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Event-Related Potentials and Electroencephalograms in Adaptive Operator Training: Rationale and Annotated Bibliography

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13. ABSTRACT *(Maximum 200 words)*

This report presents summaries of research on physiological metrics of learning and memory, task performance, attention, imagery, mental workload, and adaptive training. The focus of the report is on the potential for physiological metrics such as electroencephalograms and event-related potentials to serve as control variables in adaptive operator training. An adaptive training system could use such variables to adapt the frequency and difficulty of training so as to accelerate learning and enhance transfer of training to real-world environments.

This report also describes problems in learning and performance of Navy tasks that call for research on adaptive operator training. Such problems include the complexity of current combat systems, individual differences in learning strategies and ability, and poor transfer of training using conventional training methods. An example of how adaptive training could apply to Navy training is developed for the emitter classification task performed by Navy electronic warfare operators.

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Foreword

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J. C. McLACHLAN
Director, Training Research Department

Summary

The concept of using physiological metrics such as electroencephalograms (EEGs) and event-related potentials (ERPs) to infer psychological processes involved in learning has been the subject of many studies since the early 1960s. However, to our knowledge, this report is the first attempt to collect and summarize studies that focus on the potential relevance of physiological metrics to adaptive training.

This report has four goals. The Introduction addresses the first three goals. First, we define problems in learning and performance of Navy tasks that call for improved methods of training to accelerate learning and enhance transfer of training to real-world situations. Second, we introduce the concept of adaptive training in which the frequency and difficulty of training interventions may be adjusted using inferences about psychological processes from EEG and ERP measures. Third, we discuss the technical and scientific background issues that support the concept of EEG- or ERP-based adaptive training. The technical issues include, for example, the types of tasks for which such training may be appropriate and the optimal time course of demands placed on a trainee during training. The scientific issues include evidence that EEG and ERP measures can provide information about psychological processes, including mental workload, memory encoding, retrieval from long term memory, memory representations, attention, and imagery. Fourth, in the Annotated Bibliography we present a collection of summaries from articles and reports that bear on the range of issues discussed in the Introduction. These summaries are divided into four groups: (1) ERPs, learning, and memory; (2) EEG states in learning and task performance; (3) ERPs and cognition: attention, imagery, and mental workload; (4) adaptive training.

Contents

Introduction

Problem

Combat system operators are technicians who perform critical defensive functions such as surveillance, threat recognition, electronic countermeasures, course change recommendations, and chaff launching. Although peace-time operations are often slow and uneventful, operational exercises and conflict situations can be fast-paced and life-threatening. Under such conditions, operators are susceptible to information overload, which may be aggravated by stress and fatigue and which may lead to serious errors or accidents.

Objective

Recent research in cognitive neuroscience suggests that real-time monitoring of alertness, attention, workload, and cognitive processing may be aided by analysis of event-related potentials (ERPs) and the electroencephalogram (EEG). Changes in cognitive variables that occur during learning are also reflected in components of task-relevant ERPs and in EEG spectra.

The Navy Personnel Research and Development Center (NAVPERSRANDCEN) is proposing to examine ERP and EEG effects as adaptive variables for controlling operator training. The annotated bibliography of this report collects and presents developments in psychology and cognitive neuroscience that are relevant to adaptive training. The bibliography focuses on (1) ERPs, (2) states in learning and task performance, (3) ERPs and cognition, and (4) adaptive training.

Approach

The Navy must take reasonable measures to ensure that operators can continue to be effective under demanding conditions. One approach is to improve the hardware and software in the combat systems themselves. However, system upgrades will come slowly during the defense drawdown, which has already begun.

Adaptive operator training is a dynamic process in which interactive training systems adjust the frequency and difficulty of instruction according to the learning style and current ability of a trainee. In manual control tasks, research has shown that acquisition and transfer performance may be related to adaptive parameters of the training system (Ricard & Norman, 1975). For more complex tasks, adaptive training may serve as an alternative approach towards ensuring that operators will function adequately under demanding operational conditions. This alternative involves lower cost and risk than system upgrades and can take advantage of new methods from cognitive neuroscience for improved training effectiveness. These methods can be applied to the development of training systems that adapt to individual rates of skill acquisition. Such systems could produce a high level of initial training in a minimum amount of time by tracking the time course of skill development at the individual trainee level.

In adaptive training, a computer would collect and manipulate information about trainees during the training process. Two types of information will be collected: (1) information about the strategies and knowledge structures trainees use to perform a task, and (2) information about when trainees develop these strategies and knowledge structures. The approach would be inferential. Combined performance measures and measures of brain electrical activity would be used to infer strategies and knowledge structures during training, which would be used to adjust training time and difficulty. In addition, the duration and intensity of exposure to overload conditions during training would be varied to determine which sequences produce good transfer of training to operational conditions. The techniques developed may also be used to measure the effectiveness of existing training materials.

Technical Background

The basic tasks required of combat system operators are not inherently complex. However, complexity arises from the need to identify and integrate information from many sources at once. The emergence of this complexity can be seen in the following example from electronic warfare (EW) operations.

When an EW operator detects a single new radar emitter on his system console, he needs to decide whether it is coming from a friend, a foe, or a neutral platform and then act accordingly. To make this decision, he checks a database to see if the key parameters of the unknown emitter match those of known platforms. If an unambiguous match is found, the classification is straightforward.

This simple emitter classification task becomes more complex and error-prone when several emitters appear at once. Then, the operator must prioritize and sequence through the emitters. For a small number of emitters, he may keep the chosen sequence in working memory, updating it as he deals with each one and as new ones arrive. However, limitations on attention and working memory (Baddeley & Hitch, 1974; Miller, 1956) will lead to neglected emitters and forgotten sequences when operators are faced with several new emitters at once. Exceeding the "bottleneck" of attention and short-term memory may be characterized as *information overload* (or simply, overload). Research at NAPVERSRANDCEN has shown that as few as three new emitters appearing simultaneously can lead to overload in some EW operators (Trejo, Kramer, & Humphrey, 1992). The number of emitters that produces overload will be reduced further when the operator is tired or under combat stress.

Finally, emitter classification is rarely straightforward. Instead, operators must often choose one platform from a list of close, but inexact, matches in a database. Operators must relate the platforms in the list of close matches to other sources of information, such as intelligence reports and past experience, in order to choose the most likely candidate. These associative requirements induce additional short-term memory load, further reducing the number of emitters the operator can deal with simultaneously. In addition, the preceding example assumes that operators always make good decisions when unambiguous information is present, which is not generally true. Some errors of classification are due to response biases that develop during operations. Other errors are due to faulty basic skills, such as confusion of symbols or emitter parameters.

Replacements or upgrades of systems used by combat system operators will be minimal in the next 10 years. Some small-scale interface and software improvements may occur in 10 years, but it is unlikely that overload problems will be eliminated. Adaptive, intelligent interfaces could reduce overload, but such systems will not be available in the next 10 years. Furthermore, system improvements will not prevent errors due to response biases and inadequate basic skills.

In the near term, revising and extending basic and operational training could lