER
FIXATION LIGHTS
2-CHANNEL OSCILLOSCOPE
COMPUTER
AUDITORY SOUND GENERATOR
FM TAPE RECORDER
EXPERIMENTER STIMULUS KEYS
DISK DRIVE
CALIBRATION PULSE
(OFF-LINE)
2-CHANNEL OSCILLOSCOPE
LINE PRINTER
MULTIPLEX DIGITIZER
X-Y PLOTTER

Task 1. Each trial consists of the presentation of a pair of tones in the following possible combinations: HIGH/HIGH, HIGH/LOW, LOW/LOW, LOW/HIGH. The subject is asked beforehand if the stimulus pair to be presented will be a "DIFFERENT" pair (HIGH/LOW, LOW/HIGH) or a "SAME" pair (HIGH/HIGH, LOW/LOW). The occurrence of each of the four possible pairs is approximately equal across each of four blocks of 35 trials for a total of 140 trials.

Task 2. The same pairs of stimuli are used and they are presented in the same manner. The prediction, however, now becomes "HIGH" or "LOW" with the outcome dependent on the particular combination of tones (see Appendix B). For example, there are two possibilities for a correct guess; if the guess was "LOW" and the pair was low/low, then the outcome would be 'win confirmed', while if the pair was high/low, then the outcome would be 'lose cancelled'. A "LOW" guess would result in a wrong trial for the following tone pairs; a high/high pair being a 'lose confirmed' or a low/high pair being a 'win cancelled'. There are now four possible guess outcomes, rather than two, and discrimination of the individual tones is necessary instead of a relative judgment of same or different.

Instructions

Task 1. All subjects were read the following:

In this test we play a kind of guessing game. The purpose of this test is to record your brain waves and the changes in your pupil while you perform this task. We will present you with two short sounds and there is about one second between them. One of the sounds is a high pitched tone and the other is a lower pitched tone. Here is what they sound like:

THIS IS THE HIGH PITCHED TONE (DEMONSTRATE)

THIS IS THE LOW PITCHED TONE (DEMONSTRATE)

HERE THEY ARE AGAIN (REPEAT SEVERAL TIMES)

IS THIS THE HIGH TONE OR THE LOW TONE ?

DO YOU HEAR THE DIFFERENCE ?

PROCEED UNTIL PERFECT DISCRIMINATION

Now during the test you will hear two tones, one after the other with about one second between them. There are four different combinations: you could hear "HI/HI", "LO/LO" or "HI/LO", "LO/HI" (repeat and demonstrate pairs).

As you can hear, in two of these combinations the tones are the same (HI with HI, LO with LO) and in two of the pairs the tones are different (HI with LO, LO with HI). Your task is to try to guess beforehand what the next pair will be, two of the same sounds or two different sounds. Let's try it, sit here and look away from the equipment. What will the next pair be ? (Try guessing several times with tone pair presented as feedback).

Now we can go on to the next step. Do you see the two little red lights there ? These are called the FIXATION lights. We would like you to go into the biteboard with your forehead leaning against the headrest. FIXATE THE RED LIGHTS. Once you are in position another small red light will go on which means that we are recording data and you will hear the pair of tones momentarily. It is very important that you remain as still as possible during the time that the lower red is light is on, which is only about four seconds. When the warning light goes off you may blink but REMAIN IN THE FIXED POSITION.

You will then hear a very low short beep which means you are to come out of the biteboard and report the outcome of that trial. That is tell us if your guess was right or wrong, and your guess for the next trial (give examples of guess and outcome). You then go into the biteboard after your guess and fixate the red lights. It is very important that you do not move your eyes away or blink when the lower red light is on because that is when we are recording your pupil size and brain waves. Whenever you move or blink during that period, the trial is no good and we can not use it. We will present the sound pairs in groups of 35 and you will have a rest between each block. We will then tell you how many correct and wrong guesses you have made for that block. We want you to try and get as many correct guesses as possible, most people use some method for keeping track of their guesses to increase their number correct. The four pairs occur about equally often over one block of trials.

Do you have any questions ? Now let's repeat the procedure one more time. Make your guess, "SAME" or "DIFFERENT", go into the biteboard, fixate the lights sand try not to blink, listen to the pair of tones, when the lower red light goes off you may blink but stay in the biteboard. When you hear the beep come out and report if you were RIGHT or WRONG and your next guess, RIGHT or SAME.

We will turn off the lights in the room so you will be in total darkness. We will talk to you through the intercom here. We will start with 10 practice trials so you can get comfortable with the procedure. Do you have any questions ?

Task 2. All subjects were read the following:

In this test we play a new kind of guessing game. The purpose of this test is to record your brain waves and the changes in your pupil while you perform the task we are going to explain to you.

We will present you with the same pairs of tones used in the first test. There is about one second between the two sounds. One of the sounds is a high pitched tone and the other a lower pitched tone. Here is what they sound like:

THIS IS THE HIGH PITCHED TONE (DEMONSTRATE)

THIS IS THE LOW PITCHED TONE (DEMONSTRATE)

HERE THEY ARE AGAIN (REPEAT SEVERAL TIMES)

DO YOU HEAR THE DIFFERENCE ?

PROCEED UNTIL PERFECT DISCRIMINATION

Now during the test you will hear two tones, one after the other with about one second between them. There are four different combinations: you could hear "HI/HI", "LO/LO" or "HI/LO", "LO/HI" (repeat and demonstrate pairs).

In this new task you will be asked to guess "HI" or "LO" and the result, that is whether you are correct, will depend on both tones. For example, if you guess "HI" and the pair of tones is "HI/HI", your guess is "WIN CONFIRMED". Here is a list of guesses and their outcomes which you should study for a few minutes (see Appendix B).

(CORRECT GUESS) If your guess matches the first tone that is a "WIN", if it also matches the second tone then the win is "Confirmed"___ "WIN CONFIRMED"

(CORRECT GUESS) If your guess does not match the first tone that is a "LOSE", if it matches the second tone then the loss is "Cancelled"___"LOSE CANCELLED"

(WRONG GUESS) If your guess matches the first tone that is a "WIN", if it does not match the second tone then the win is "Cancelled"___"WIN CANCELLED"

(WRONG GUESS) If your guess does not match the first tone that is a "LOSE", if it does not match the second tone then the loss is "Confirmed"___LOSE CONFIRMED"

We will present the sound pairs in groups of 35 and after each block you will have a few minutes to rest. We will then tell you how many correct and wrong guesses you have made for that block. We want you to get as many correct guesses as possible. You can choose whatever strategy works best for you. The different pairs also occur equally often. Do you understand that a win confirmed and a lose cancelled are both correct guesses, while a lose confirmed and win cancelled are both wrong guesses ?

The procedure is the same as in the first test. Make your guess "HI" or "LOW", go into the biteboard position, look at the red fixation lights. FIXATE THE RED LIGHTS. Once you are in position another small red

> light will go on which means that we are recording data and you will hear the pair of tones momentarily. It is very important that you remain as still as possible during the time that the lower red light is on, which is only about four seconds. When the warning light goes off you may blink but REMAIN IN THE FIXED POSITION.
>
> You will then hear a very low short beep which means you are to come out of the biteboard and report the outcome of that trial and your next guess. For example: " WIN CONFIRMED" and "HI" or "LOSE CONFIRMED" and "LO". Do you have any questions ? We will turn off the lights and do 10 practice trials before we begin.

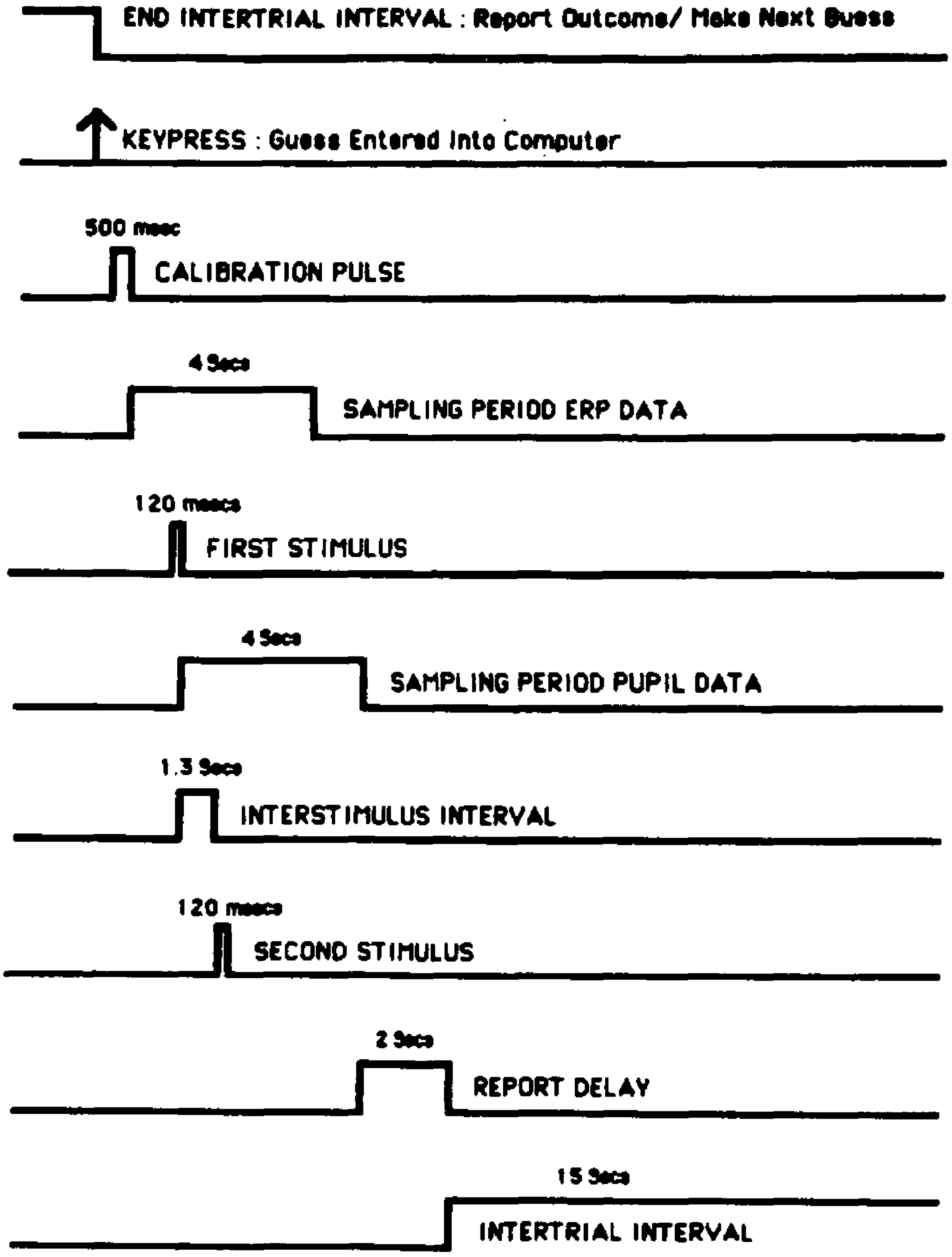
Following each experiment the subjects were asked to fill out a brief questionnaire about each task (see Appendices D and E). These will be used to obtain some feedback data on each task and perhaps compare approaches in guessing strategies both within and across twin pairs.

Pupillary Recording

Pupil size was measured with an electronic TV and monitor pupillometer system, using infrared light (Whittaker, model #1992S, Applied Science Laboratories). The pupillometer system consists of a camera which is positioned on the left eye and allows a grid made up of 525 horizonal scan lines to be superimposed on the pupil. Pupil size is measured by the extent of interruption of the lines which have a precision of better than .01 mm. In order to minimize head movements and insure that proper focus was maintained, a forehead rest and biteboard (teeth imprint made with Kerr dental compound) combination were employed. While sitting in this fixed position, recordings were made in total darkness using an infrared light with the camera directed at the left eye. Since pupillary responses are consensual, it is only necessary to record from one eye. The subject's gaze was focused on two very small red fixation lights (1 mm diameter) about 5 mm apart and one meter in front of the subject. These remained on throughout the recording session. Prior to all data acquisition, dark adaptation for at least 15 minutes was necessary and this was accomplished largely during the practice trials.

The pupillometer samples at the rate of 50 data points per second (1 point/20 msec). Each trial consisted of a four second epoch, beginning immediately following the first tone of each pair (see Figure 2). The subject initiated the beginning of the session by making a prediction over the intercom and when ready, assuming the recording position. The experimenter entered the guess into the computer initiating the recording segment, upon confirming on the pupil monitor that the subject was in position. The start of data collection was signaled by a third red light (1 mm diameter), 3 mm below and central to the two fixation lights, which was only on during recording and indicated that as little movement or blinking as possible should occur. The recording epoch was terminated at the offset of this warning light, yet the subject had to remain in the biteboard position (about 2 s) until a 20 ms

<u>Figure 2</u>. Trial sequence for data collection.


END INTERTRIAL INTERVAL : Report Outcome/ Make Next Guess
KEYPRESS : Guess Entered Into Computer
500 msec
CALIBRATION PULSE
4 Secs
SAMPLING PERIOD ERP DATA
120 msecs
FIRST STIMULUS
4 Secs
SAMPLING PERIOD PUPIL DATA
1.3 Secs
INTERSTIMULUS INTERVAL
120 msecs
SECOND STIMULUS
2 Secs
REPORT DELAY
15 Secs
INTERTRIAL INTERVAL

beep was heard, so that this movement did not affect the baseline of the ERPs. This brief tone alerts the subject to report the outcome of the trial and make the next prediction which reinitiates the series of events (see Figure 2). A total of four blocks of 35 trials (N=140) were run with a rest of 20 minutes between pairs of blocks and five minutes between blocks in each pair.

Event-Related Potential Recording

The ERPs were recorded from four midline positions according to the 10-20 system (Jasper 1958) : frontal (Fz), central (Cz), parietal (Pz) and occipital (Oz). The scalp was swabbed with alcohol and abraded (Buf-Puf) slightly to remove the outer layer of dead epidermis and debris. Beckman (#330421) large silver-silver chloride electrodes were then affixed to the scalp, using Grass (EC2) electrode paste, and covered with gauze to insure secure placements. Small Beckman (#650399) electrodes and adhesive collars were applied to the earlobes which were linked and served as the reference. The mastoid process just behind the ear was used as the ground and all electrode resistances were kept below 5,000 ohms.

Princeton (model #113) pre-amplifiers set to a band pass of .03 to 30 Hz (-3 dB roll-off) were used for recording. The amplification was calibrated at 10,000 with a sine wave of known voltage and was periodically checked.

The output of the four pre-amplifiers was directly recorded on separate analog tape channels.

When recording began, as signaled by the red warning light, a 500 ms calibration pulse was simultaneously deposited on one tape channel, marking the beginning of each four second epoch. All data was then digitized and averaged off-line using the calibration pulse to identify the start of each trial.

An electrooculogram (EOG) recording was not made as trials with eye movement artifacts were removed during offline analysis. The pupil was visually and electronically monitored on the pupillometer and any trials with artifacts were automatically indicated and tallied on-line to insure that an adequate number of good trials were collected. A change in pupil size of more than 0.03 mm, from one data point to the next, which is equal to a pupil contraction speed of 8 mm/s, was interpreted as a blink or movement. At this time though all pupil trials were still tagged by the computer as either correct or incorrect and the rejected trials were only tallied to allow the experimenter to run additional trials if the number of good trials was exceedingly low.

Data Retrieval and Analysis

Pupillary Responses. All pupil trials were reanalyzed offline in order to determine those trials which exceeded the blink criteria. Those trials were then tagged as rejected, whereas a good trial retained its original on-line tag as a correct or incorrect guess. The coded outcome of each pupil trial was then printed out so that the trial numbers could then be input into the program which then selectively averaged all the correct or incorrect pupil trials across all blocks for each task. The digital data for each selected pupil trial were then added together, averaged and put on floppy disks along with their standard deviations for each subject by task. All subjects therefore acquired both a mean correct and mean incorrect pupil response to Task 1 and 2. These were also stored on disk for retrieval in printing and plotting programs.

A number of analyses were performed on the mean pupil waveforms. The peak dilation magnitude consisted of a three point average surrounding the largest value following S_2. This mean peak dilation value was then subtracted from the baseline computed by averaging the digital values 100 ms post-S^1. If a flattened peak occurred, that is a series of identical values, the median point was chosen as peak and averaged with the one value above and below it. The latency of these three peak values was also averaged to obtain peak dilation latencies.

A difference (D) function was computed between MZ twin pairs in the following manner; the mean correct or wrong waveforms were superimposed at peak for each pair by task, with the peak determined to be the largest value after the second tone (S_2). When a flattened peak occurred, such as a series of identical values, the median point was chosen as representative of the latency of the peak dilation magnitude. The difference obtained by subtracting the largest peak dilation from the smallest was added to the latter function in order to adjust it vertically on the Y axis. The 200 digital data points which described each function were then subtracted from one another point by point and the mean of the absolute difference values was then calculated to obtain a single mean D value for each MZ pair under two trial conditions for each task.

Another index of similarity used was that of pupil response correlations. The pupil waveforms for each pair of twins were again superimposed at peak by adjusting the smaller one on the Y axis, but now a correlation was performed between the data points for the entire waveform. In this instance, the correct and wrong trials were averaged together or collapsed and these mean values were then correlated, providing one $\underline{r}$ value for each pair on each task. Unfortunately, nontwin correlations done in the same manner were not available since the computer system changeover rendered the original pupil data irretrievable for use in later analyses.

Control Group. In order to statistically assess the degree of similarity between MZ twin waveforms, a number of procedures were utilized. Due largely to technical and practical considerations, no separate control group was included in this study. The twin comparisons were contrasted with nontwin indices of similarity obtained in the following manner. Each twin (N=14) was compared on whatever measure of interest to every other individual, excepting the cotwin, and these measures (N=12) were then averaged for each subject. At this point 14 non-twin scores were produced, one for each cotwin (7 MZ pairs) and these two scores for each cotwin were then averaged. A nontwin score to be compared to a MZ pair score consisted of the mean of all possible combinations or pairings of each cotwin (N=12) with all other individuals. This mean nontwin score was then averaged with the corresponding twin's mean nontwin score.

Although this procedure is somewhat unusual it appeared a better alternative than simply selecting seven nontwin pairs as a basis for comparison. By chance alone these random selections could be biased and in order to compare across varying measures and statistics, this random control group would have had to be retained throughout. The measure chosen can be viewed as representative of a population baseline for this particular study; all possible relationships of nontwin pairings are incorporated in the analyses. There is also the advantage that no matching of groups was necessary as all analyses become repeated measures. The one possible query might be in the contrasting of scores where one was based on a larger N, which should make it more robust. Nonetheless, since a larger N theoretically provides a better estimate of the real value, this should not be a difficulty. The twin comparisons were made against the entire sample for this study.

ERP Responses. The ERPs were digitized on an IBM AT microcomputer equipped with a Data Translation (DT 2701s) analog to digital conversion card. All four electrode locations (Fz, Cz, Pz, Oz) were digitized simultaneously at the rate of 10 ms per data point. The trial numbers for the correct and wrong trials determined in the analysis of the pupil trials were utilized for ERP trial selection. The calibration pulses were tallied by the computer and allowed the proper trial number to be selected by the analysis program. The digitized values of the target trial were then added to the next one selected such that a running total of the digitized trials was computed continuously across all four blocks of trials for correct and then wrong predictions on both tasks. When completed the number of trials, the averages and standard deviations were stored on disk for each subject for retrieval by statistical and plotting programs.

Analyses of the ERP data also made use of both correlations and difference (D) scores. Two twin pairs did not have an Oz electrode for technical reasons, therefore only Fz, Cz and Pz were used in all analyses. Since initial observations found no remarkable disparities between correct and wrong ERPs, all of the wrong trials were omitted from further analyses at this time. The twin correlations for the whole waveform (4 s epoch) were produced by directly comparing the correct mean digital data at each electrode placement to the corresponding waveform of the cotwin. No adjustments were made in this case and the mean responses were compared directly for each task.

The waveform was then separated into two parts such that: the first half was 500 ms pre-S_1 to 30 ms pre-S_2 while the second half was 30 ms pre-S_2 and extended well beyond P3 resolution (2.3 s). This was done in order to assess earlier versus later segments of the ERPs and the correlations were computed exactly as for the entire waveform. Furthermore these whole, first and second half correlations were also obtained for all possible nontwin pairings as described above. A cotwin's mean correlation with all other subjects (N=12) was averaged to the corresponding twin's mean correlation with all others.

All correlations or _r_ values were always Z transformed before being averaged or entered into any analyses of variance followed by reconversion to correlations for ease of interpretation in the results section. Furthermore the analyses of variance in all cases were executed as repeated measures with no between factors. Although the pairings and comparisons provided two groups (twin, nontwin), the same subjects provided all the scores.

Amplitude measures were made on a base to peak basis and included four components; N1 and P2 following the first stimulus (S_1N_1, S_1P_2) and N1 and P3 following the second stimulus of the tone pair (S_2N_1, S_2P_3). These were selected as they were present for all subjects in all conditions, while other components were more variable. Separate baselines were computed 500 ms pre-S_1 and 500 ms pre-S_2. This was felt to be more suitable as the presence of contingent negative variations (CNVs) in expectation of the second tone were often large. The following latency windows were observed: N1 (80-160 ms), P2 (170-250 ms), P3 (250-500 ms). Peak amplitude was determined by a three point average surrounding the largest value and this mean was then subtracted from the baseline value for each waveform. The latency values were also determined by a three point average of the time values at peak amplitude of each component.

In order to compare twin and nontwin similarities in both amplitude and latency, difference scores (D) were computed between each twin pair for all four components at all three electrode placements for each task. The nontwin comparisons again consisted of means based on all possible Ds or differences between each twin and all others (see above). The analyses of variance were then performed directly on these D scores based on digital values, but later transformed to the corresponding microvolt and millisecond equivalents for ease of discussion.

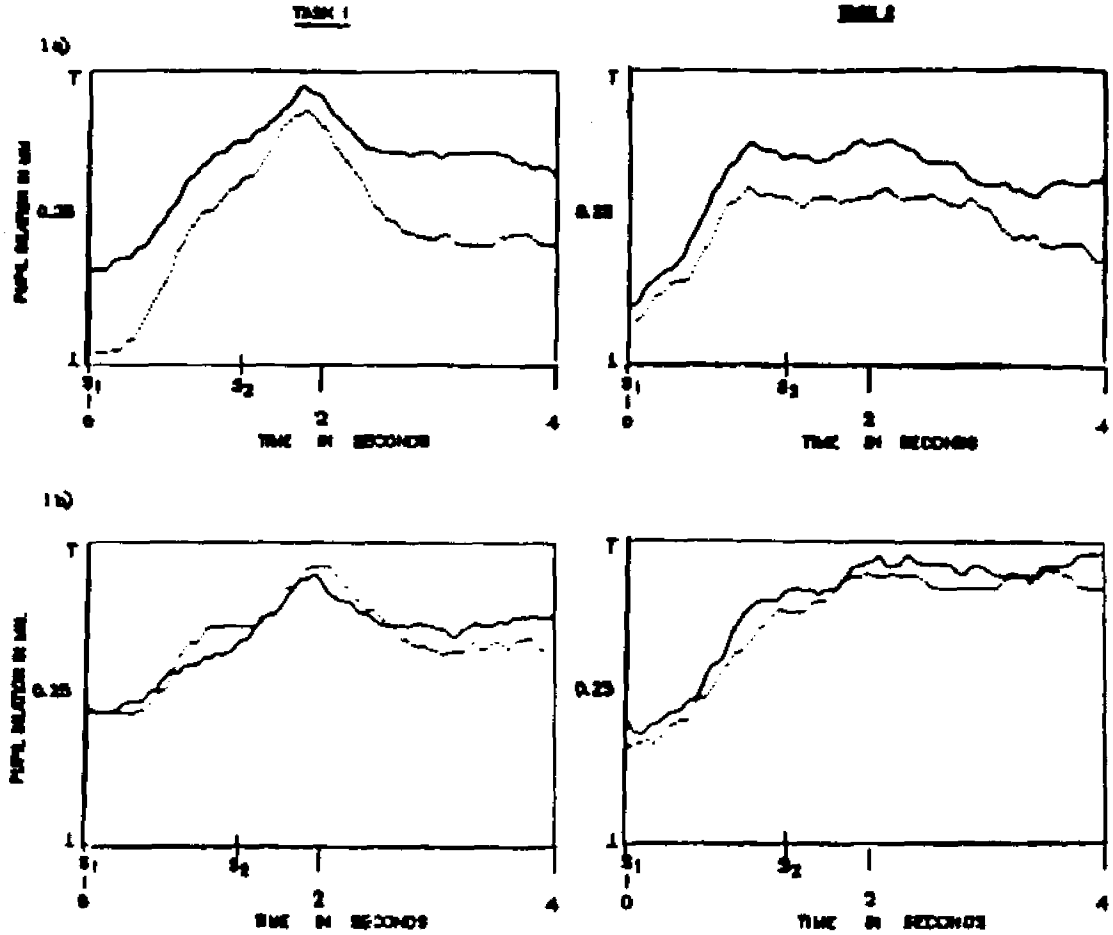
Results

Pupillary Responses

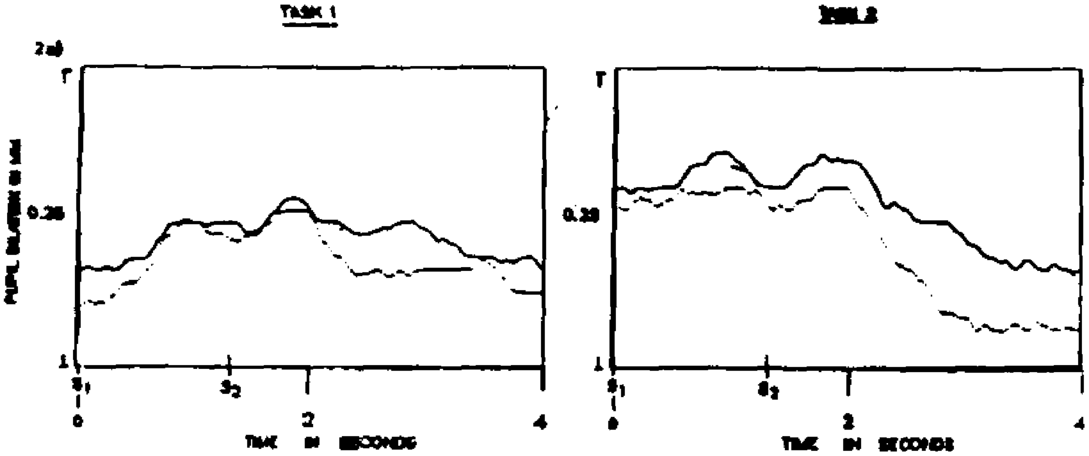
There were two foremost objectives in analyzing the pupillary responses. First to determine if the MZ twins did indeed show more similar response patterns and second, if there were any differences between tasks. The responses for both correct and wrong trials were averaged separately for both tasks. For each subject the correct and wrong pupillary responses were plotted together by task and revealed very small discrepancies (see Figures 3a-3g). The overall shape of these curves indicated that the pupil responded analogously to an event which was cognitively identified as either a correct or wrong guess. No adjustments were made in plotting these curves. The waveforms are unmistakably alike and notable amplitude differences are only evident on visual inspection in 8 out of 28 plots (29%).

There were no statistically significant findings in comparing peak pupil dilation magnitude for correct and wrong trials across tasks (see Table 1). Peak dilation magnitudes for combined correct and wrong trials were 0.084 and 0.102 mm, respectively, for Task 1 and Task 2. These peak dilations were not statistically different between tasks.

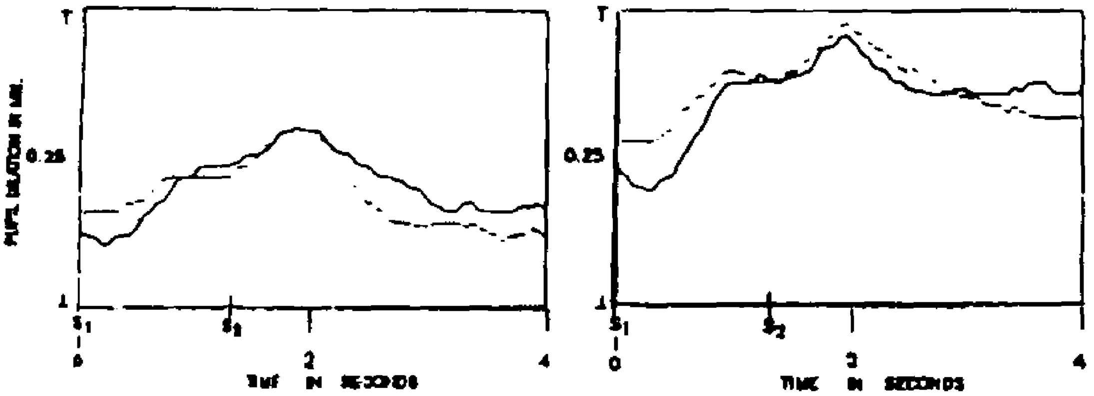
Figure 3. Mean Pupil Dilation Responses of Correct(___) and Wrong (---) Trials for Seven Pairs (3a-3g) of Monozygotic Twins in Task 1 and 2.

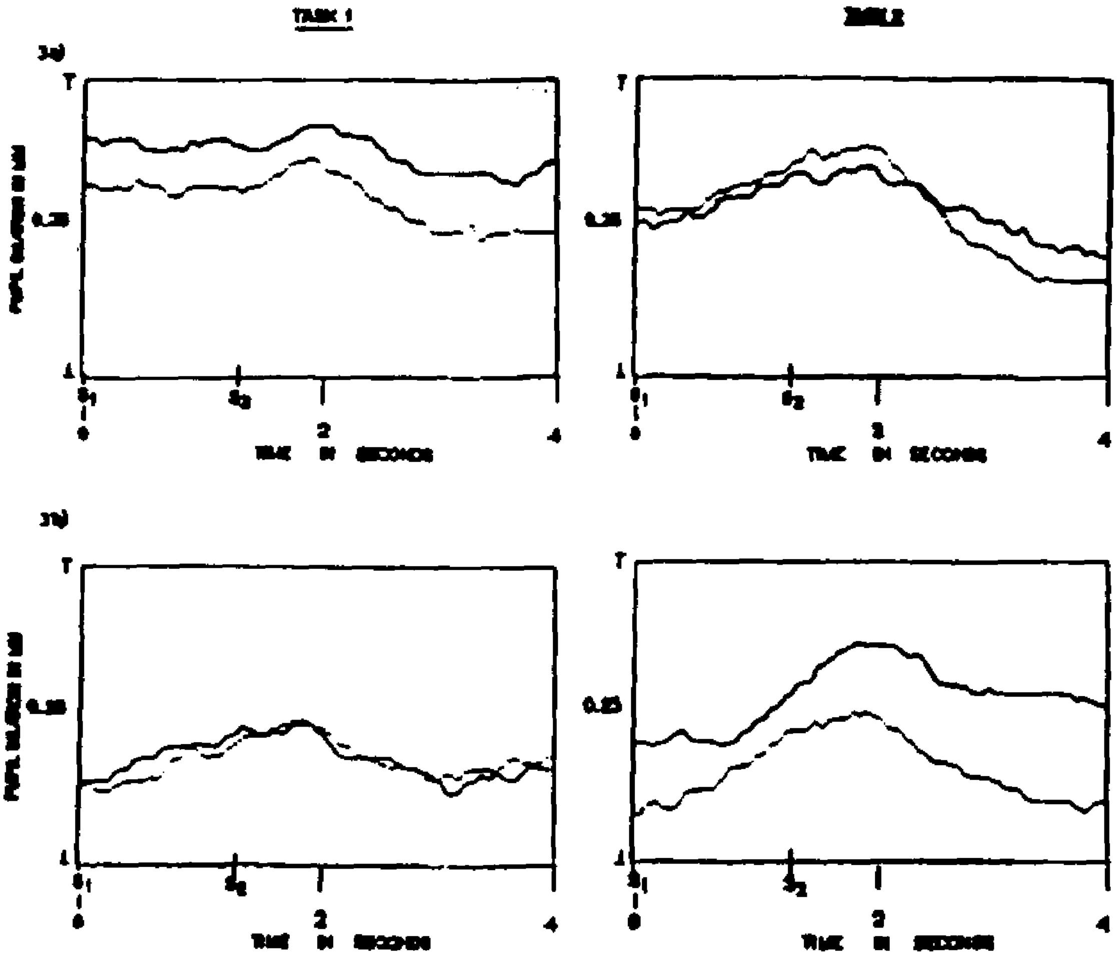

TASK 1
TASK 2
1a)
1b)
PUPIL DILATION IN MM
T
0.25
⊥
S1
S2
0
2
4
TIME IN SECONDS

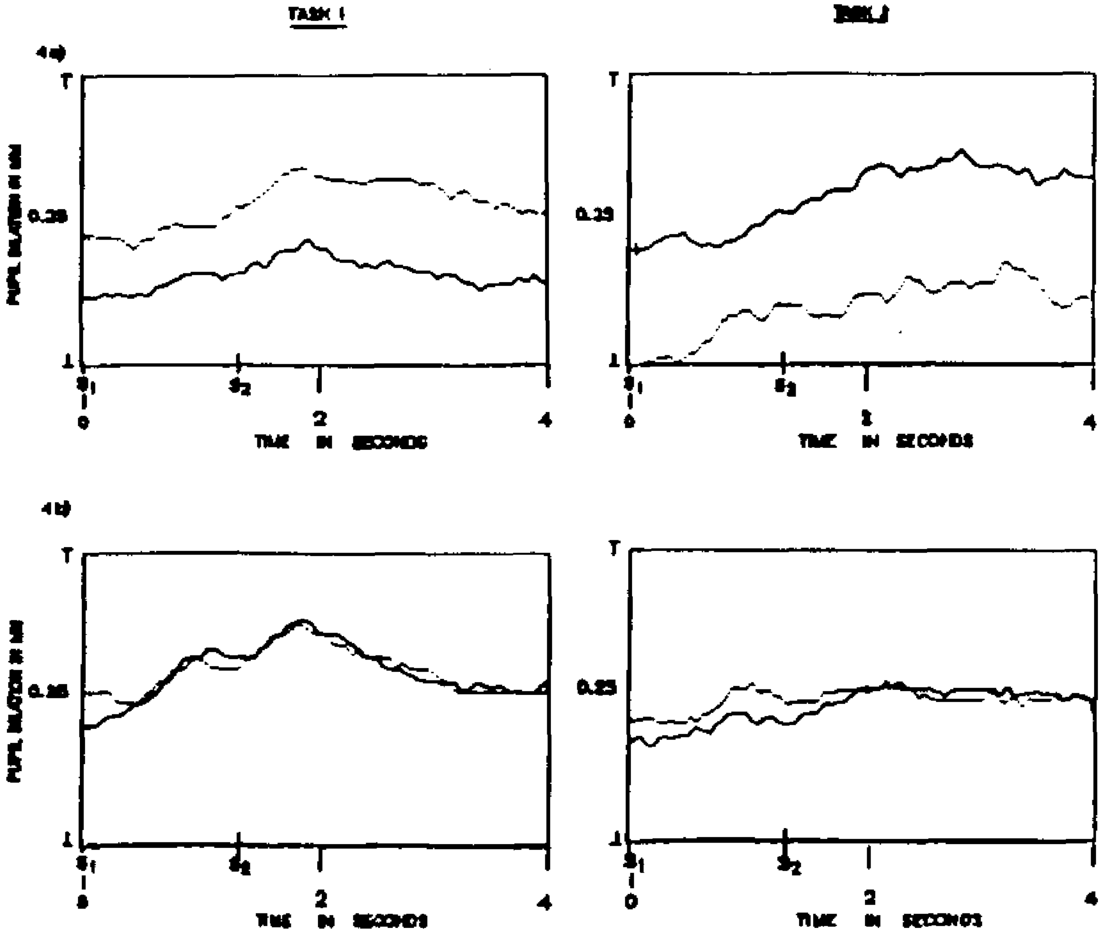
2a)


TASK 1
TASK 2
PUPIL DILATION IN MM.
T
0.25
⊥
S1
S2
0
2
4
TIME IN SECONDS

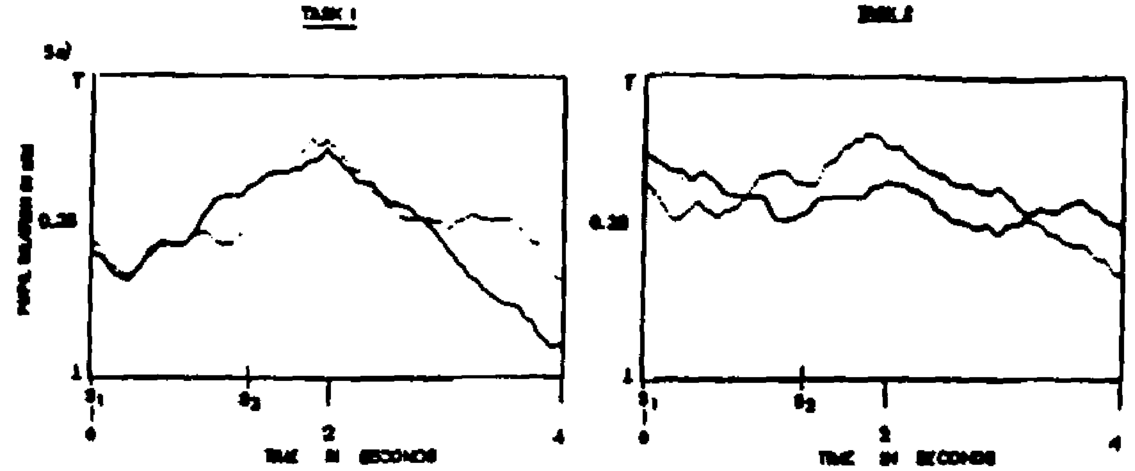
2b)


PUPIL DILATION IN MM.
T
0.25
⊥
S1
S2
0
2
4
TIME IN SECONDS

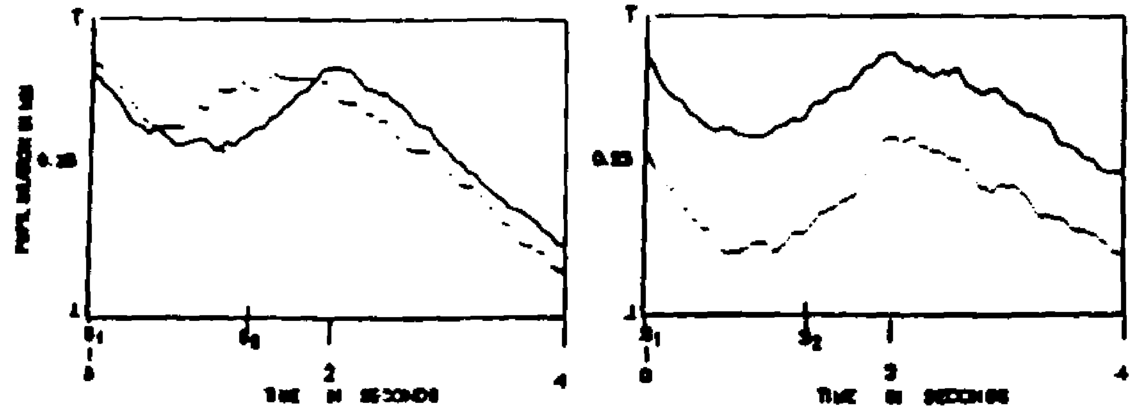

TASK 1
TASK 2
3a)
3b)
T
0.25
⊥
PUPIL DILATION IN MM
S_1
S_2
0
2
4
TIME IN SECONDS


TASK I
TASK J
4a)
4b)
PUPIL DILATION IN MM
T
0.25
⊥
S_1
S_2
0
2
4
TIME IN SECONDS

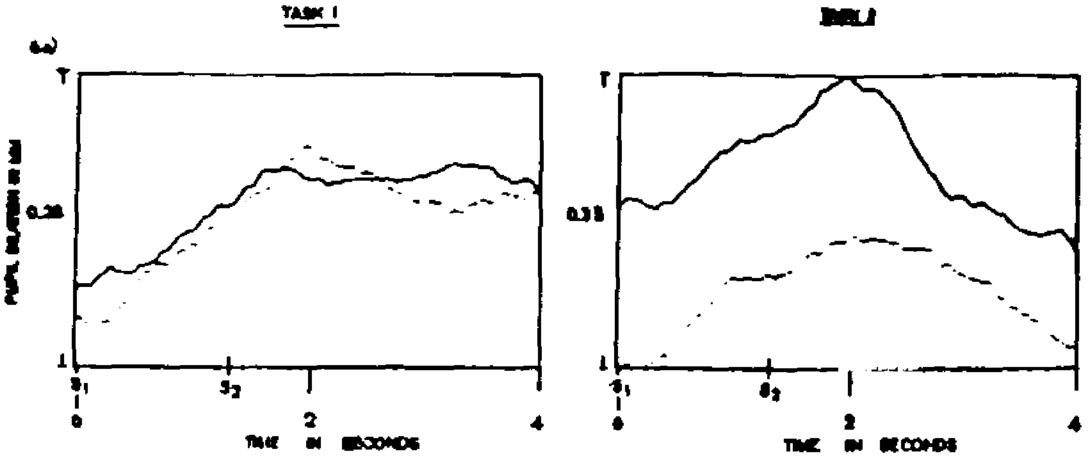
5a)


TASK 1
TASK 2
T
0.25
1
PUPIL DILATION IN MM
S1
S2
0
2
4
TIME IN SECONDS

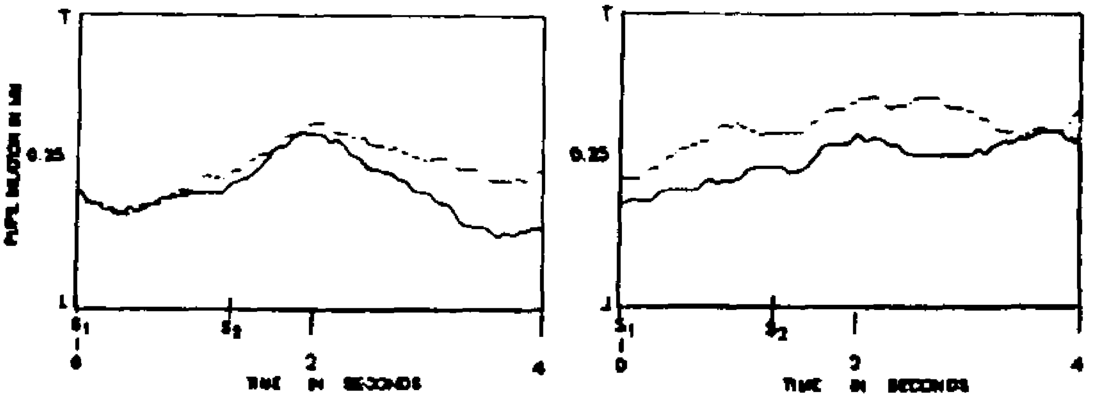
5b)


T
0.25
1
PUPIL DILATION IN MM
S1
S2
0
2
4
TIME IN SECONDS

6a)


TASK I
T
0.28
L
PUPIL DILATION IN MM
S_1
S_2
0
2
4
TIME IN SECONDS
T
0.38
L
S_1
S_2
0
2
4
TIME IN SECONDS

6b)


T
0.25
L
PUPIL DILATION IN MM
S_1
S_2
0
2
4
TIME IN SECONDS
T
0.25
L
S_1
S_2
0
2
4
TIME IN SECONDS

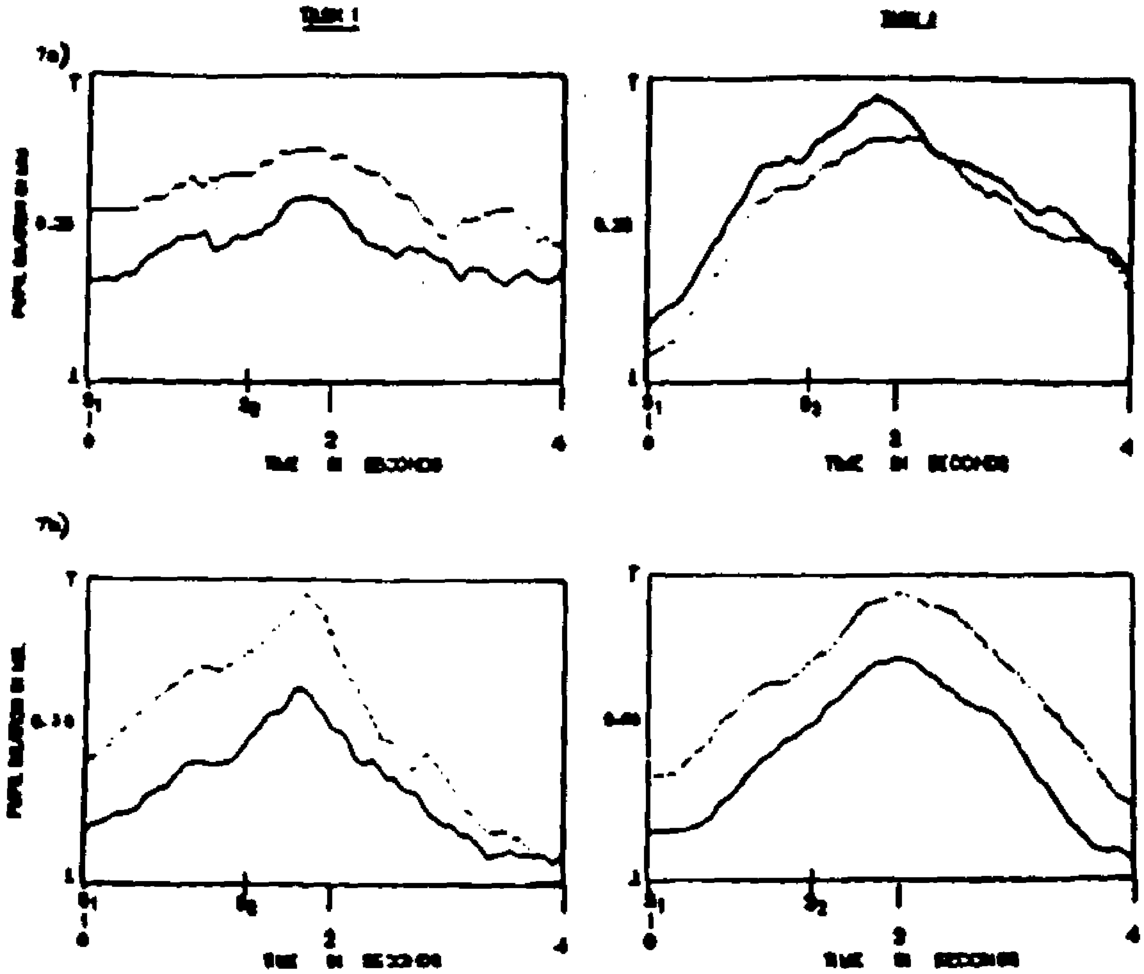

TASK 1
TASK 2
7a)
7b)
PUPIL DILATION IN MM
0.25
0.10
0.40
S1
S2
0
2
4
TIME IN SECONDS

Table 1.

Results of 2x2 Anova for Peak Pupil Dilation Magnitude (mm) of Correct and Wrong Trials for Task 1 and 2 (n=14).

Source	df	SS	MSS	F	P
Task (T)	1	.005	.005	1.097	.30
Type Trial (A)	1	0	0	.071	.79
T x A	1	0	0	.051	.82
Treatment	3	.005			
Within Groups	52	.220	.004		
Total	55	.225			

p < or =.05 ** p < or =.01

Table of Means

	TYPE TRIAL		Overall
	Correct	Wrong	
Task 1	.079	.088	.084
Task 2	.101	.102	.102
	.09	.095	.093

Latency to peak dilation also did not differ for the type of trial or task (see Table 2). The mean latency from the first stimulus onset was 1.86 s across tasks. Since the interstimulus interval was 1300 ms, this is a 560 ms latency from onset of the second stimulus in the pair to peak dilation.

The comparisons of greater interest were those between the cotwins of each MZ pair. Figures 3a-3g allow twin pairs to be compared for both tasks by contrasting the two graphs in the left hand column, which each represent a member of a MZ twin pair for Task 1, with the two graphs in the right column which represent the same pair in Task 2. The most striking finding was the congruence between the pairs. The waveforms did change from one task to the other; the overall pattern often did fluctuate, while the twins most decidedly paralleled each other in these shifts. Unfortunately, there are no statistical methods which can be applied to clearly depict what is visually quite apparent.

Statistical support for these observations was obtained by computing a difference (D) function for each twin pair. These D functions were computed for both correct and wrong trials in both tasks by superimposing the curves at peak dilation.

An analysis of variance found no significant differences for each twin pair comparison under correct and

Table 2.

Results of 2x2 Anova for Peak Pupil Dilation Latency (ms) of Correct and Wrong Trials for Task 1 and 2 (n=14).

Source	df	SS	MSS	F	P
Task (T)	1	8016.002	8016.002	.107	.75
Type Trial (A)	1	516.089	516.089	.007	.93
T x A	1	8501.821	8501.821	.113	.74
Treatment	3	17033.91			
Within Groups	52	3903565	75068.55		
Total	55	3920599			

* p < or =.05 ** p < or =.01

Table of Means

	TYPE TRIAL		Overall
	Correct	Wrong	
Task 1	1883.57	1865	1874.29
Task 2	1835	1865.71	1850.36
	1859.29	1865.36	1862.321

wrong trials for both tasks (see Table 3). The degree of similarity between the pairs was sustained under differing task conditions and trial outcomes.

The type of trial, correct or wrong, did not generate any significant results, therefore all trials were combined and averaged for each subject by task. The waveforms for each MZ pair were then superimposed at peak dilation, as in the calculation of the D curve previously described. Figures 4a-4d represent the mean pupillary responses of all 7 MZ pairs, such that each pair is contrasted on one plot. These plots reveal not only striking similarities in overall waveform and magnitude, but task effects can also be seen (e.g. Figure 4a (lab), 4d (7ab)) where fluctuations between tasks are also mirrored by the cotwin. The mean pupil waveform, including both correct and wrong trials, was superimposed at peak on the cotwin pupil response and a correlation was computed between the two sets of data points. The correlations calculated for each MZ pair on both tasks were quite high as indicated on each graph with only one value ($r=.27$) below .54 and the highest being .98. The mean correlation for Task 1 was .85 which was not statistically different from .69 for Task 2 ($F=3.82$ (1,6), $p=.099$).

There are still no definitive statistical techniques for judging similarity between two waveforms. Often visual

Table 3.

Results of 2x2 Anova for Mean D Values between Pairs of Monozygotic Twins of Correct and Wrong Trials for Task 1 and 2 (n=7)

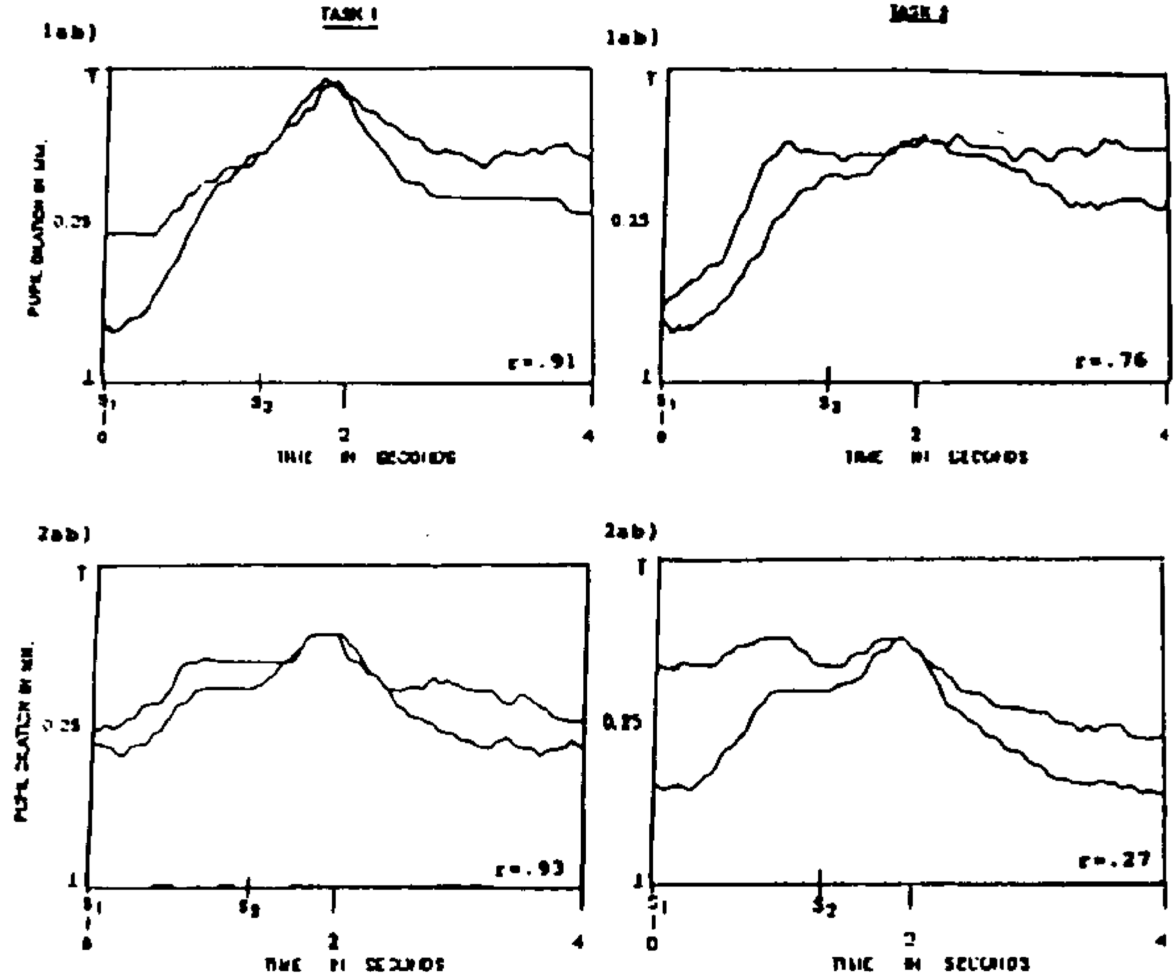
Source	df	SS	MSS	F	P
Task (T)	1	.001	.001	1.141	.30
Type Trial(A)	1	0	0	.044	.84
T x A	1	0	0	.461	.50
Treatment	3	.001			
Within Groups	24	.018	.001		
Total	27	.019			

* p < or =.05   ** p < or =.01

Table of Means

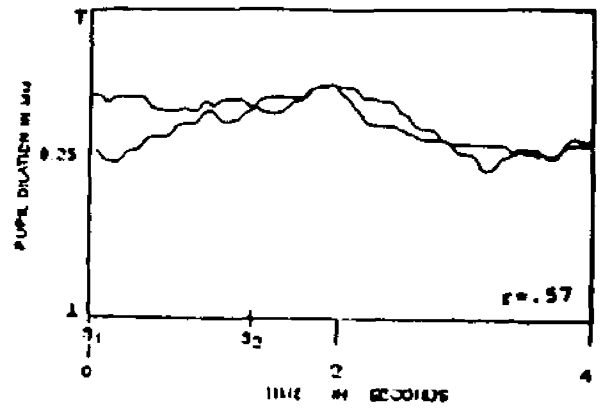
	TYPE TRIAL		Overall
	Correct	Wrong	
Task 1	.025	.034	.03
Task 2	.043	.038	.041
	.034	.036	.035

Figure 4. Superimposed Mean Pupil Dilations (combined correct and wrong trials) for Seven Pairs (4a-4d) of Monozygotic Twins on Task 1 and 2.


TASK 1
TASK
1ab)
1ab)
2ab)
2ab)
PUPIL DILATION IN MM.
T
0.25
⊥
r=.91
r=.76
r=.93
r=.27
S_1
S_2
0
2
4
TIME IN SECONDS

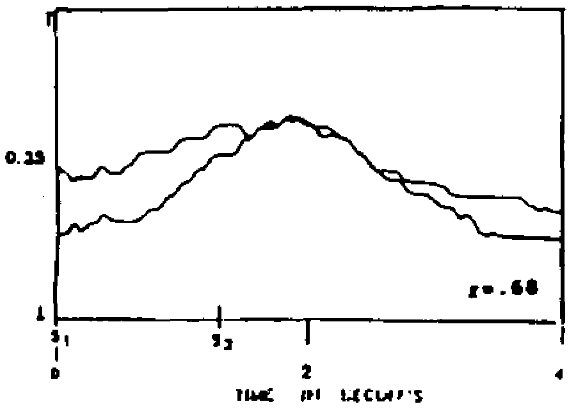
TASK 1

3ab)

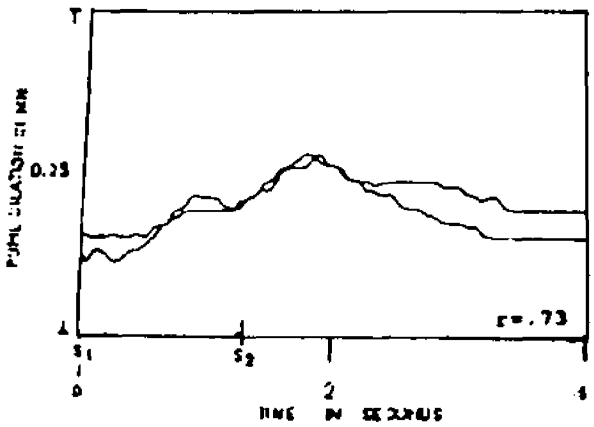


TASK 2

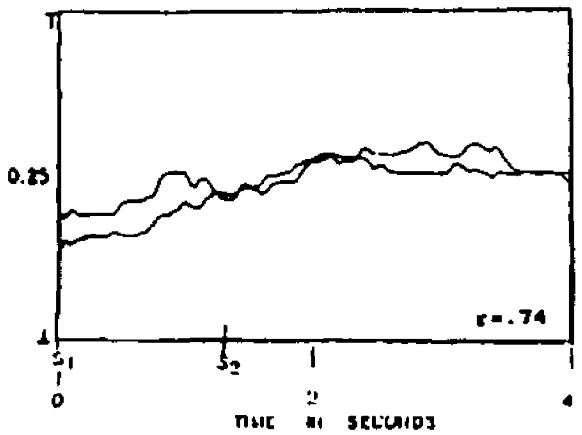
3ab)

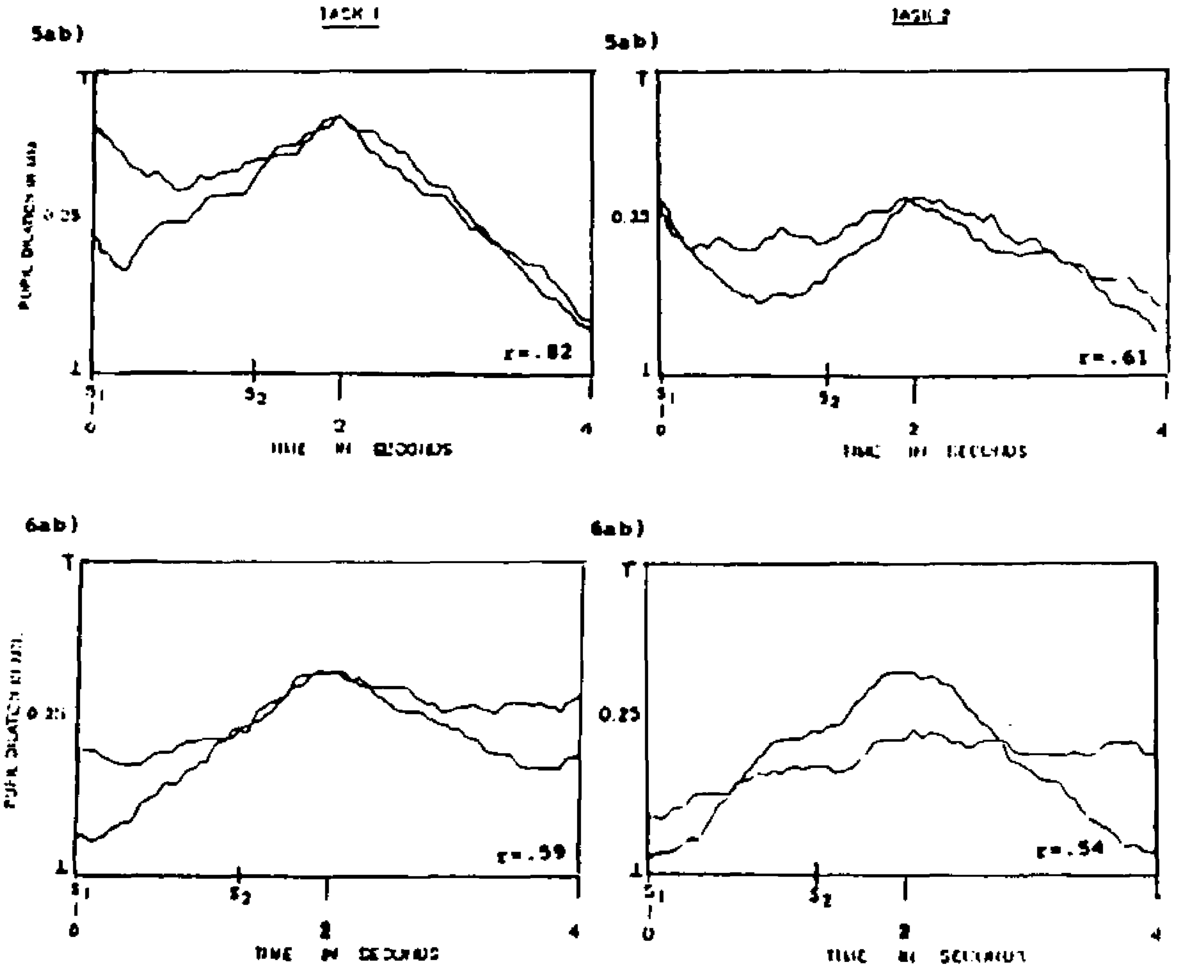


4ab)



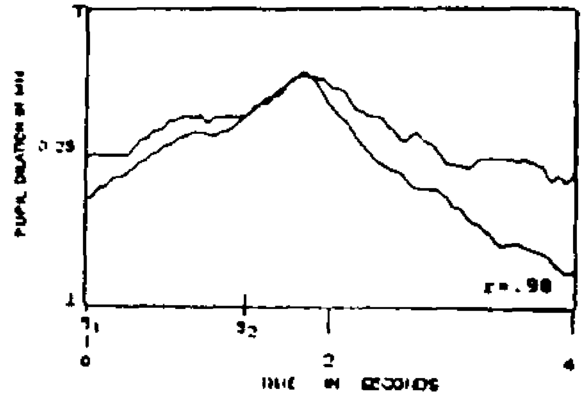
4ab)




TASK 1
TASK 2
5ab)
5ab)
6ab)
6ab)
T
⊥
0.25
PUPIL DILATION IN MM
r=.82
r=.61
r=.59
r=.54
S_1
S_2
0
2
4
TIME IN SECONDS

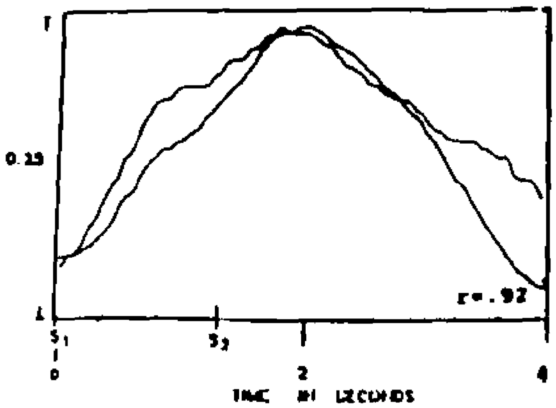
7ab)

TASK 1



7ab)

TASK 2



inspection still provides the strongest appraisal and sense of the results. This was even more difficult when dealing with more complex waveforms such as ERPs, rather than the simpler pupil dilation curves. ERPs represent a summation of events which are not simply linear or additive.

Analysis ERPs - Matching

The commonly employed latency and amplitude measures of specific ERP components are not suitable when the goal is one of ascertaining the degree of similarity in overall ERP waveforms. Consequently, the first analysis performed was one requiring the visual inspection and judgment of ERPs by naive judges.

A matching to sample forced choice technique was used. A single waveform was presented and one of four ERPs had to be selected as the best overall match (see Appendix F). A total of 55 such matches were performed for each task. The composition of 52 of these 55 waveforms included Fz, Cz and Pz for two twin pairs (N=12; 3x4) and Fz, Cz, Pz, and Oz for the remaining five twin pairs (N=40; 4x10), for each task. For 45 of these 52 matches the four choices included the cotwin's corresponding ERP and three foils chosen randomly from all available ERPs, regardless of placement.

To estimate the strength of matching between two electrode placements within one twin, against an identical electrode in the two cotwins, seven (7) of the 52 waveforms provided choices which incorporated: the corresponding cotwin ERP, an ERP from a different electrode placement for that individual and two randomly selected ERPs, regardless of placement. This matching was made more difficult by always providing Fz with its corresponding Cz ERP, or vice versa and Pz with its corresponding Oz ERP, or vice versa. The expectation was that one cotwin should have more similar FZ/CZ or PZ/OZ waveforms than the corresponding electrodes from each cotwin.

The last three (3) of the 55 total waveforms (52+3) functioned as identity matches. They were randomly selected and in addition to the usual choice of the cotwin ERP, an identity match was required by inserting the ERP to be matched itself along with two random foils. This was done to get an indication of the care exercised and discrimination ability of the subjects. Twenty naive subjects (mean age 36.8 years), without vision problems, completed all matches for both tasks (N=110). They were simply instructed to choose the best match by looking at the overall waveform as well as specific parts.

The results indicated that more correct matches were made for Task 2 than Task 1 (61% vs. 50%) (F=56.17 (1,19), p=.001) (see Table 4). For both tasks, matching of the twin ERPs was much better than the 25% (4 choices) chance performance level.

Table 4.

Percentage of Correct Twin Matches for 20 Naive Judges in an ERP Forced Choice Match to Sample Procedure.

Judge	TASK 1	TASK 2
1.	.44	.53
2.	.51	.53
3.	.42	.47
4.	.58	.69
5.	.51	.60
6.	.53	.67
7.	.42	.58
8.	.56	.69
9.	.51	.67
10.	.64	.69
11.	.49	.51
12.	.56	.80
13.	.62	.73
14.	.40	.60
15.	.42	.62
16.	.44	.49
17.	.58	.64
18.	.47	.49
19.	.47	.60
20.	.44	.56
Mean	.501	.608

F= 56.1738 (1,19) p=.001 **

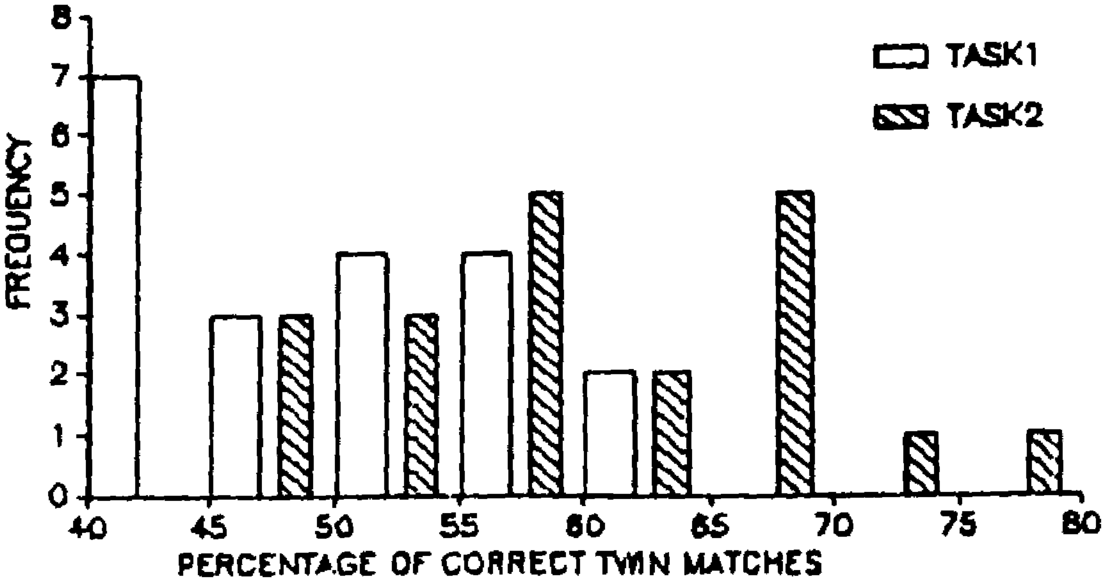
* p < or =.05 ** p < or =.01

Figure 5 shows the range and frequency of matching performance levels for all 20 subjects. For Task 1, 43% correct matches (range .40 -.64) was the mode, while Task 2, 60% and 68% correct matches were equally common performance levels (range .47 -.80).

The identity matches were overall easily accomplished with a mean of only 9% being incorrect for the tasks combined. The twin versus electrode matches (N=7) revealed that for Task 1; 47% chose the corresponding twin waveform while 42% chose the different electrode from the same subject. In contrast, for Task 2 only 8% chose the corresponding cotwin while 82% chose the different electrode from the same subject.

Task 2 provided significantly more correct matches (61% vs. 50%) therefore, it might be presumed that the twins were more similar or at least that the matches where somehow easier. On the other hand, it would be expected that two consecutive electrode placements (i.e., Fz/Cz; Pz/Oz) should be most often preferred as the best match rather than a cotwin, no matter how similar. The cotwin and electrode conditions were picked about equally often for Task 1 thus, the twins must have been quite similar to result in equally probable selection of the cotwin or the neighboring electrode in one twin. Task 2 however resulted in the expected outcome that the consecutive electrode would be

Figure 5. Frequency Distribution of Percentages of Correct Twin ERP Matches by Naive Judges.



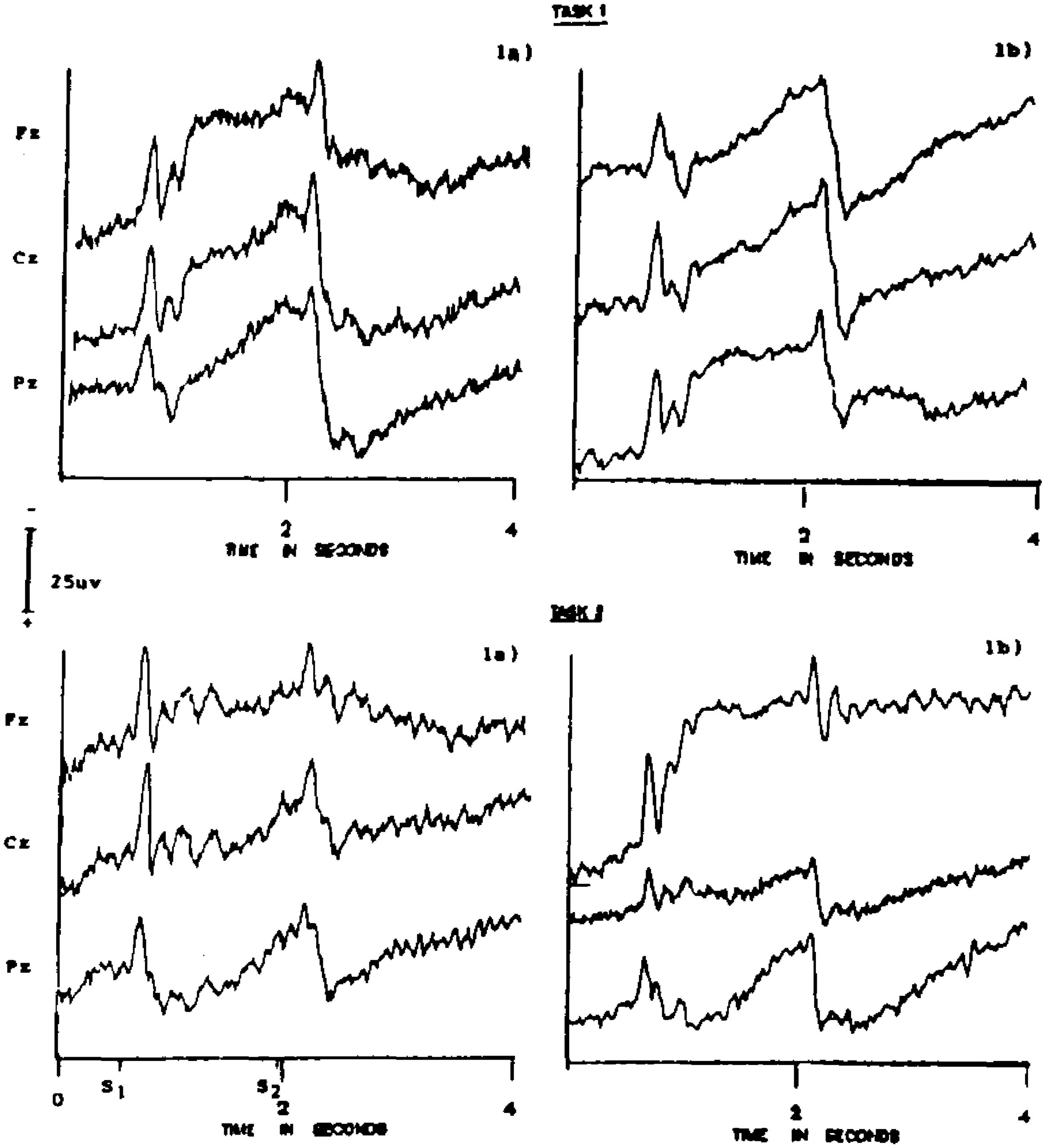
8
7
6
5
4
3
2
1
0
FREQUENCY
TASK1
TASK2
40
45
50
55
60
65
70
75
80
PERCENTAGE OF CORRECT TWIN MATCHES

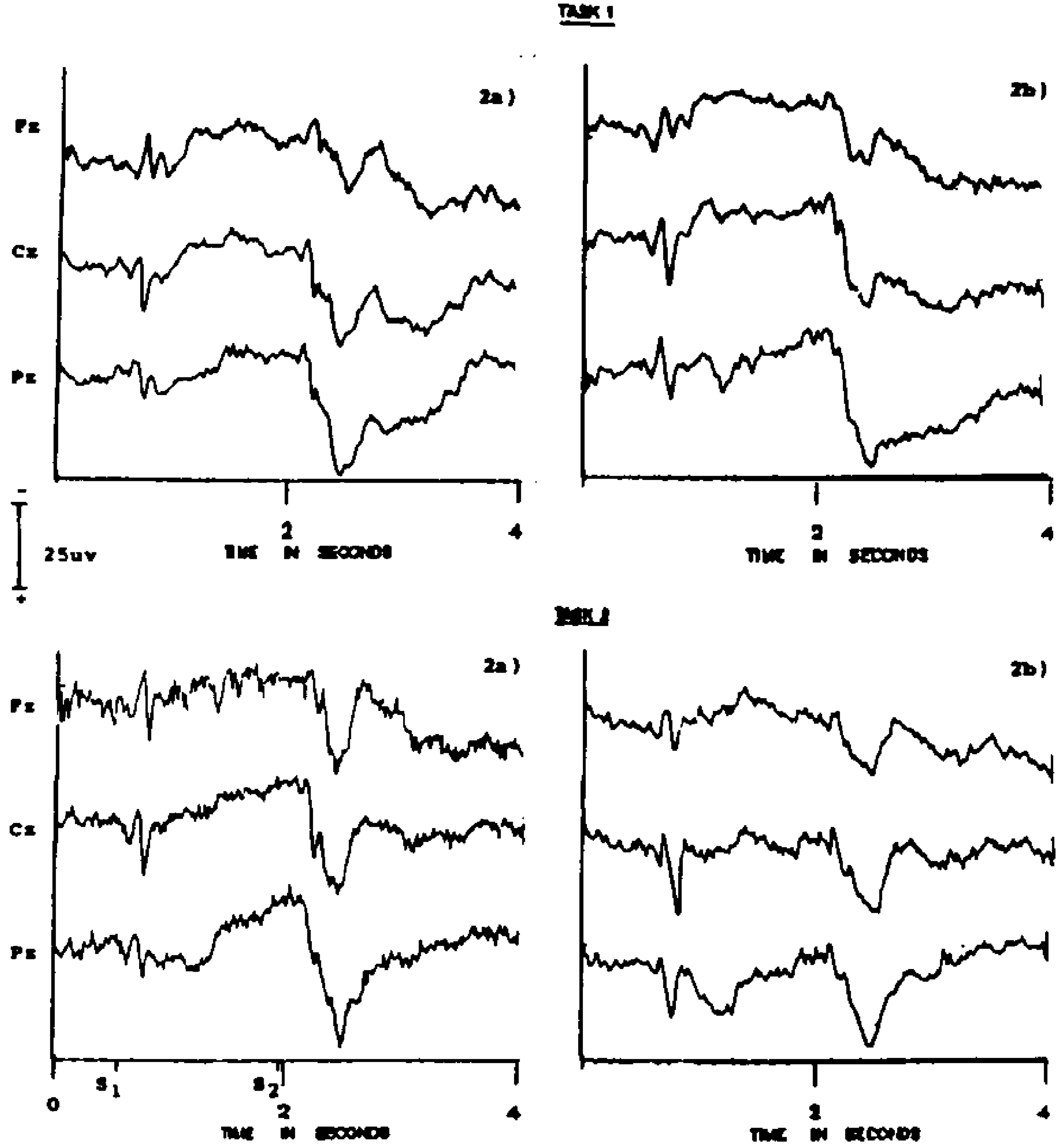
chosen almost exclusively (82%), therefore the cotwins were not as similar, which contradicts the overall better matching performance for Task 2. Perhaps a subgroup of the Task 1 waveforms were particularly difficult and lowered overall performance and also these results were only based on a subsample of seven waveforms. Further analyses should provide additional support of the extent of twin similarity under both task conditions.

Similarity of Twin ERPs

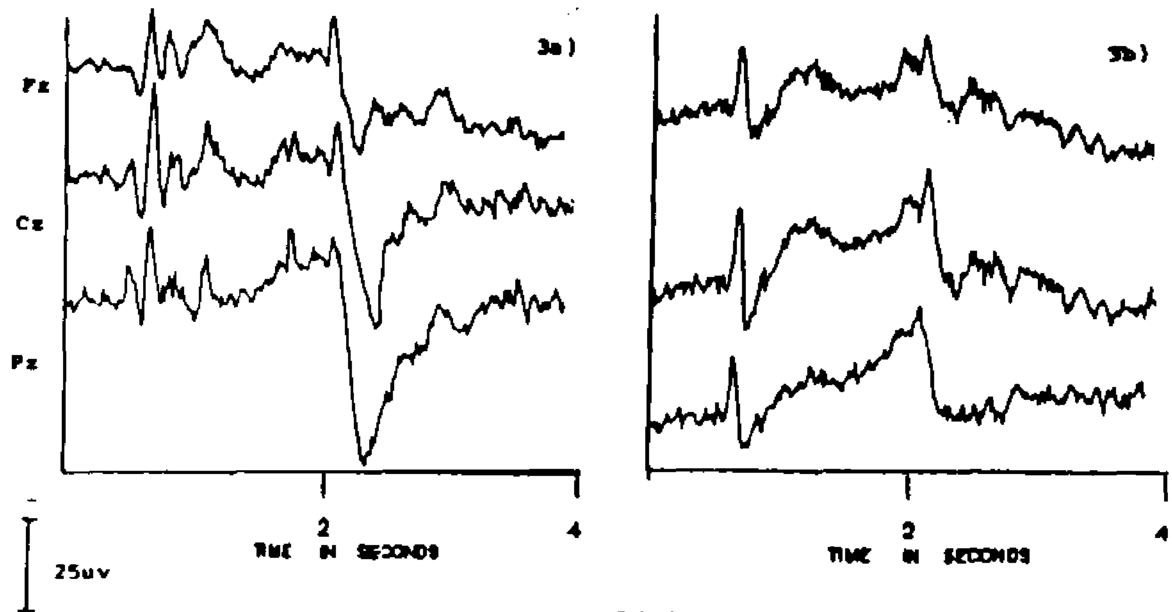
Inspection of the twin ERPs recorded for both tasks provides a distinct impression of similarity (see Figure 6a-6g). The MZ twin pairs can be compared by examining the left and right plots of each figure which each represent a cotwin. Overall the N1s to both stimuli and P3 amplitudes appeared very much alike. Although all subjects presented the same basic pattern of components, differences between unrelated individuals (compare ERPs on one page to figures on any other page) emphasize the degree of congruence of these complex waveforms in MZ twins. Figure 6c showed fairly large N1s and P3s for both twins whereas Figure 6e depicted remarkably flat ERPs for both. A consistent pattern of differences between Task 1 and 2 (compare top and bottom figures of each column) was not discernable visually and overall more resemblance than dissimilarity was apparent in all waveforms between the cotwins.

Figure 6. ERPs for Seven Pairs (6a-6g) of Monozygotic Twins at Fz, Cz, and Pz for Task 1 and 2.

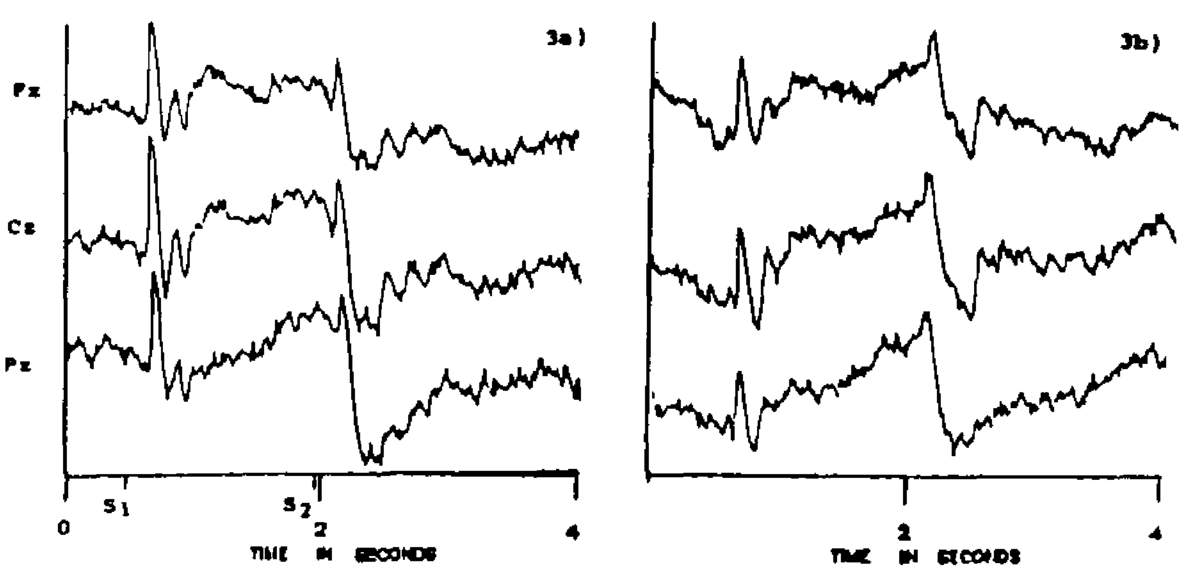

TASK 1
1a)
1b)
Fz
Cz
Pz
2
4
TIME IN SECONDS
-
25uv
+
TASK 2
1a)
1b)
Fz
Cz
Pz
0
S1
S2
2
4
TIME IN SECONDS


TASK 1
2a)
2b)
Fz
Cz
Pz
-
25uv
+
2
4
TIME IN SECONDS
TASK 2
S1
S2
0

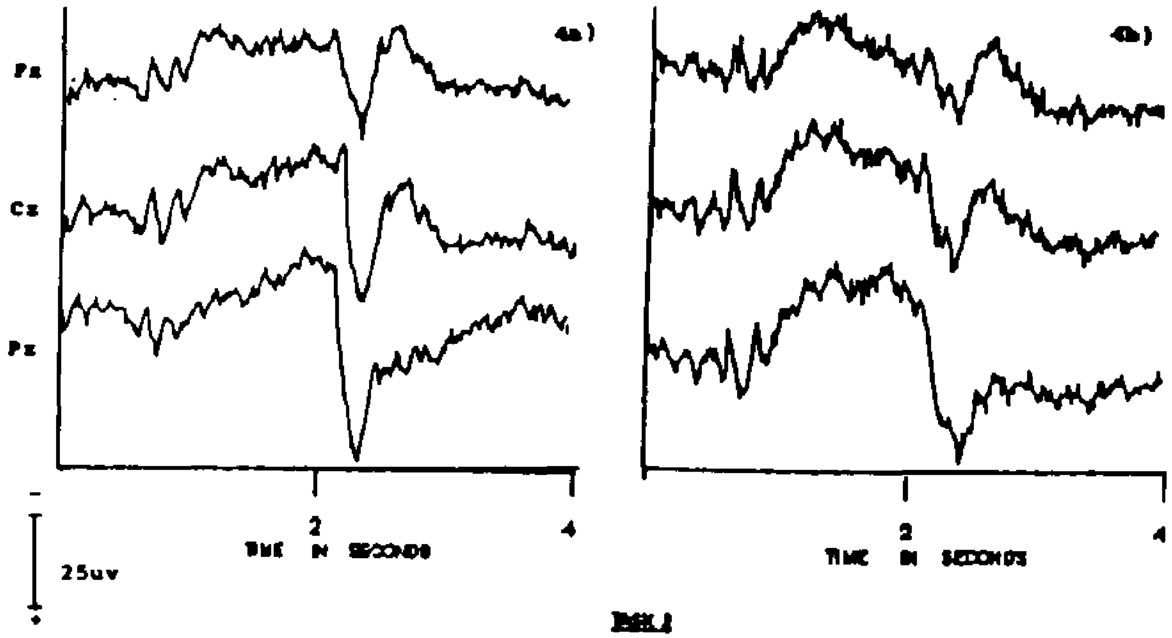
TASK 1


3a)
Pz
Cz
Pz
2
4
TIME IN SECONDS
25uv
3b)
2
4
TIME IN SECONDS

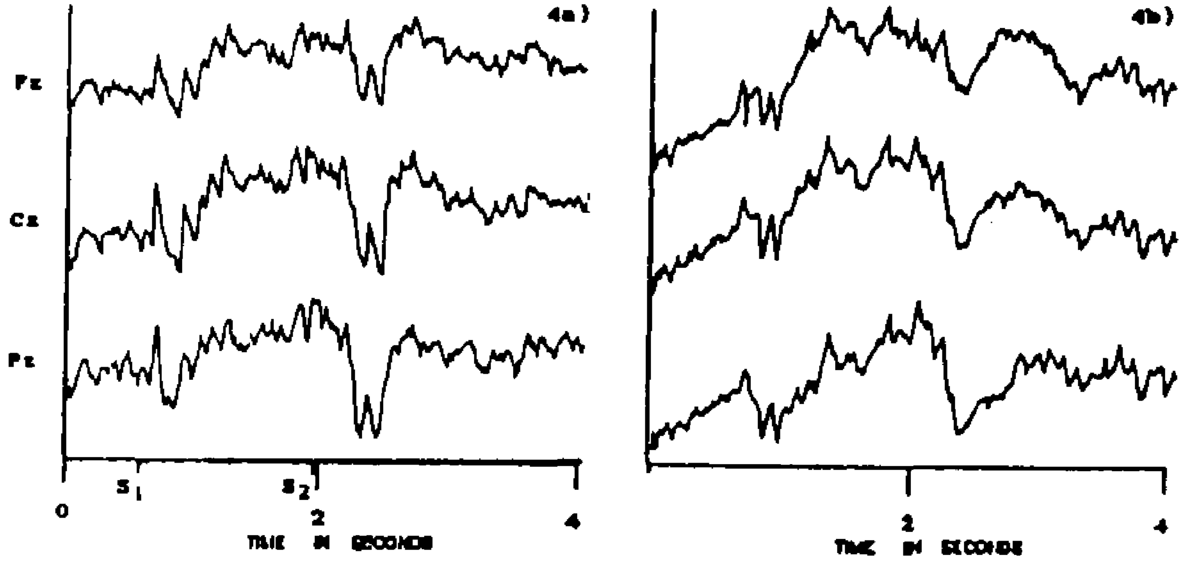
TASK 2

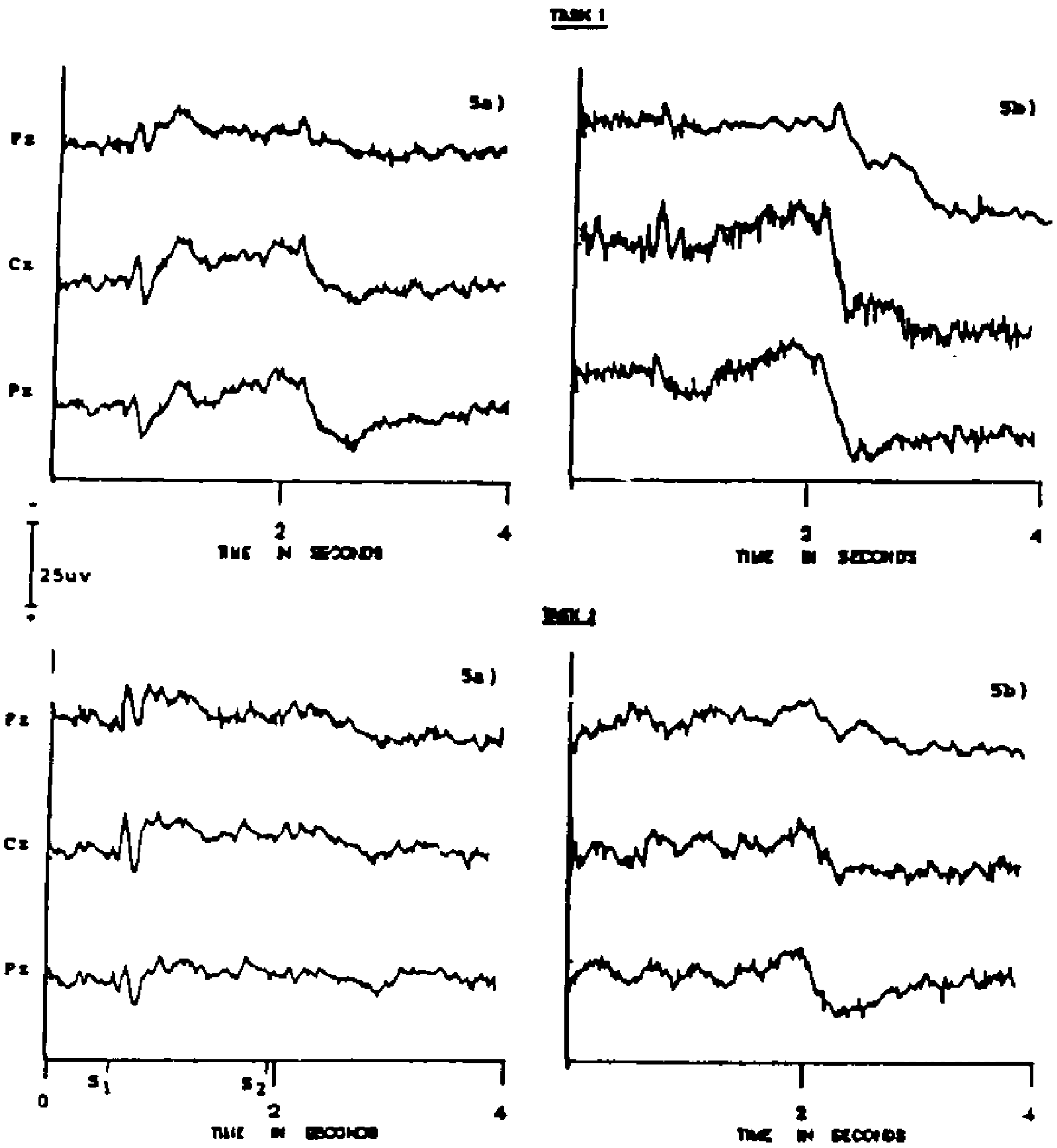

3a)
Pz
Cz
Pz
0
S1
S2
2
4
TIME IN SECONDS
3b)
2
4
TIME IN SECONDS

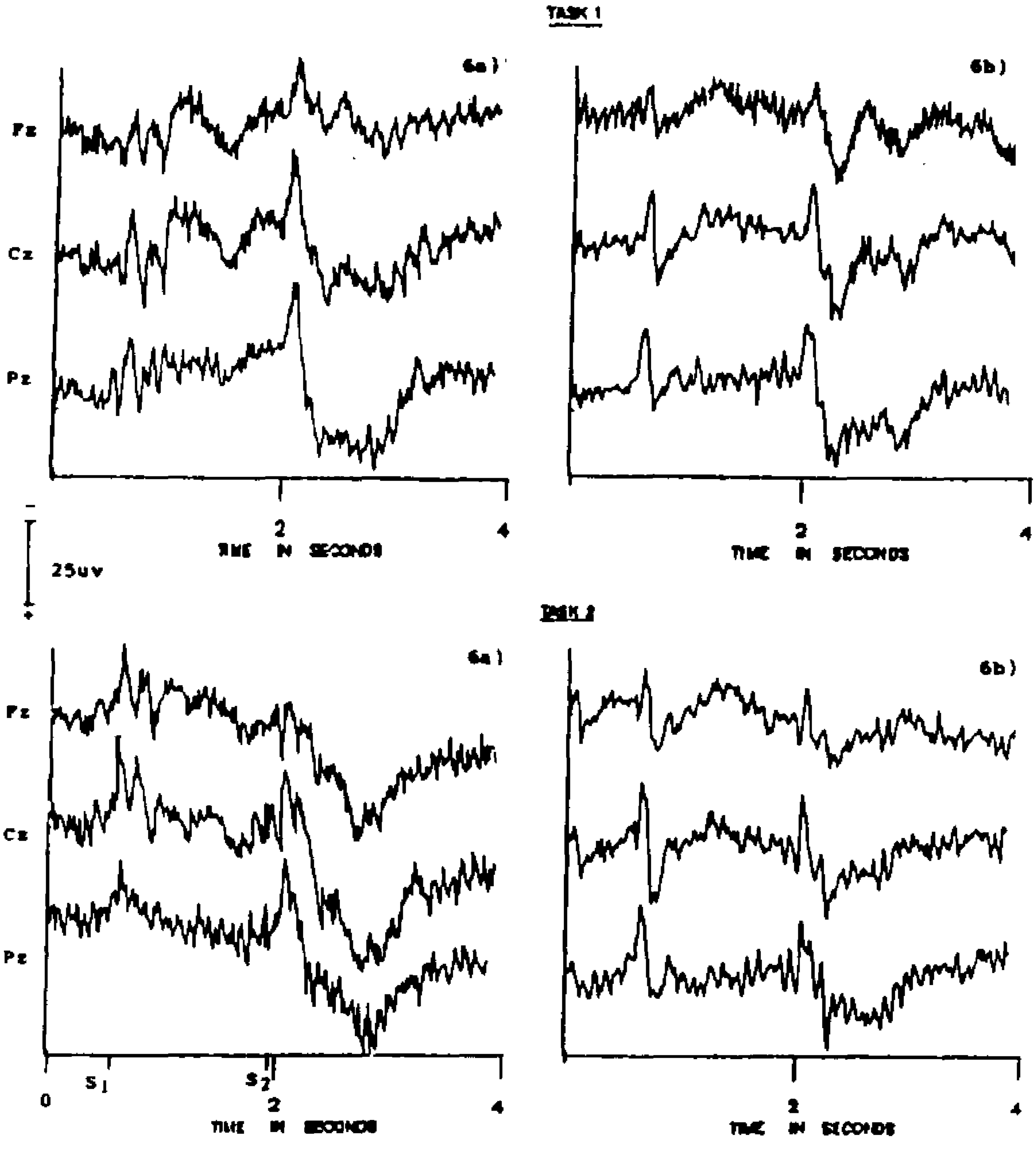
TASK 1

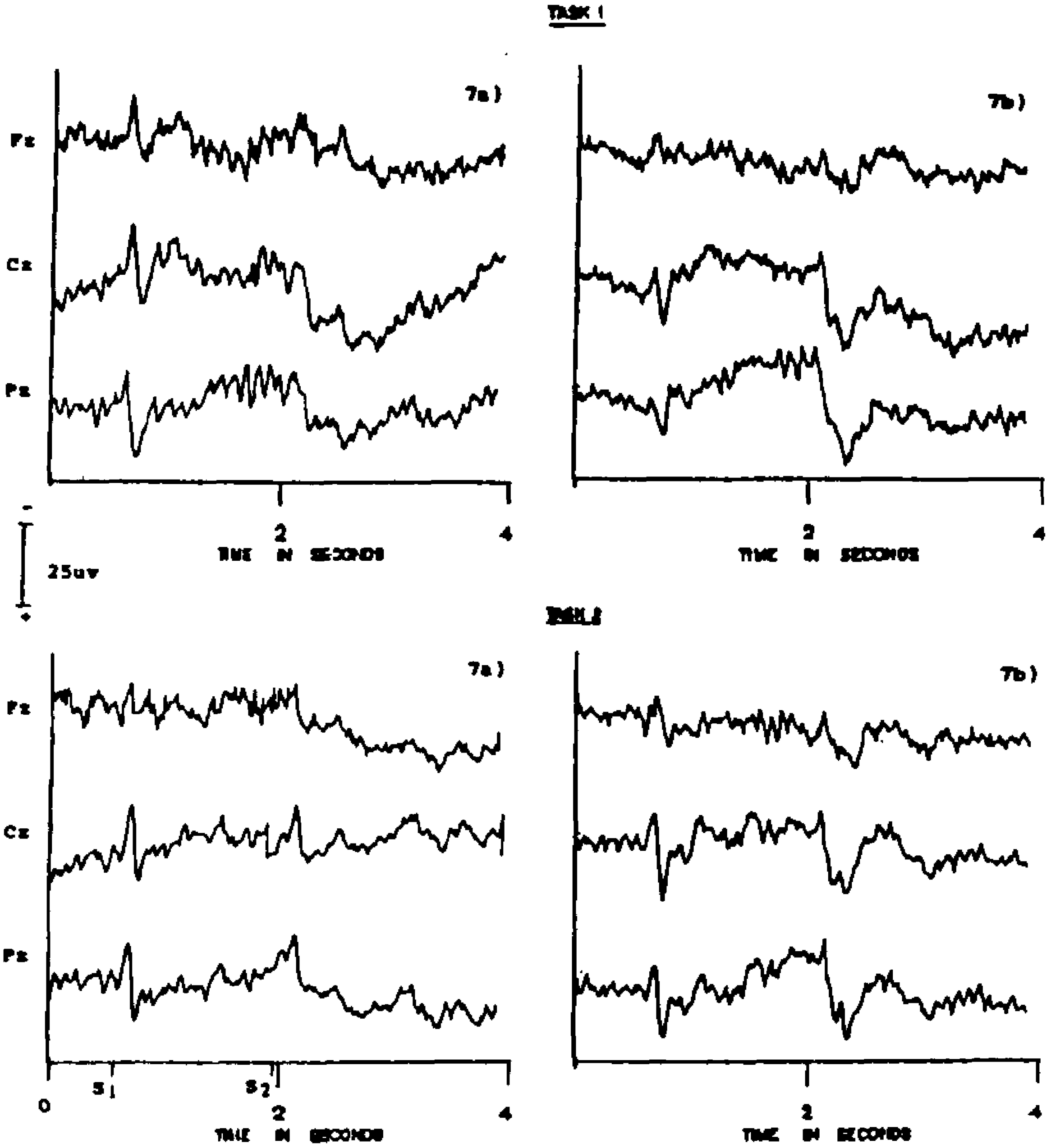

4a)
4b)
Fz
Cz
Pz
2
4
TIME IN SECONDS
25uv
-
+

TASK 2


4a)
4b)
Fz
Cz
Pz
0
S_1
S_2
2
4
TIME IN SECONDS


TASK 1
5a)
5b)
Fz
Cz
Pz
2
4
TIME IN SECONDS
25uv
TASK 2
S1
S2
0


TASK 1
6a)
6b)
Fz
Cz
Pz
2
4
TIME IN SECONDS
-
25uv
+
TASK 2
6a)
6b)
Fz
Cz
Pz
S1
S2
0
2
4
TIME IN SECONDS


TASK 1
7a)
7b)
Fz
Cz
Pz
2
4
TIME IN SECONDS
-
25uv
+
TASK 2
7a)
7b)
Fz
Cz
Pz
0
S1
S2
2
4
TIME IN SECONDS

The following statistical analyses can not be graphically represented from the data. The analyses utilized either correlations or differences (D) between amplitude or latency scores and as such are not exemplified directly by observing or averaging waveforms. The control group includes all subjects and it is unlikely that a grand mean of all the waveforms would be representative of the statistical findings. The comparisons of interest contrast an index of the degree of similarity between pairs of twins with a grand mean of all other possible nontwin pairings for each member of the twin pair.

Analysis ERPs - Correlation

The initial measure of interest was in the degree of correspondence between twins and nontwins. Correlations were performed on twin waveforms for both tasks at electrode positions Fz, Cz and Pz, using only ERPs from correct guesses. The twin correlations for the whole waveform (4 s epoch) were then compared to the nontwin correlations obtained as described above (averaged mean nontwin correlations for both cotwins).

An analysis of variance (task 1/task 2; twin/nontwin; Fz/Cz/Pz) found twin correlations to be significantly greater than that for nontwins (.69 vs. .47) for the entire ERP (F=7.96 (1,77), P=.03) (see Table 5). Table 5 also indicates two additional effects; the first is an overall

Table 5.

Analysis of Variance of Correlations for the Whole Waveform in Twin and Nontwin comparisons for Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	8.123			
Twin/Nontwin (G)	1	2.299	2.299	7.957	0.031 *
G X Subject Within Groups	6	1.733	0.289		
Task (T)	1	0.847	0.876	20.194	0.004 **
T x Subject Within Groups	6	0.252	0.042		
Placement (P)	2	0.012	0.006	0.062	0.940
P X Subject Within Groups	12	1.102	0.092		
GT	1	0.099	0.099	3.150	0.126
GT X Subject Within groups	6	0.188	0.031		
GP	2	0.2310	0.1155	2.062	0.1687
GP X Subject Within Groups	12	0.6722	0.0560		
TP	2	0.236	0.118	4.735	0.030 *
TP X Subject Within Groups	12	0.2986	0.0249		
GTP	2	0.0093	0.0046	0.379	0.6947
GTP X Subject Within Groups	12	0.1466	0.0122		

* p < or =.05   ** p < or =.01

task difference where Task 1 has significantly higher correlations than Task 2 (.65 vs. .51) (F=20.19 (1,6) P=.004). The second is an interaction between task and electrode, with Task 1 showing a greater correlation than Task 2, and smaller at Fz than Cz or Pz respectively, (.60, .67, .68). Task 2 showed the largest correlation at Fz compared to Cz and Pz, respectively, (.57, .49, .51) (F=4.74 (2,12), P=.03). Both twins and nontwins are more similar for Task 1 at Cz and Pz in comparison to Task 2 which produced greater similarities at Fz.

The same procedure of correlations and analyses of variance were then repeated for both the first half (500 ms pre-S_1 to 30 ms pre-S_2) and the second half (30 ms pre-S_2 to end 4 s epoch) of the waveform. The overall degree of correlation for whole wave (.59), first half (.56) and second half (.63) were not very different nor were twin vs. nontwin or Task 1 vs. Task 2 overall values (see Table 6). The standard deviations were also within similar ranges.

There were some expectations that the earlier components might be more similar for all subjects. Though both segments included N1s, the latter half represents task resolution and decision processes, perhaps indexed by P3, which would be predicted to be more subject to inter-individual variation. Later specific component analyses may address this issue, but the assessment of the overall pattern or waveform does not suggest that correlations are

Table 6.

Summary of Mean Correlations from Analyses of the Whole, First and Second Half of the ERP Waveform.

Table of Means

Whole Waveform	Task 1	Task 2	Overall
Twin	.72	.65	.69
Nontwin	.57	.36	.47
	.65	.51	

First Half	Task 1	Task 2	Overall
Twin	.72	.60	.66
Nontwin	.51	.36	.44
	.62	.48	

Second Half	Task 1	Task 2	Overall
Twin	.75	.65	.70
Nontwin	.61	.46	.54
	.68	.56	

influenced to a greater extent by the earlier or later segment of the ERP.

The analysis of variance for the first half of the waveform also found twin correlations to be significantly larger than those of the nontwins (.66 vs. .44) (F=5.72 (1,77), P=.05) (see Table 7). Task 1 again produced higher correlations than Task 2 (.62 vs. .48) (F=6.49 (1,6), P=.04) with the addition of an electrode placement difference with Cz and Pz showing the greatest similarities overall (F=5.75 (2,6), P=.02) (see Table 7). The interaction of relationship (twin/nontwin) and electrode placement was also significant (F=7.77 (2,6), P=.01) with twins illustrating much larger correlations and especially at Cz and Pz (see Table 7). The last significant result of interest in Table 7 is the 3 way interaction confirming higher correlations for Task 1 overall, with twins demonstrating more similarity in both tasks and an electrode location effect where twins and nontwins were most similar at Cz and Pz (F=4.54 (2,12), p=.03).

In contrast, the results for the second half of the waveform indicated only one significant effect. Twins had significantly greater correlations than nontwins (.70 vs. .54) (F=6.49 (1,77), P=.04) (see Table 8).

In brief, twins in all three conditions (whole wave, first half, second half) have significantly larger correlations than nontwins. Task 1 resulted in more similar

Table 7.

Analysis of Variance of Correlations for the First Half of the ERP Waveform in Twin and Nontwin Comparisons for Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	8.796			
Twin/Nontwin (G)	1	2.256	2.256	5.719	0.054 *
G X Subject Within Groups	6	2.367	0.395		
Task (T)	1	0.830	0.830	6.490	0.044 *
T X Subject Within Groups	6	0.768	0.128		
Placement (P)	2	0.548	0.274	5.75	0.018 *
P X Subject Within Subjects	12	0.572	0.048		
GT	1	0.006	0.006	0.067	0.804
GT X Subject Within Groups	6	0.560	0.093		
GP	2	0.183	0.092	7.766	0.007 **
GP X Subject Within Groups	12	0.142	0.012		
TP	2	0.143	0.071	3.68	0.056
TP X Subject Within Groups	12	0.233	0.019		
GTP	2	0.081	0.041	4.535	0.034 *
GTP X Subject Within Groups	12	0.107	0.009		

* p < or =.05 ** p < or =.01

Table 8.

Analysis of Variance of Correlations for the Second Half of the Waveform in Twin and Nontwin Comparisons for Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	9.552			
Twin/Nontwin (G)	1	1.552	1.552	6.486	0.044 *
G X Subject Within Groups	6	1.436	0.239		
Task (T)	1	0.796	0.796	3.398	0.115
T X Subject Within Groups	6	1.405	0.234		
Placement (P)	2	0.468	0.234	2.483	0.124
P X Subject Within Groups	12	1.132	0.094		
GT	1	0.0002	0.0002	0.002	0.968
GT X Subject Within Groups	6	0.819	0.137		
GP	2	0.076	0.038	0.796	0.478
GP X Subject Within Groups	12	0.570	0.048		
TP	2	0.016	0.008	0.172	0.845
TP X Subject Within Groups	12	0.549	0.046		
GTP	2	0.239	0.120	2.903	0.093
GTP X Subject Within Groups	12	0.494	0.041		

* p < or =.05 ** p < or =.01

waveforms than Task 2 for the analysis of the whole waveform (.65/.51 p=.004) and first half (.62/.48 p=.04), but the second half difference was not significant (.68/.56). An interaction for the whole ERP revealed larger correlations at Cz and Pz for Task 1 and larger correlations at Fz for Task 2. The first half correlation also showed larger values for Cz and Pz both overall and in combination with task and relationship variables. Though not statistically significant the trend for the second half analysis was definitely that of greater correlations at Pz for all levels of analysis.

<u>ERPs</u> - <u>Amplitude</u> <u>and</u> <u>Latency</u>

The analyses of variance by component showed significantly smaller differences between twin amplitudes than nontwin for S_1N_1 (4.56 uv vs. 9.59 uv) (F=18.73 (1,77), P=.005) (see Table 9). A significant interaction is also present in Table 9 for task and electrode placement, such that Task 2 resulted in larger amplitude differences for all three electrodes. Task 1 differences were smaller and showed more similarity or the smallest values at Pz (F=5.01 (2,12), p=.03). These larger D scores or differences overall for N1 amplitudes in Task 2 do not appear to be due to greater variability. In effect Task 2 values had smaller standard deviations than those for Task 1 at Fz, Cz

Table 9.

Analysis of Variance for Twin and Nontwin S_1N_1 Amplitude Difference (D) Scores in Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	23904.445			
Twin/Nontwin (G)	1	8497.278	8497.278	18.728	0.005 **
G X Subject Within Groups	6	2722.3699	453.728		
Task (T)	1	291.537	291.537	0.639	0.454
T X Subject Within Groups	6	2739.348	456.558		
Placement (P)	2	358.395	179.198	2.530	0.120
P X Subject Within Groups	12	849.942	70.829		
GT	1	163.661	163.661	0.473	0.576
GT X Subject Within Groups	6	2074.371	345.728		
GP	2	242.126	121.063	0.659	0.539
GP X Subject Within Groups	12	2204.630	183.719		
TP	2	922.575	461.287	5.012	0.026 *
TP X Subject Within Groups	12	1104.402	92.034		
GTP	2	361.905	180.952	1.583	0.244
GTP X Subject Within Groups	12	1371.901	114.325		

* p < or =.05   ** p < or =.01

and Pz, respectively (3.99, 1.98, 2.47 vs. 4.11, 5.76, 3.16).

Similar results were also obtained for S_1P_2 amplitudes. Twins exhibited significantly smaller differences in their P2 amplitude values than nontwins (4.52 uv vs. 7.17 uv) (F=6.33 (1,77), p=.05) (see Table 10). There was also an overall task effect, with Task 2 again showing larger Ds (F=9.11 (1,6), p=.02) and an interaction of task and electrode placement, where Task 2 differences were largest and especially at Cz (F=4.75 (2,12), p=.03) (see Table 10). Larger variances again do not seem to be a factor in this effect.

Amplitude differences for S_2N_1 further supported previous findings of smaller twin differences than nontwin (4.00 uv vs. 6.96 uv) (F=49.83 (1,77), P=.0005) (see Table 11). Although task differences were not significant, an overall electrode placement effect was evident with Fz (4.67 uv) showing much smaller differences, more similarity, than either Cz (5.79 uv) or Pz (5.98 uv) (F=6.24 (2,6), P=.01) (see Table 11).

Finally, only one significant effect was manifested for S_2P_1 amplitudes, that of electrode placement. Twin differences were not significantly smaller, but Fz (8.39 uv) differences for all subjects were smaller than those for Cz (10.13 uv) or Pz (11.84 uv) (F=3.76 (2,6), p=.05

Table 10.

Analysis of Variance for Twin and Nontwin S_1P_2 Amplitude Difference (D) Scores in Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	18666.969			
Twin/Nontwin (G)	1	2369.534	2369.534	6.330	0.046 *
G X Subject Within Groups	6	2246.040	374.340		
Task (T)	1	4114.319	4114.319	9.110	0.024 *
T X Subject Within Groups	6	2709.690	451.615		
Placement (P)	2	596.214	298.107	2.782	0.101
P X Subject Within Groups	12	1285.669	107.139		
GT	1	19.817	19.817	0.061	0.813
GT X Subject Within Groups	6	1940.622	323.437		
GP	2	652.957	326.479	3.219	0.076
GP X Subject Within Groups	12	1217.186	101.432		
TP	2	349.256	174.628	4.749	0.030 *
TP X Subject Within Groups	12	441.238	36.770		
GTP	2	133.951	66.976	1.361	0.291
GTP X Subject Within Groups	12	590.466	49.206		

* p < or =.05   ** p < or =.01

Table 11.

Analysis of Variance for Twin and Nontwin S_2N_1 Amplitude Difference (D) Scores in Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P	
Within Subjects	77	9988.434				
Twin/Nontwin (G)	1	2945.910	2945.910	49.831	0.001	**
G X Subject Within Groups	6	354.712	59.119			
Task (T)	1	119.691	119.691	0.593	0.470	
T X Subject Within groups	6	1211.747	201.958			
Placement	2	449.688	224.844	6.235	0.014	**
P X Subject Within groups	12	432.712	36.059			
GT	1	48.899	48.899	0.864	0.388	
GT X Subject Within Groups	6	339.456	56.576			
GP	2	198.717	99.359	1.216	0.328	
GP X Subject Within Groups	12	980.474	81.706			
TP	2	37.648	18.824	0.157	0.858	
TP X Subject Within Groups	12	1438.650	119.888			
GTP	2	140.100	70.050	0.652	0.542	
GTP X Subject Within Groups	12	1290.026	107.502			

* p < or =.05 ** p < or =.01

(see Table 12). All subjects must therefore be more similar for S_2N_1 and S_2P_3 at the Fz position.

In short, the smaller twin differences, thus greater similarity, was apparent for S_1N_1, S_1P_2, and S_2N_1 and not significant for S_2P_3, though in the right direction. The standard deviations for P3 D scores in Task 1 were almost three times that for Task 2 (7.91 vs. 2.80). There was an effect of task for S_1N_1 and S_1P_2 such that Task 1 always indicated greater similarities for both twins and nontwins, albeit the group differences were also discernable. An overall electrode effect for S_2N_1 and S_2P_3, with Fz showing more overall similarity.

Another analysis of variance was performed on the actual component amplitudes of the 14 subjects. There were no task differences in amplitude but, a component effect (F=16.15 (3,13) p=.001) was prominent with all subjects showing significantly larger amplitudes for S_2P_3 (19.19 uv) in post-hoc comparisons (Tukey A) than S_1N_1 (11.49 uv), S_1P_2 (6.64 uv), or S_2N_1 (6.99 uv) (see Table 13). There was also an effect of electrode placement with overall smaller amplitudes at Fz (8.73 uv) than Cz (12.41 uv) or Pz (12.09 uv) (F=22.07 (2,39) p=.001) (see Table 13). Table 13 also depicts the three following statistically significant interactions: an effect of task by component such that the greatest amplitudes for both tasks occur for S_1N_1 and

Table 12.

Analysis of Variance for Twin and Nontwin S_2P_3 Amplitude Difference (D) Scores in Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P	
Within Subjects	77	37493.594				
Twin/Nontwin (G)	1	2818.920	2818.920	2.431	0.170	
G X Subject Within Groups	6	6957.040	1159.507			
Task (T)	1	3167.871	3167.871	2.666	0.154	
T X Subject Within Groups	6	7128.299	1188.050			
Placement	2	2663.890	1331.945	3.759	0.054	*
P X Subject Within Groups	12	4251.568	354.297			
GT	1	872.041	872.041	1.113	0.332	
GT X Subject Within Groups	6	4702.756	783.793			
GP	2	312.547	156.274	0.929	0.426	
GP X Subject Within Groups	12	2019.361	168.280			
TP	2	491.306	245.653	2.200	0.152	
TP X Subject Within Groups	12	1340.054	111.671			
GTP	2	240.190	120.095	2.731	0.105	
GTP X Subject Within Groups	12	527.748	43.979			

* p < or =.05 ** p < or =.01

Table 13.

Analysis of Variance for Amplitude (uv) Measures of S_1N_1, S_1P_2, S_2N_1, S_2P_3 in Task1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	322	380026.620			
Task (T)	1	408.542	408.542	1.021	0.331
T X Subject Within groups	13	5200.640	400.049		
Component (C)	3	137469.094	45823.031	16.150	0.001 **
C X Subject Within Groups	39	110655.578	2837.322		
Placement (P)	2	14899.928	7449.964	22.069	0.001 **
P X Subject Within Groups	26	8777.144	337.582		
TC	3	13244.559	4414.853	5.415	0.003 **
TC X Subject Within Groups	39	31797.209	815.313		
TP	2	1809.397	904.698	10.862	0.004 **
TP X Subject Within groups	26	2165.452	83.287		
CP	6	10552.010	1758.668	6.221	0.00 **
CP X Subject Within Groups	78	22049.828	282.690		
TCP	6	2075.566	345.927	1.426	0.214
TCP X Subject Within Groups	78	18921.507	242.583		

* p < or =.05   ** p < or =.01

S_2P_3 (F=5.42 (3,26), p=.003); an effect of task by placement such that both tasks result in larger amplitudes at Cz and Pz compared to Fz (F=10.86 (2,39), p=.004), and an effect of component by placement such that Fz values are somewhat smaller than Cz or Pz, but again S_1N_1 and S_2P_3 amplitudes are by far the largest (F=6.22 (6,26), p=0).

Latency differences were not found between tasks, for all 14 subjects or at any electrode placements (Fz, Cz, Pz) or for any specific components (S_1N_1, S_1P_2, S_2N_1, S_2P_3) (see Table 14). The mean latencies for the four components examined were consonant with previous ERP findings: S_1N_1 (138 ms), S_1P_2 (228 ms), S_2N_1 (155 ms), S_2P_3 (393 ms). An effect of increased P3 latency was not manifested for Task 2 (391 ms) over Task 1 (396 ms). Table 14 shows that the only effect approaching significance (p=.06) was that of a trend for overall greater latencies at Cz.

Latency D scores were then calculated by taking the absolute values of the differences between component latencies for each twin pair and again averaging the mean differences of all possible nontwin pairings for each cotwin. An analysis of variance (task 1/task 2, twin/nontwin, Fz/Cz/Pz) was performed for each of the four components (S_1N_1, S_1P_2, S_2N_1, S_2P_3) separately. The only significant effects were that of smaller Ds, or more similarity for twins vs. nontwins at S_1N_1 (F=17.36, (1,7),

Table 14.

Analysis of Variance for Latency (ms) Measures of S_1N_1, S_1P_2, S_2N_1 and S_2P_3 in Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	322	3700691.200			
Task (T)	1	4576.189	4576.1885	1.465	0.248
T X Subject Within Groups	13	40598.7890	3122.984		
Component (C)	3	3419394.500	1139798.120	483.883	0.010 ***
C X Subject Within Groups	39	91865.445	2355.524		
Placement (P)	2	1307.750	653.875	3.100	0.061
P X Subject Within Groups	26	5483.927	210.920		
TC	3	7159.526	2386.509	0.968	0.423
TC X Subject Within groups	39	96165.453	2465.781		
TP	2	400.595	200.297	0.477	0.630
TP X Subject Within Groups	26	10924.404	420.169		
CP	6	1444.635	240.773	1.648	0.144
CP X Subject Within groups	78	11397.023	146.116		
TCP	6	242.262	40.377	0.324	0.923
TCP X Subject Within Groups	78	9732.740	124.779		

* p < or =.05 ** p < or =.01

*** These comparisons represent two N1, a P2 and a P3 component and as such would be expected to be significantly different.

p=.006) (see Table 15) and S_1P_2 (F=8.58, (1,6), p=.03) (see Table 16). There were no latency effects for task or electrode placements when analyzing D scores.

The final analysis undertaken was that of calculating the ratio of Fz/Pz amplitudes for the same previous four components in both Task 1 and 2. This measure evaluated the topography in brain activity on both tasks. None of these comparisons produced any significant results in this instance.

Questionnaire Findings

All twins (N=14), except one, found both tasks interesting and able to keep their attention (see Appendices D and E). None of the subjects found Task 1 difficult, yet exactly half found Task 2 to be more difficult than the first one. The strategies utilized in these guessing games were predominantly some variant of guessing a series of one guess (same or different) followed by an alternation. Several felt there must be some pattern, though this was never even implied, and would often keep the same guess when wrong or alternate when correct. Two individuals guessed in random fashion for Task 1 and three did as well for Task 2.

One suggestive difference between tasks is that 71% of the twins did not keep track of "same" and "different"

Table 15.

Analysis of Variance of S_1N_1 Amplitude Difference (D) Scores in Twin and Nontwin Comparisons for Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	8022.712			
Twin/Nontwin (G)	1	3266.017	3266.017	17.357	0.006**
G X Subject Within Groups	6	1128.995	188.166		
Task (T)	1	27.360	27.360	0.260	0.628
T X Subject Within Groups	6	631.365	105.228		
Placement (P)	2	104.213	52.107	9.34	0.424
P X Subject Within Groups	12	669.232	55.769		
GT	1	12.236	12.236	0.251	0.634
GT X Subject Within groups	6	292.422	48.737		
GP	2	99.985	49.993	0.482	0.632
GP X Subject Within Groups	12	1245.494	103.791		
TP	2	51.854	25.927	2.263	0.146
TP X Subject Within groups	12	137.457	11.455		
GTP	2	106.836	53.418	2.572	0.117
GTP X Subject Within Groups	12	249.243	20.770		

* p < or =.05 ** p < or =.01

Table 16.

Analysis of Variance of S_1P_2 Amplitude Difference (D) Scores in Twin and Nontwin Comparisons for Task 1 and 2 at Electrode Placements Fz, Cz and Pz.

Source	df	SS	MSS	F	P
Within Subjects	77	22866.229			
Twin/Nontwin (G)	1	2552.893	2552.893	8.582	0.027*
G X Subject Within Groups	6	1784.855	297.476		
Task (T)	1	1917.545	1917.545	3.914	0.095
T X Subject Within Groups	6	2939.278	489.880		
Placement (P)	2	439.753	219.877	1.951	0.183
P X Subject Within Groups	12	1352.318	112.693		
GT	1	237.822	237.822	0.309	0.598
GT X Subject Within groups	6	4623.334	770.556		
GP	2	139.772	69.886	1.086	0.366
GP X Subject Within Groups	12	772.366	64.363		
TP	2	147.428	73.714	0.181	0.838
TP X Subject Within groups	12	4891.484	407.624		
GTP	2	2.381	1.190	0.013	0.987
GTP X Subject Within Groups	12	1064.999	88.750		

* p < or =.05 ** p < or =.01

guesses knowing they were equiprobable. On the other hand, 50% of them reported they attempted to keep track of all four categories in Task 2, while 20% only tallied correct or wrong outcomes. Furthermore about half also made additional comments that Task 2 required more concentration, thinking and was more interesting or enjoyable.

Discussion

Summary Pupil Findings

The major finding was that of substantial similarity between MZ twins in both Task 1 and 2. The correct and wrong trials were also very similar for each subject and is not surprising since there is little agreement in the literature as to definitive differences. This supports other findings of no differences between correct and wrong trials in a number of situations (Kuc and Janisse 1976a, 1976b; Friedman et. al. 1973).

The pupil response was analogous for a guess cognitively identified as either correct or wrong. Since there were no differential rewards (Steinhauer 1981) associated with either outcome, perhaps the salience of either event did not differ. Subjects were urged to maximize correct guesses in the initial instructions and in feedback following each block. Furthermore, since the pairs of stimuli were equiprobable, these results are in agreement with Friedman et al. (1973) in not manifesting dilation amplitude differences between correct and wrong trials. Motivational factors were not evaluated or manipulated, however most subjects did display a moderate degree of competitive spirit, especially in wanting to match or exceed their cotwin.

The dilation and constriction slopes also did not show consistent results in any one direction. Headly (1981) had found a steeper recovery slope for correct answers contrary to Levine (1969) who found greater post-peak constriction for incorrect answers.

There was an absence of a statistically significant difference in peak dilation magnitude between tasks. Since the pupil is usually very sensitive to processing demands, the tasks presented stimuli which were easily distinguished and must have been processed in a fairly automatic mode. If larger pupil size is more indicative of increased effort (Kuc et al., 1976a, 1976b), these tasks may provide relatively equivalent structural demands. The effort necessary for performance of both tasks may be the same with a consequent lack of noticeable effects on amplitude, latency and constriction slope.

There are two meaningful explanations for these findings which must be kept in mind. As Sutton (1969) so aptly pointed out subjects have 'options' and no matter how a task is envisioned or presented, in the end the subject decides what use he will make of the information. In accordance with this the task questionnaires did reveal that half of the subjects did not find the second task to be more difficult. Therefore the perception by 50% of the subjects was of greater task demands for Task 2, while the other 50% did not experience a reportable difference. Since the pupil has been shown to be quite sensitive to memory load, effort and attention demands (Beatty 1982; Kuc and Janisse 1976b;

Kahneman et al., 1968), it may be that the tasks as designed using the same stimuli did not provide differential demands or the subjects had the option to disregard or minimize any differences. Perhaps the increased difficulty takes place at the response level, were there are more categories from which to select the appropriate choice. In terms of information content two versus four outcomes only represents one added bit of information. The pupillary dilation response did prove to be largely determined by genetic factors. As with all physiological measures, day to day variations can often be quite large. Yet, seven pairs of monozygotic twins, each tested singly and on two occasions sometimes weeks apart, showed outstanding similarities in their waveforms. In view of all the factors which could have contributed to variations, these results clearly provide support for the familial basis of the pupil response. We have known for some time about the pupil's sensitivity to task demands, but not as to the degrees of freedom available for momentary or strategic fluctuations. It would appear that the pupil in being responsive to cognitive demands is influenced by familial hereditary factors which would depend on physiologically hard-wired mechanisms.

Summary ERP Findings

The twin pairs were statistically more similar when compared to nontwins for the entire ERP waveform, as well as the first half or the second half alone. These latter segments do not directly correspond to early, exogenous components and later more endogenous potentials as the stimuli were tone pairs providing for N1s in both segments. There were, however, only small P3s to S_1 as this tone provided only half of the information or feedback value. The repetitive nature of the task is crucial as the largest P3 amplitudes are obtained with low probability and novel stimuli in contrast to our equiprobable, recurring four possible pairs of stimuli. The P3 obtained in this study accords best with its role in uncertainty resolution, and context updating or closure, which would take place following the feedback or pair of tones. P3 amplitude did reveal much greater variability than any other component in support of its endogenous nature, subject to greater interindividual variation (Donchin et al., 1969; Regan 1972).

Latency was very consistent in both tasks and in all electrode locations. The exogenous components (N1, P2) were not more similar for all subjects as contrasted to the endogenous P3 usually found to be more similar only in MZ twins (Surwillo 1980). However, when twin and nontwin difference (D) scores were analyzed both S_1N_1 and S_1P_2, the earlier components, were significantly more similar for MZ twins. The assumption that exogenous components are more stimuli dependent or physiologically determined would be supported by this greater similarity in the twin pairs.

Electrode Placement Effects

Correlations revealed more similarities at Cz and Pz electrode locations for both twin and nontwin comparisons in Task 1. Task 2 showed the greatest correlations at Fz. This would indicate that Task 1 demands were such that, cognitive processing at Cz and Pz was not as variable for both groups. Task 2, on the other hand, found greater similarities at Fz since by comparison the Cz and Pz placements were more variable perhaps due to differing demands or strategies. This is further supported by amplitude findings which detected less similarity, larger Ds for Task 2. The component analysis also revealed that regardless of task S_1P_2, S_2N_1 and S_2P_3 had much more similar amplitudes at Fz, again the assumption being that Cz and Pz as indicative of central cognitive processing are more subject to interindividual differences. When twin and nontwin differences in amplitude (D) were analyzed, S_2N_1 and S_2P_3 differences were smaller at Fz, that is all comparisons were more similar for these two Fz components. Conceivably, the Fz component values could have been more similar because they were smaller and less variable while the Cz and Pz values being overall quite large facilitated larger interindividual differences.

Task Effects

Task 1 waveforms disclosed more overall similarity than those for Task 2 for both the twin and nontwin comparisons, both when analyzing the whole waveform or only the first half (S_1N_1, S_1P_2). Perhaps a simple task using few processing resources produces little variability between individuals. Though the stimuli were identical, Task 2 produces less similar waveforms due to an individual's unique contribution or allocation of functional resources. The ratio results of Fz to Pz did not show any differences in topography for the two tasks.

Additional support comes from the amplitude differences of S_1N_1 and S_1P_2; the D scores were much larger for both twins and nontwins in Task 2 at all electrode placements. Therefore the amplitude differences were more variable in Task 2. There was, however, no task effect for the raw amplitudes of the 14 subjects. Consequently, the task effect only emerges when contrasting the twins and the mean differences in overall waveform morphology rather than specific component amplitudes. The direct amplitude findings were of larger magnitudes for the first N1 in the stimulus pair and for P3 to the second stimulus. This is hardly astounding as attention was most keenly set for the first stimuli and baseline effects may also reduce the second N1. Furthermore since P3s are always fairly prominent this accords with most descriptions of its role in a final analysis, updating, or closure role in cognitive tasks (Donchin 1981; Verleger 1988).

The most significant ERP findings were the occurrence of striking similarities in cotwin waveforms at all electrode placements and in both tasks. Examination of the raw data surely prompts the notion that these measures are genetically determined. In further analyses greater twin similarities were almost always quite significant.

The present research established convincing support for the presence of a striking degree of similarity in the ERPs of MZ twins performing a cognitive task (Bock 1975). An visual judgment technique requiring naive judges to select the cotwin waveform produced results far above chance. Statistically this was also strengthened by contrasting twins with an aggregate sample mean comparing all possible nontwins.

Monozygotic twins were more similar than nontwins on all measures, except for P3 amplitude. The P3 component has been characterized as a 'terminal aspect of a subject's judgment' (Rohrbaugh et al., 1974) and was expected to evidence more variability, although greater twin similarities were anticipated (Surwillo 1980).

P3 amplitudes did not differ between tasks overall and this may be due to the equiprobability of the stimuli and lack of increase in information actually presented in Task 2 (Hillyard et al., 1971; Tueting et al., 1971; Ruchkin et al., 1975). Polich and Burns (1987) concluded that a low level cognitive task (i.e., target/non-target discrimination) possibly results in greater reliance on neurophysiological structures rather than functional processes which may be more influenced by environmental factors and this may also be the case in this study.

In summary our primary proposition was supported in that the MZ twins were extremely similar on both pupil and ERP measures. Both tasks produced mean waveforms which were matched at greater than chance levels by naive individuals. Surprisingly, the pupil functions did not exhibit a significant task effect while the mean differences between ERP functions did. This might suggest then that ERPs were more sensitive to task demands or some aspect of performance.

Many research findings attest to the physiological effects of experience (Hubel et al., 1959; Held et al., 1963; Cru et al., 1975).Therefore most individuals would possess a unique, personalized functional cortical organization. In MZ twins there would likewise be some degree of freedom for environmentally based changes which would only be parallel if they occurred in some genetically programmed manner.

Vandenberg (1984) asserted that the supposition that equivalent environments contribute to similarities in MZ and DZ twins is no longer justified. The environment would be best viewed as contributing to differences between MZ twins and as such perfect correlations on most factors are never found. In view of recent findings in the area of twin research (Tellegen, et al., 1988), it may be presumed that genetic factors largely determine not only structure and physiology of the brain, but also some functional level of operation which encompasses psychologically defined variables such as intention, strategy, memory, feedback and decision processes. Processes in time may be logical and understandable, but the overriding control of psychological processes in an individual can not be identified, quantified or duplicated, but, if a genetic component is present this adds to our ability to judge it as having a basis in heredity.

Appendix A

Review Information Processing

Information Processing and Structural Models

Numerous models of human information processing have been proposed, albeit with differing emphases. Most assume that stimuli are 'processed' through a series of stages, be they at times serial, parallel or both. The study of selective attention, determining just 'what' gets selected and processed has generated voluminous research as well as numerous theories.

The earliest theories of attention were based on a structural bottleneck model because it was evident that there were severe limits on the number of activities that could be performed simultaneously. One of the marked beginnings of the new cognitive psychology was the proposal by Broadbent (1958) of the existence of a filter which served to block out irrelevant stimuli. Our limited capacity single information channel provided for perceptual analysis of only those stimuli that were attended. The experimental paradigm employed was that of dichotic listening, where the message to one ear is repeated or 'shadowed' while the one heard simultaneously in the other ear is ignored (Cherry 1953; Moray 1959; Duncan 1980). Since some information from the unattended channel did get through, Treisman (1960, 1969) proposed a modification (Filter-Attenuation Model) which presumed only attenuation of unattended information. "Early selection" of input occurs on the basis of simple physical characteristics (e.g., location, pitch, color, size). Attention was synonymous with consciousness; it was viewed as a unitary phenomenon to be allocated in all-or-none fashion in order to regulate what stimuli entered consciousness.

An alternative formulation at that time was Selective Response Theory (Deutsch and Deutsch 1963) which placed the processing bottleneck at the response selection stage of processing. All stimuli were believed to be perceptually analyzed in parallel channels, with selection of the response based on the differential importance of the stimuli (Deutsch et al., 1963; Norman 1968; Lindsay 1967). Response priming and search tasks were the most often used to assess the response bias, with reaction time latency as the measure of interest (Schneider and Shriffin 1977; Posner 1978, 1982). The effects of selective attention were postulated to occur after perceptual processing at the level of short-term memory (Shiffrin 1975).

Modes of Processing - Serial vs. Parallel

A most important development from these attempts to locate the processing bottleneck was the ensuing prominence of the issue of serial versus parallel processing. Unfortunately this seemingly simple question has proven to be quite complex. Sternberg (1966, 1969, 1975) measured the time necessary for a single display item to be compared to a series of items, the memory set, previously committed to memory. Memory set size linearly increased average response time (38 ms/item), therefore a serial comparison process was hypothesized.

On the other hand, Neisser (1963, 1967) found that the time necessary to detect one or several targets from a visual display did not differ. The targets must then undergo simultaneous or parallel search. The apparent impasse is resolved, in this instance, by noting that the tasks are actually invoking different processes and thus different stages; pattern recognition (Neisser 1963) which occurs early after stimulus onset, is largely automatic, parallel and not under strategic control, while the search task (Sternberg 1966) occurs in primary memory, serially and later in the information processing sequence under the subject's control (Lachman, Lachman and Butterfield 1979).

Neisser (1967) elaborated a two-process theory whereby pre-attentive processes monitored unattended inputs for important information, unconsciously using stored information, in contrast to focused attention or consciousness which was the result of full constructive processing.

Modes of Processing - Automatic vs. Controlled

There was an emerging consensus that human performance can proceed in two qualitatively different manners.

Shiffrin (1975) elaborated systemic processing as perceptual, whose stages occurred automatically with or without the person's control. Floods of information were dumped into a short-term or active memory store. By comparison, cognitive processing consisted of control processes, rather than structures, such as scanning, rehearsal, coding and decision making based on short-term memory information (Shiffrin 1975).

A recent and detailed analysis by Schneider, Dumais and Shiffrin (1984) delineates automatic processing as fast, parallel, fairly effortless and not limited by short-term memory capacity or susceptible to direct control. This mode of processing is responsible for performance of well-developed skilled behaviors and evolves when stimuli are processed consistently over many trials. In contrast, control processing is slow, serial, effortful and capacity limited. It is a subject controlled processing mode that is used to handle novel or inconsistent information. The authors furthermore presume that all tasks are accomplished by varying degrees and mixtures of both types of operation (Schneider et al., 1984).

Information and Capacity Models

Automatic processing is determined by structures over which we have little direct control whilst the very term control processing implies effort and attention are expended. When we pay attention we "exert effort" or "invest capacity" (Kahneman 1973) and there are limits on our capacity to do mental work. Kahneman's (1973) capacity model of attention is based on the 'allocation of capacity' which is influenced by the momentary intentions of that person when voluntary selection occurs. The available capacity, although an undifferentiated pool, can be increased by arousal or by effort. The task demands rather than the person's intentions mobilize effort and thereby increase available capacity. The related concepts of arousal and activation will be further clarified at a later time.

The terms capacity, attention, effort and more recently resources are often used interchangeably to denote some limited underlying commodity (Wickens 1984). Resources, having a less ambiguous, connotative meaning, has been widely adopted in the formulation of quite sophisticated theories (Wickens 1980; Norman and Bobrow 1975; Navon and Gopher 1979). One basic assumption is that capacity or resource is a single undifferentiated reservoir and can be used or allocated in graded quantities to all stages of processing or mental operations. Therefore as the demands of one task increase, there are fewer remaining resources for other tasks and performance on these deterio-rates. The experimental paradigm most often employed is that of dual task performance. The degree and type of interference in time-shared tasks is noted as task priority and difficulty are manipulated.

In some instances, task difficulty or demand for resources of one task does not affect performance on the other. As part of a larger theory, Norman and Bobrow (1975) have diagrammed a hypothetical construct (Performance-Resource function) to account for the concept of resource-limited versus data-limited performance. When the quality of the data limits performance, no further improvement is obtained with the investment of additional resources. Bottom-up processing where the actual stimuli are the limiting factor depend on automatic operations. Top-down processing allows for the influences of set, attitude and memory; conceptually driven processes of an endogenous nature.

Perfect time-sharing and difficulty insensitivity mentioned above, both of which among other phenomena can not be accounted for by data limits have induced dissatisfaction with the single resource theory in favor of a multiple resources conception. Performance can often be better justified by speculating a processing system comprised of a number of mechanisms, each having its own capacity or separate resource rather than a central generalized pool of capacity (Kinsbourne and Hicks 1978; Navon and Gopher 1979). The <u>structure</u>-<u>specific</u> capacity is a hybrid conceptualization integrating structural and capacity theories of dual task performance (Wickens 1980). Structural theories inferred attention-related competition of tasks for specific information processing structures, whereas capacity theories regard attention as a processing resource to be allocated and modulated by task demands, in addition to being under some level of cognitive control (Kahneman 1973; Moray 1967; Navon et al., 1979; Norman et al., 1975). Multiple resource theory provides for competition for resources that drive the structures (Wickens 1984) rather than direct competition for structures (Kahneman 1973; Keele 1973).

Kinsbourne and Hicks (1978) proposed that limitations on dual task performance depend critically on the 'cerebral localization of the control centers' involved. They have formulated the concept of "functional cerebral distance" and find this more efficient than even the structure-specific reservoirs of processing. Intertask interference is greatest when neuronally interconnected centers, highly linked 'functional space', are active. This concept of competition for functional cerebral space serves more as a unifying concept rather than specific theory and accords well with a structure-specific capacity view (Wickens 1984).

Controls of Attention - Arousal and Activation

Arousal and activation can be considered controls of a control process, attention. McGuinness and Pribram (1980) distinguish three major physiological systems which account for: the effects of effort or voluntary control on attention, the effects of arousal and the effects of activation or involuntary modes of attention. What follows is further elaboration of their work (Pribram 1971; McGuinness et al., 1980).

Arousal is a phasic or orienting type of response, mediated by the amygdala and involved in generating emotional responses. When the input is surprising, uncertain, novel or complex, that is contains information; momentary cessation of ongoing behavior occurs manifested in alpha-blocking of the EEG and ensuing discrimination and categorization of the input.

Activation is a tonic response, mediated by the basal ganglia and involved in generating motivation. It is the basis for readiness to respond and maintain set to continue ongoing behavior manifested in the CNV (contingent negative variation) (Walter, Cooper, Aldridge, McCallum and Winter 1964; Donchin, Otto, Gerbrandt, and Pribram 1971) of the evoked cortical response and possibly related to reasoning.

Effort is reflected centrally and peripherally as the expenditure of energy, mediated by the hippocampus and involved in coordinating the readiness of the organism with processes which result in their momentary suspension. It modulates maintenance of a particular state when external stimulation is changing or when central control processes are in flux. Emotional processes are hereby delineated from motivational processes, with attention as the common denominator or control process that links both emotion and motivation to cognitive operations.

The work of Kahneman (1973) also finds arousal and effort playing key roles in attention. However, effort is seen as a special case of arousal. Effort is mobilized only by the task demands which in turn increases arousal and thereby the available capacity to deal with that activity. The available capacity and arousal covary at moderate levels of arousal. Activation and arousal continue to be used interchangeably in much of the present literature. Nonetheless, the most often made distinction is that of activation as electrocortical activity or desynchronization and arousal as its behavioral manifestation (Morruzi and Magoun 1949; Lindsley 1960). The ascending reticular activating system (ARAS) modulates electrocortical activation determining behavioral arousal and alerting of enduring persistence as in sleep and waking. The diffuse thalamocortical projection system (DTPS), on the other hand, stems from thalamic areas which elicit recruiting responses that are not long lasting, but transient or phasic increases in arousal and attention (Lindsley 1960).

Higher cortical information processing functions depend on the integrating, activating processes of the brainstem core. Lindsley (1961) further suggested that during EEG desynchronization, low voltage high frequency activity, the neural elements were functionally independent of each other and available to operate as separate information processing channels. In this scheme activation and arousal can both be defined as phasic or tonic in duration, while with Pribram's physiological distinctions activation was tonic as opposed to phasic arousal processes.

This briefest of reviews provides a sense of the multifarious nature of alternative formulations and definitions of hypothetical structures and processes in information processing. There are also limitations in both time and space which pertain to attention (Keele 1973) and as Posner (1975) has remarked "attention is not a single concept, but the name of a complex field of study (p.441)."

Pupillometry and Activation

The pupillary dilation response as an indicator of central nervous system activation, a sign of orienting (Sokolov 1960) has long been known. As a component of the "orienting reflex" (OR), pupil dilation occurs in response to novelty or stimulus change. However, pupillary responses accompany all types of activation as noted by Lowenstein (1920) who stated that dilation of the pupil occurs "with every increase of attention by intellectual processes of every kind, with the beginning of the volitional impulses, or during the course of emotions (p.194)." Significant effects on pupil size were found by inducing muscle tension (lifting weights), fear (threat of gunshot), intense sensory stimulation (loud pure tones), increased attention (novel pictures) and positive or negative affect (pleasant/ unpleasant pictures) (Nunnally, Knott, Duchnowski and Parker 1967).

An important finding has been the absence of fatigue or habituation in pupil dilation to auditory stimuli after several 100 trials (Clynes 1962). Subsequent research has fully substantiated this effect as dilation responses continue to be exhibited over long testing periods with repetitive stimuli. The meaning or significance to the individual of that particular event (Levine 1969) rather than the mere sensory properties determine the response. Habituation is often employed to characterize the OR, therefore pupil dilation must also index other types of phasic activation.

Lowenstein and Lowenfeld (1962) have attributed psychosensory pupil dilation to four mechanisms: active sympathetic pathways to the dilator muscle; or an inhibitory mechanism acting upon the Edinger-Westphal nucleus, the reflex center for constriction; and two adrenergic humoral mechanisms, one adrenal epinephrine, and the other a nonadrenal adrenergic substance (Goldwater 1972).

Because of the complexity of the autonomic nervous system, the pupil, as a reflection of the interplay between sympathetic and parasympathetic systems, is sensitive to a host of factors.

Pupil Dilation and Information Processing

Pupil size reliably reflects mental activity and differentiates among levels of task difficulty. The pupillary dilations which occur during cognitive tasks have short latencies (100-200 ms) and terminate rapidly upon completion of processing or responding. These task-evoked pupillary responses (TEPR's) (Beatty 1982) are best observed when time-locked to the presentation of the stimuli or information to be processed. Bradshaw (1967) illustrated the effect of task difficulty in increasing pupillary diameter using mental arithmetic problems. Peak dilations occurred at the moment of solution followed by an immediate decrease. When no solution was found, or the subject was instructed to maintain attention, pupil size remained at a very high or asymptotic level.

Similarly using a digit span task, a "loading phase" was observed where pupil size steadily increased with each digit read; followed by an "unloading phase" where pupil size steadily decreased with each digit repeated, until the baseline level was reattained (Kahneman and Beatty 1966). Peak dilation, just before responding began, was a monotonic function of the number of digits held in immediate memory. Kahneman et al. (1966) further demonstrated that increasingly greater dilations were displayed for storage of more difficult items from four digits to words to digit transformations (add 1 to each digit). They postulated that the storage of more difficult items required greater processing capacity.

Even simple processes such as perceptual detection appear to exact processing demands. Hakerem and Sutton (1966) believe that pupil dilation discloses the cortical demand for activation necessary to process a detected stimulus, one that is meaningful for the individual. Perceptual discrimination of differences in pitch between two tones also results in larger dilations for the more difficult judgments (Kahneman & Beatty 1967). These researchers urge for more specificity in correlating pupil dilation to various kinds of attention, such as watching for a faint signal, attempting to recall a phone number or doing mental arithmetic.

Data collected by Kuc and Janisse (1976a, 1976b) using a digit span task indicates that larger pupil size is more reflective of greater effort than greater difficulty. The fundamental element is in their evaluation of correct versus incorrect trials which demonstrated that pupil dilation was greater for both input and output phases of correct trials. Incorrect trials, which were presumably more difficult, exhibited smaller pupil size. These findings also concur with others, using children (Boersma, Wilton, Barham and Muir 1970), interpreted as revealing greater effort exerted on the correct trials.

The distinction sought is between the concept of effort, as indicating "processing load" and demands for capacity, with that of difficulty and general arousal. The work of Kahneman and Beatty (1966, 1967; Beatty and Kahneman 1966; Kahneman, Beatty and Pollack 1967) has established the reliability of the pupil dilation curve. Second to second processing demands are precisely mirrored using increasing informational input and thus necessary rehearsal. Sudden shifts in processing load, achieved by a signal to intentionally forget, provide further support for this notion and results in the expected constriction or "unloading" (Johnson 1971).

Kahneman's (1973) model of attention is based on these findings, where pupil dilation as a physiological index of arousal indicates mental effort exerted due to task demands, rather than volition. The dilation ceases once the problem is solved and a response is initiated. The exquisite sensitivity of the pupil to processing strategy is apparent when groups of digits are presented and reported; there is a corresponding wave of dilation and then constriction which gives a clear stepwise or "scalloped" appearance (Kahneman, Onuska and Wolman 1968). A notable point is that the postdilation constriction is theorized to be more than reconstriction or a simple return to baseline.

In his succinct review of task-evoked pupillary responses (TEPR's), Beatty (1982) showed that there was an orderly, logical progression, in absolute magnitude of pupil dilation, across a wide range of quantitatively and qualitatively diverse tasks (e.g., arithmetic, digit span, grammatical reasoning). Less demanding tasks, as rated by independent criteria, produced smaller peak pupil dilations. There also are demonstrable effects of difficulty on the slope of the pupillary response. A steeper dilation slope to more difficult items was found in a study by Kahneman et al. (1966). Although the authors did not explore this finding, a study by Ahern and Beatty (1978) revealed that the recovery slope or constriction showed a fairly rapid return to baseline for easy mental arithmetic problems, while with increasing difficulty there was an absence of recovery within the same time interval; the dilation curve reached an asymptote. Possibly this reflects a momentary capacity limit (Peavler 1974) or at least continued problem solving during the asymptotic phase (Headly 1981).

Using a general knowledge questionnaire, Headly (1981) confirmed that the amount of processing or effort required resulted in differential peak dilation magnitudes. Furthermore, the constrictive process depended on trial outcome with incorrect answers resulting in much less constriction and a leveling off. This same slower return to baseline was also observed between easy and hard conditions with both structural and semantic orienting tasks (Krinsky and Nelson 1981).

Though the effects of information processing on the pupillary response provide reliable dilation patterns, there exists the possibility that other confounding variables may be additionally operating. The autonomic nervous system responds to a variety of influences, some of which may be noncognitive in nature: emotional or motoric processes (Goldwater 1972). Consequently before pupillary reactions can be employed as a dependent variable or measurement tool, we must account fore emotional and response processes which may elicit sympathetic activation.

Pupil Dilation and Emotion

Information processing taking place in the intact functioning human being is vulnerable to perturbations by other concurrent physiological processes. Several studies have evaluated the role of emotional factors in the form of task anxiety. Kahneman, Peavler and Onuska (1968) varied the monetary incentive under two levels of task difficulty and found an increase in peak dilation for the greater incentive only on the easier task. Two possible explanations were provided either; (1) that higher incentive involves more risk and therefore evokes an emotional response which affects pupil size and possibly increases baseline and (2) that high risk trials may elicit greater effort and so a larger pupil response. The authors postulated that the more difficult task required already much effort such that an added incentive provided no benefit, while in the easier task the incentive caused the subject to try harder.

In a paired associate learning task (digit/noun), larger pupil dilations were obtained under a high reward (HR) condition than low reward (LR) with better ensuing recall of the paired nouns (Kahneman and Peavler 1969). Nonetheless the effect was concluded to have been due to effort, not emotionality or arousal, since when the digit was heard alone (even/HR, odd/LR) no differences were evidenced in pupil size until the response or recall phase.

As a test of the hypothesis that pupil dilation may be due in part to anxiety, Peavler (1974) studied information overload using 5,9 or 13 digit strings. If the TEPRs were consequent to fear of performance failure, the largest responses should accompany the last digits in the 13 digit string, as the subject knows that his capacity is being exceeded. Instead a leveling pattern, not due to a ceiling effect, occurred at the ninth digit as if processing effort was suspended and concentration was now on "holding" the digits already stored. Motivation may have played a role as the subjects were told that almost no one could perform the long trials correctly, although they did report sincere attempts, their expectations were nonetheless affected by the instructions (Peavler 1974).

According to Karl Pribram (1967) a strictly neuro-endocrine model or approach to motivation and emotion is insufficient. Our experience constructs neuronal models and sets expectancies, which are cognitive in nature. It is the distribution of excitation that is altered and not strictly amount of activation; this amount of change can be measured as information and uncertainty (Pribram 1971). Emotion expresses the relationship between perception and action, it therefore relates information processing and control mechanisms to an image or plan (Pribram 1967). Jackson Beatty (1977) echoes some of these same concerns in stating that cortical activation is more than simple excitation, for the firing rates remain relatively constant and it is a change in pattern that occurs. The distinction and independence between phasic and tonic activation allows for the discernment of brief more phasic responses to cognitive activity from generally longer lasting tonic emotional arousal (Beatty 1982). Therefore emotional factors should mostly influence basal pupillary diameter rather than the phasic responses themselves.

Another problem that arises when studying mental processes is the possibility that a motor component may be confounded with the cognitive effects. Campos and Johnson (1966, 1967) have reported that both verbalization and preparation to verbalize can consistently increase autonomic activity, while Bernick and Oberlander (1968) have further found that pupillary dilations can be directly elicited by manual, as well as, verbal responses.

In a series of studies on imagery, Paivio and Simpson examined the relationship of overt responses to the magnitude of pupil dilation. Initially pupil dilation was discovered to be greater when mental images were generated to abstract rather than concrete words (Paivio and Simpson 1966). This is consistent with the notion that forming images to abstract words is more demanding and requires more effort (Paivio 1966). Further study showed that the differential effect of abstract and concrete words occurred only when an overt response was necessary; a key press to indicate the image was secured or a verbal description of that image (Simpson and Paivio 1966). Regardless of the response, motor, verbal or none, it was the latency of peak dilation rather than the maximum dilation which was related to word abstractness, with a shorter latency for concrete words (Paivio and Simpson 1968; Simpson, Molloy, Hale, and Climan 1968).

In his review of pupil responses, Goldwater (1972) suggested two explanations for the above findings: (1) the motor responses are directly relevant to the mental task and thereby exert an effect (Simpson 1969) and (2) the motor responses have an effect due to the demand it imposes on the subject to make a decision (Simpson and Hale 1969).

In our attempts to partition cognitive and response factors, caution must be exercised as a third variable may be mediating both effects. For instance, equally large dilations were found in a paired associate task whether the subject responded verbally or merely thought about the answer (Kahneman et al., 1968). Perhaps effort is the variable correlated with any response and not the overt motor component per se. Only if the motor response elements directly modify autonomic activity would we be faced with artifactual data. Thus the validity of the pupillary response is sustained, whether (1) the overt response places additional information processing demands, or (2) affects the task organization or strategy when performed with or without overt responses (Kahneman et al., 1968; Simpson et. al., 1966). More recently Paivio (1973) has reiterated four possible reasons for the augmenting impact of overt responses: (1) the making of an explicit decision, (2) the anticipation of making an overt response, (3) an enhanced level of activation due to feedback from the motor response, and (4) arousal induced by the publicly observable and potentially evaluated nature of the response. Bearing on the issue of anxiety and emotional arousal, evaluation apprehension was found to augment the pupillary response (Simpson and Molloy 1971), although the shape of the pupil response curve consistently reflected cognitive load and task difficulty.

The decision, preparation and execution of a response has been most recently explored in speeded reactions by Beatty's group. In reaction time tasks, a slowly developing response preparation process was recorded with its rate dependent on the length of the foreperiod (Richer, Silverman and Beatty 1983). The portion of the pupillary response indicating response selection was estimated to be 55% of that associated with motor preparation and execution. Movement-related pupillary responses (MRPRs) were evaluated for self-triggered finger flexions and determined to begin 1.5 seconds before the response and peak 0.5 seconds after the response (Richer and Beatty 1985). These latencies are comparable to the response functions evoked by sensory stimuli. Peak pupillary amplitude was res- ponsive to both the complexity (number of flexions) and the force of the movements while the latency was influenced by complexity alone.

These findings indicate that motoric processing alone alters autonomic activity such that increasing requirements are paralleled in the pupil response, just as with perceptual or cognitive demands. It is this aggregate expenditure of processing resources, regardless of the type of task, which is reliably and validly indexed by the pupil.

N1 Component and Selective Attention

Attention as an information processing control system has two aspects (Hillyard, Picton and Regan 1978); an intensive or alerting one, where a general increase in sensory processing capacity occurs (Kahneman 1973) and a selective one where processing improves for one class of stimuli in preference to another. An increase in the intensity of attention or vigilance uniquely enhances the N1 (160 ms) component (Haider, Spong and Lindsley 1964). A large N1 develops in a task requiring an auditory discrimination or decision (Davis 1964). Selective attention to one stimulus channel has also produced a larger amplitude (30-40%) N1 (80-110 ms) to attended ear tones, with a corresponding decrement for unattended ear stimuli (Hillyard, Hink, Schwent and Picton 1973). The attended/nonattended ear differential in several different studies has shown mean increases of 10%, 25%, and 54%, respectively (Wilkinson and Lee 1972; Hink and Hillyard 1976; Hink, Hillyard and Benson 1978) for attended stimuli. Using complex sounds (e.g., "ba", "da"), N1 was found to be a constant sum to stimuli in both ears during divided attention (Hink, Van Voorhis, Hillyard, and Smith 1977).

Furthermore during selective attention, the N1 to the targets in one ear was increased while that of the unattended ear was proportionately decreased.

Hillyard and Picton (1979) interpreted N1 enhancement as an index of 'stimulus set' selection that utilizes only simple physical attributes (e.g., pitch, location) (Broadbent 1970). The N1 effect is strongest with a rapid stimulation rate that insures selectivity, with low and moderate intensity stimuli, with equiprobable stimuli and with both relevant and irrelevant stimuli within a selected channel (Hillyard et al., 1979). More recently Hansen and Hillyard (1980) discovered that N1d latency systematically increased as the seperation between channels decreased. They postulated that it is the duration of processing required to determine which channel a stimulus belongs to, not channel selection itself, and its further processing once judged to be in the relevant channel that account for latency differences. Naatanen (1982) has distinguished between the N1 and an associated negative shift jointly referred to as 'processing negativity'. This negative shift was suggested to reflect orienting and further processing of relevant input and when short interstimulus intervals are used, it may overlap the N1 EP making it appear larger (Naatanen and Michie 1979). The interpretation of N1 as reflecting 'stimulus set' was not disputed as long as based on memory matches of the input.

Auditory N1-P2 Complex

The auditory N1-P2 complex has a broad scalp distribution with an amplitude maximum at the midline just anterior to the vertex. Since stimuli in other modalities result in similar morphologies, they were referred to as the "vertex potentials" in the 1960's and presumed to derive from 'diffuse or non-specific thalamocortical pathways (Wood, McCarthy, Squires N., Vaughan, Woods and McCallum 1984). Vaughan and Ritter (1969, 1970) challenged that assumption when they recorded an inverted N1-P2 over the Sylvian fissure. This finding "was most consistent with dipole sources within the primary auditory projection cortex of the supratemporal plane" (Vaughan et al., 1970). Kooi, Tipton, and Marshall (1971) contested these results and believed the cause of this reversal was due to the use of a nose reference because they and others could not replicate it with a noncephalic reference (Picton, Hillyard and Galambos 1974, 1978; Streletz, Katz, Hohenberger and Cracco 1977). Widespread cortical areas, especially frontal cortex, were concluded to be the source.

The N1-P2 complex is not generated by a single source so both groups are correct in part, with combined temporal lobe and frontal cortex sources the best explanation of seemingly asynchronous, multiple sources (Wood and Wolpaw 1982). Yet the debate still remains as to what extent the vertex potentials manifest a 'neural substrate of information processing' across modalities rather than distinctive, but overlapping modality specific cortical regions (Hillyard, Picton and Regan 1978). Cross-modal interactions occur with a prior stimuli in one modality suppressing the N1-P2 following in another modality by 35-40% (Davis, Osterhammel, Wier and Sjardingen 1972). The N1 component especially indexes the distribution of selective attention among competing sources in a similar manner for all modalities.

N2 Component and Sensory Processing

A modality specific negative component, N2 (200 ms), is evoked when a random change or deviation occurs in a repetitive series of background stimuli. It is the deviation which is essential, for an infrequent stimulus alone is not sufficient for this effect that ensues both with and without attention. Ritter and his associates (Ritter, Simson, Vaughan, and Friedman 1979) found N2 to covary in latency with reaction time and postulated that this component signifies a decision process that regulates the behavioral response once a sensory discrimination is made. The latency of N2 (250 ms), understandably increases from an easy to a hard discrimination, as the decision requires more time (Ritter, Simson and Vaughan 1972; Towey, Rist, Hakerem, Ruchkin and Sutton 1980).

A positive sensory component, P2, frequently overlaps the N2 but can be eliminated using an omitted stimulus paradigm (Simson, Vaughan and Ritter 1976). When the absence of a stimulus is task relevant, it elicits an N2 component. Under these conditions two types of N2 waves have been found; a central N2 (265 ms) and an earlier parietal-occipital N2 (220 ms), yet they are not independent as their onsets and offsets covary. The N220 reflects omission detection and is based on expected stimulus onset while N265 concurrent with the end of the parietal-occipital wave may index orientation. The authors concluded these two components may support a parallel or cascade processing model. (Renault, Ragot, Lesevre and Remond 1982). A consensus exists regarding N2 as manifesting an aspect of the discrimination process (Ritter, Ford, Gaillard, Harter, Kutas, Naatanen, Polich, Renault and Rohrbaugh 1984). Naatanen (Naatanen, Simpson and Loveless 1982) divided N2 into 'mismatch negativity' and N2b since the negative shift has properties of a mismatch detector. It may be associated with the orienting response (OR) (Sokolov 1969; Snyder and Hillyard 1976) and automatic processes not under voluntary control, in contradistinction to 'processing negativity' which is under voluntary control.

In many studies N2 is followed by a P3 component when the aberrant stimulus is attended (Naatanen 1978, 1979; Donchin, Ritter and McCallum 1978; Ford, Roth and

Kopell 1976). The N2/P3 complex may also occur when a change is perceptually obtrusive, but usually depends on the degree of stimulus deviation and the direction of attention. In addition, several stimulus variables can be critical such as; a priori probability, novelty, intensity, and recency of the eliciting stimulus (Rosler 1982). Under passive attention N2-P3 has a smaller amplitude and shorter latency than during active attention (Shiga 1977; Smith, Lell, Sidmen, and Mavor 1973; Hillyard 1971; Sutton, Braren, Zubin and John 1965).

P3 Component and Information Processing

The P3 component originally found by Sutton (Sutton et al., 1965) has the largest amplitude with low probability or more uncertain events. It is observed in a myriad of decision making tasks with a latency that ranges from 250-500 ms, following the presentation of relevant information. The functional role of P3 has been variously described as that of uncertainty reduction or information delivery (Sutton 1967), task relevance (Donchin 1976), stimulus salience (Jenness 1972; Paul and Sutton 1972), generalized arousal (Naatanen 1975), orienting response (Ritter, Vaughan, and Costa 1968), and subjective probability (Roth 1973).

In all modalities the maximum amplitudes are recorded at central and parietal scalp regions. The work of

Hillyard and his colleagues (Hink, Hillyard, and Benson 1978) dissociated channel selection (N1 effect) from within channel selection. Only the targets in the attended ear elicited a P3, therefore the interpretation of P3 was made in terms of a 'response set' mode of selective attention (Broadbent 1971; Hillyard and Picton 1979). In contrast to the stimulus set mode (N1), all stimuli are first analyzed and the response is uniquely selected (i.e., target/ nontarget) (Deutsch et al., 1967; Norman 1968). When the absence of a stimulus is task relevant, the omission also results in a P3 (Klinke, Fruhstorfer and Finkenzeller 1968; Ritter et al., 1968; Ruchkin, Sutton, Munson, Silver and Macar 1981). Response set is a subsequent processing stage where sensory information is matched to templates or models in memory; it facilitates the recognition of important signals (Hillyard et al., 1973).

More recently the trend has been to search form more than one type of P3 (e.g., P3a, P3b, P3 visual frontal, P3 go/nogo task, P3 vertex) (Tueting 1978). A P3a (240 ms), evoked while 'ignoring' low probability stimuli, has an early latency, small amplitude and frontocentral maximum. A P3b (350 ms), evoked while attending low probability stimuli, has a longer latency, larger amplitude and a centroparietal maximum (N. Squires, Squires and Hillyard 1975; Ford 1978; Roth 1973). Passive attention or orienting

(N2/P3a) is differentiated from an active attention or response set mode (P3b). In information processing terms automatic versus controlled processes are being evaluated (Neisser 1967; Posner and Snyder 1975; Schneider and Shiffrin 1977).

The specific role or element of stimulus evaluation indexed by P3, such as initial sensory processing, comparison with memory, target identification or response selection and organization, has not been unequivocally confirmed thus, interpretations differ. However, there is some agreement that N1 and P3 effects represent hierarchically organized, sequential processing stages (Hillyard et al., 1973; Hink et al., 1978; Schwent, Hillyard and Galambos 1976; Schwent, Snyder and Hillyard 1976). P3 reflects "some terminal aspect of a subject's judgment" (Rohrbaugh, Donchin and Eriksen 1974) and its emission follows higher level processing with identification requiring rather full analysis and comparison to relevant patterns (Friedman, Simson, Ritter and Rapin 1975; Kutas and Donchin 1980; Courchesne, Hillyard and Galambos 1975). Discrimination difficulty can increase P3 latency and associated reaction time (Ritter, Simson and Vaughan 1972) but, P3 amplitude and latency have not shown consistent correlations with reaction time data. For instance, reaction time has even preceded the occurrence of P3 (Ritter et al., 1972); the assumption must therefore be that no causal link exists between this component and response selection specifically (Karlin, Martz and Mordkoff 1970, 1973; Squires, Wickens, Squires and Donchin 1976).

If P3 was indeed a concomitant of stimulus identification it should be completed before the response, while if it is a process related to 'contextual updating' (Pribram and McGuinness 1975) with implications for future responses and not the present one, then there is no need for a relationship between P3 amplitude and latency with reaction time (Squires et al., 1976). Context updating is a process of memory revision and is a useful concept as applied to the P3. Donchin (1981) elucidates the role of P3 as being associated with the updating of schemas which are the long-term memory representations of all available data about our environment. When new information is received it is incorporated into the existing reservoir of information as needed. This idea is also consonant with the fact that the largest P3s are evoked by rare, relevant stimuli since they would mandate a revision of the neuronal model (Donchin 1981).

A related concept views P3 as indicative of 'strategic information processing' rather than 'tactical information processing'; the evaluation of ongoing strategies using feedback information such that the timing of P3 depends on 'processing time' to identify strategically relevant information (Kutas and Donchin 1979; Kutas, McCarthy and

Donchin 1977). Tactical information processing reflects processes involved in response selection while strategic processing occurring in parallel involves the assessment of priorities, probabilities and attention deployment (Donchin et al., 1978). The sensitivity of P3 to probability is consonant with the notion that low probability or rare events result in a greater need for readjustment (Donchin 1978). P3s are obtained to stimuli giving feedback on guessing outcome or discrimination accuracy which entail reassessment of relative probabilities and the costs of subsequent decisions. Posner and Snyder (1975) assess the occurrence of P3 directly as cost versus benefit, as it indicates the commitment of the central processor. Controlled rather than automatic processing invokes a processor with broad capabilities to perform any decision or cognitive task and this endogenous cortical process is revealed by the P3 component (Smith, Donchin, Cohen and Starr 1970).

The functional characterization of P3 is not the only source of debate, indeed component overlap, the most troublesome problem encountered, makes physical characterization of ERPs complicated at best. The P3 component coincides with the 'resolution' of the contingent negative variation (CNV) (Walter et al., 1964) with both occurring in similar experimental manipulations (Donchin and Smith 1970). In addition the 'resolution' of P3 corresponds to the late slow wave (SW) which may influence P3s amplitude and return to baseline (N. Squires et al., 1975).

CNV, BP and Preparation

The contingent negative variation (CNV) is best elicited during the interval between two stimuli, the first serving in effect as a warning stimulus when there is an intention to respond to the following imperative stimulus (Hillyard and Galambos 1967). It has been pointed out however that a motor response is not necessary and that mental preparation to make any response is the primary psychological correlate of the CNV (Low, Borda, Frost and Kellaway 1966). This slow negative shift begins about 400 ms after the warning stimulus and has an amplitude maximum at the vertex; it ends following the imperative stimulus whether a mental or motor task is required, the indispensable element is for some action to be taken by the subject (Donchin, Ritter and McCallum 1978). Hillyard (1973) enumerates four types of effective CNV paradigms as: (1) holding a motor response in readiness (2) preparing for a perceptual judgment (3) anticipation of reinforcement, positive or negative and (4) preparing for a cognitive decision.

The psychological processes presumed to coincide with the CNV range from expectancy (Walter et al., 1964), conation (i.e., intention to act, Low et al., 1966) motivation (Rebert, McAdam, Knott and Irwin 1967) and attention (McCallum 1969; Tecce 1970,1971). Tecce (1972) proposes a two process model, where the magnitude of the CNV is positively and monotonically related to attention and has an inverted-U relationship to arousal.

A motor specific component, the 'Bereitschaft potential' (BP) or 'readiness potential' (RP) has been delineated from the CNV (Deecke and Kornhuber 1977). The BP or RP also precedes planned action or movement, but only when self initiated and is therefore not controlled by external signals. The BP is much smaller in amplitude than the CNV, though it also has a widespread distribution with a maximum at vertex. In preparation for self initiated movement, the BP has a rise time of three or more seconds, .5 to 1 second preceding the motor response and with a clear asymmetry contralateral to the responding limb (Kutas and Donchin 1974, 1977; McCallum 1979).

Both of these preparatory potentials, the CNV and BP, have been partitioned into additional subcomponents with little increased explanatory power at this time (Rorhbaugh et al., 1976; Gaillard 1976, 1978; Deecke 1978; Vaughan and Ritter 1970; Rorhbaugh and Gaillard 1983).

Slow Wave and P3

On the other side temporally and coincident with the termination or resolution of P3 is the extended slow wave (SW). Slow wave begins 200-300 ms after stimulus onset with a maximum at 500-700 ms; it has a distinctive scalp distribution being positive-going at parietal sites and negative-going at frontal sites. Normally SW is not present at the vertex, but during guessing tasks it has been found to be substantially positive (Roth, Ford, and Kopell 1978; Ruchkin, Sutton, Kietzman and Silver, 1980b). SW is elicited by task relevant and uncertain events just as P3 and has been suggested as a correlate of further processing or mobilization of effort (Ruchkin et al., 1980; Friedman, Vaughan and Erlenmeyer-Kimling 1981).

This slow negative or positive shift may cause amplitude differences erroneously attributed to P3, so caution is necessary in assessing these late endogenous components (N. Squires et al., 1975). For example, using an oddball paradigm, P3 exhibits a more anterior distri- bution than the P3 to a significant missing stimulus, leading to the speculation that more than one ERP generator might be involved (Simson, Vaughan, and Ritter 1977). The differential contribution of SW (i.e., negative frontally, positive parietally) in such cases must be evaluated (Woods et al., 1984). Vaughan (Friedman et al., 1978) promotes the term, 'late positive complex', as more appropriate then speaking of P3 and its overlap with positive SW as independent components. Fitzgerald and Picton (1981) have further suggested that the frontally negative portion may be a separate component from the parietally positive one. There have been attempts to categorize SW as either phasic or tonic (Ruchkin, Sutton and Stega, 1980a). At present these conjectures merely complicate the search for functional correspondents of ERPs. For now, Ruchkin's designation of P3 as the intermediate stage of event evaluation common to many judgment tasks and SW as the ensuing final evaluation dependent on the complexity of judgment, appears a good beginning (Ruchkin et al., 1980, 1983).

ERPs - Information Processing or Arousal Modulation

For all components reviewed one or more, usually more, psychological correlates or functional definitions have been postulated. Unfortunately, psychological constructs usually fail to narrowly outline the specific process in question. Two adamant critics of these proffered explanations have been Naatanen and Karlin, who propose some adaptation of the arousal/activation hypothesis to account for most ERP findings.

Naatanen (1970) asserts that even under conditions of random stimulus presentation, in the selective attention paradigm of attended versus nonattended stimuli, the presentation rate is fairly regular and can be anticipated resulting in differential arousal. In some of his own findings, increased nonspecific cortical activation, a reduction in EEG amplitude, was observed before the relevant stimuli only. The irrelevant stimulus serves as a warning stimulus and triggers a state of general alertness "as an anticipatory and preparatory action to a relevant stimulus" (Naatanen 1967, p.46). The physiological basis for these changes have been known for some time and depend on the ascending reticular activating system (ARAS) and diffuse thalamocortical projection system (DTPS) (Lindsley 1960).

Karlin (1970) similarly interprets the enhancement of ERPs as (a) development of preparation before and/or (b) a reactive change in pre-established states of preparation, readiness or alertness after the stimulus. Since many trials are used in almost all paradigms, Karlin makes the case that learning can take place which establishes cycles of readiness. The second version of the hypothesis can basically explain any finding as the reactive change may be a decrease or increase in arousal or alertness following a stimulus.

For instance, in the Sutton et al. (1965) finding of P3 amplitude dependent on stimulus probability, since differential preparedness was not possible, a larger error rate for low probability events was postulated to result in a reactive change (Karlin 1970). Naatanen (1975) explains P3 as a case of 'generalized arousal'. Most researchers would agree with the characterization of the CNV as a pre-stimulus state of the subject; an index of cortical activation in general, without cognitive components in the most extreme form (Naatanen 1967; McAdam et al., 1969). Nonetheless, there is much disagreement as to whether P3 is specific to information processing or rather simply a termination or resolution of a general pre-stimulus state of arousal and attention (Naatanen 1975; Karlin 1970; Wilkinson and Lee 1972).

A more moderate position can include both arousal and cognitive components, where P3 may represent phasic arousal related to the consequences of making a decision or the conscious awareness of the outcome of that decision (Simson et al., 1976). P3 has been found to depend on passive and active attention plus a coincident reactive change (Shiga 1977).

Norman (1979) concisely described the problems with an information processing model as our inability to 'track detailed operations in time' using transient, gross changes in state indexed by ERPs. At best only the time of initial activation of a group of neuronal structures may be recorded. Our search for physiological correlates of hypothetical psychological processes often leads us astray when the findings are either negative or complex.

Donchin (1979) has continued to reiterate that the "important point is that an ERP component is not a 'correlate' of some diffuse psychological state variable but is rather a manifestation, at the scalp, of neuronal activity which plays a certain role in the informational transactions of the brain (p.32)."

APPENDIX B

TASK 1

GUESS	TONES		RESULT	OUTCOME
SAME	HI/HI	LO/LO	SAME	CORRECT
DIFFERENT	HI/LO	LO/HI	DIFFERENT	CORRECT
SAME	HI/LO	LO/HI	DIFFERENT	WRONG
DIFFERENT	HI/HI	LO/LO	SAME	WRONG

TASK 2

GUESS	TONES	RESULT	OUTCOME
HIGH	HI/HI	WIN CONFIRMED	CORRECT
HIGH	LO/HI	LOSE CANCELLED	CORRECT
LOW	LO/LO	WIN CONFIRMED	CORRECT
LOW	HI/LO	LOSE CANCELLED	CORRECT
HIGH	HI/LO	WIN CANCELLED	WRONG
HIGH	LO/LO	LOSE CONFIRMED	WRONG
LOW	LO/HI	WIN CANCELLED	WRONG
LOW	HI/HI	LOSE CONFIRMED	WRONG

Appendix C

TWIN QUESTIONNAIRE

NAME ______________________________ AGE _____ SEX______

OCCUPATION ________________________ MARITAL STATUS ______

PRESENT RESIDENCE____

WE WOULD LIKE TO HAVE INFORMATION REGARDING SIMILARITY BETWEEN YOU AND YOUR TWIN. PLEASE DO NOT DISCUSS THE POINTS WITH HIM OR HER BEFORE ANSWERING THE QUESTIONS.

PLACE A CROSS (X) IN THE SQUARE APPLICABLE

WERE YOU AND AND YOUR TWIN MIXED UP AS CHILDREN ?

[ ] YES -------> IF "YES" [ ] PARENTS [ ] TEACHERS
[ ] NO WHO MIXED [ ] BROTHERS & SISTERS
YOU UP ? [ ] OTHER PEOPLE
[ ] CANNOT REMEMBER

WAS IT NECESSARY FOR YOUR FAMILY TO USE SPECIAL SIGNS (BIRTH MARKS, DIFFERENTLY COLORED RIBBONS, DIFFERENT CLOTHES ETC.) IN ORDER TO TELL YOU APART ?

[ ] YES [ ] NO [ ] CANNOT REMEMBER

WHAT COLOR ARE YOUR EYES AND THOSE OF YOUR TWIN ?

MY OWN

[ ] BLUE [ ] GREY [ ] LIGHT BROWN
[ ] DARK BROWN [ ] OTHER COLOR

MY TWIN'S

[ ] BLUE [ ] GREY [ ] LIGHT BROWN
[ ] DARK BROWN [ ] OTHER COLOR

Appendix C (cont)

WHAT COLOR HAIR HAD YOU AND YOUR TWIN AS CHILDREN ?

MY OWN

[ ] BLONDE [ ] ASH BLONDE [ ] BROWN [ ] BLACK [ ] RED

MY TWIN'S

[ ] BLONDE [ ] ASH BLONDE [ ] BROWN [ ] BLACK [ ] RED

WHEN GROWING UP, WERE YOU AND YOUR TWIN "AS ALIKE AS TWO PEAS IN A POD" OR ONLY OF ORDINARY FAMILY LIKENESS ?

[ ] "AS LIKE TWO PEAS" [ ] "ORDINARY FAMILY LIKENESS"

[ ] "DO NOT KNOW"

UNTIL WHAT AGE DID YOU AND YOUR TWIN LIVE TOGETHER (WITH YOUR PARENTS OR SHARING A HOME)?________________________________

WE LIVED TOGETHER UNTIL THE AGE OF ________ YEARS

HAVE YOU LIVED ALL YOUR LIFE IN A BIG CITY, SMALL TOWN OR COUNTRY DISTRICT ?

I HAVE LIVED IN

[ ] BIG CITY ALMOST ALL MY LIFE
[ ] SMALL TOWN ALMOST ALL MY LIFE
[ ] COUNTRY DISTRICT ALMOST ALL MY LIFE
[ ] ABOUT THE SAME NUMBER OF YEARS IN TOWN AND COUNTRY

PLEASE GO THROUGH THE WHOLE FORM ONCE AGAIN TO CHECK THAT YOU HAVE PUT A CROSS FOR YOUR ANSWER TO EACH QUESTION AND THAT NOTHING HAS BEEN OMITTED

Appendix D

TASK 1 **DEBRIEFING QUESTIONNAIRE**

NOW THAT YOU HAVE FINISHED THIS TASK, WE WOULD LIKE TO ASK YOU A FEW QUESTIONS TO HELP US UNDERSTAND WHAT YOU THOUGHT ABOUT IT.

1) HOW DID YOU FIND THIS GUESSING TASK: ___ BORING
___INTERESTING ___ OTHER
____

2) DID YOU FIND THE GAME DIFFICULT ?____________________

3) WERE YOU ABLE TO KEEP YOUR ATTENTION ON THE TASK ?__________

4) DID YOU BEGIN TO ANTICIPATE WHEN THE TONE PAIRS WOULD OCCUR ? ______________________________

5) WHAT WAS YOUR STRATEGY FOR TRYING TO GET MORE CORRECT GUESSES ?______________________________
____

(FOR EXAMPLE: DID YOU SWITCH GUESS AFTER YOU WERE WRONG OR KEEP IT THE SAME KNOWING THAT IT SHOULD COME UP ?)

6) DID YOU TRY TO KEEP TRACK OF YOUR GUESSES KNOWING THAT HALF SHOULD BE "SAME" AND HALF SHOULD BE "DIFFERENT" ?
____

7) DO YOU HAVE ANY COMMENTS ABOUT ANY PART OF THIS TEST ?
____
____
____

Appendix E

TASK 2 **DEBRIEFING QUESTIONNAIRE**

NOW THAT YOU HAVE FINISHED THIS TASK, WE WOULD LIKE TO ASK YOU A FEW QUESTIONS TO HELP US UNDERSTAND WHAT YOU THOUGHT ABOUT IT.

1) HOW DID YOU FIND THIS GUESSING TASK: ___ BORING
___INTERESTING ___ OTHER
____

2) DID YOU FIND THE GAME MORE DIFFICULT THAN THE FIRST ONE?___

3) WERE YOU ABLE TO KEEP YOUR ATTENTION ON THE TASK?__________

4) DID YOU BEGIN TO ANTICIPATE WHEN THE TONE PAIRS WOULD OCCUR?__________________________________

5) WHAT WAS YOUR STRATEGY FOR TRYING TO GET MORE CORRECT GUESSES?________________________________
____
(FOR EXAMPLE: DID YOU SWITCH GUESS AFTER YOU WERE WRONG OR KEEP IT THE SAME KNOWING THAT IT SHOULD COME UP ?)

6) DID YOU TRY TO KEEP TRACK OF YOUR GUESSES KNOWING THAT; "WIN CONFIRMED", "LOSE CANCELLED" WERE "CORRECT" AND "WIN CANCELLED", "LOSE CONFIRMED" WERE "WRONG" OR DID YOU KEEP TRACK OF THE CATEGORIES SEPERATELY?__________________
____

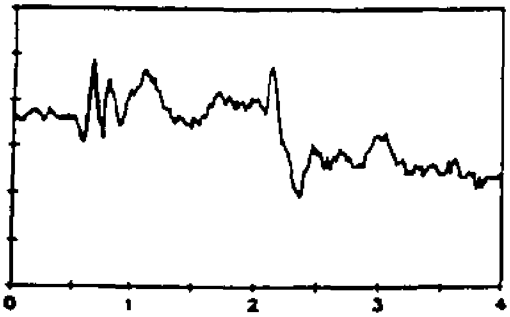
7) DID YOU REALIZE THAT HALF OF YOUR GUESSES SHOULD HAVE BEEN "HI" AND HALF "LO"?_____________________________

8) DO YOU HAVE ANY OTHER COMMENTS ABOUT ANY PART OF THIS TEST?____________________________________

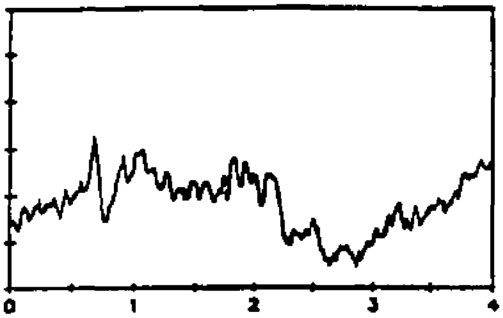
Appendix F

EXAMPLE OF MATCHING TO SAMPLE TASK

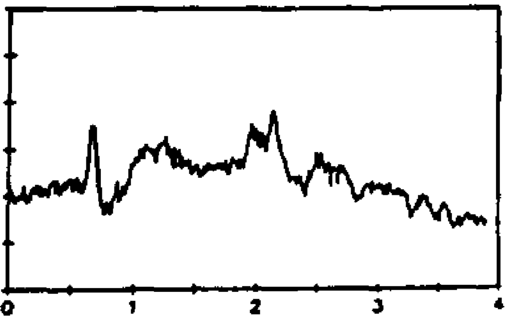
2.



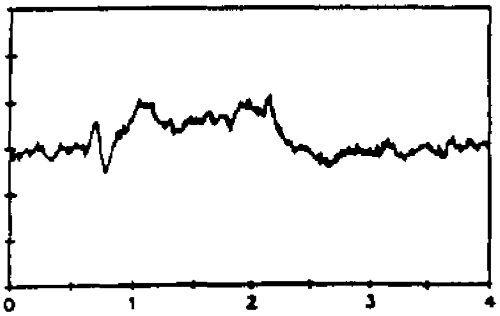
A.



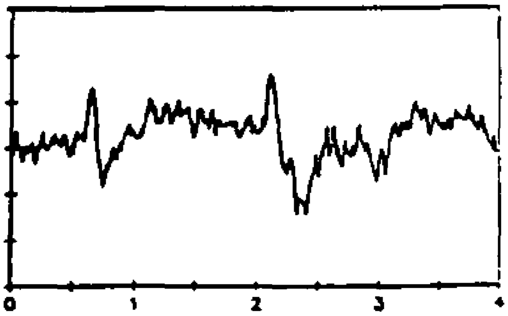
B.



C.



D.



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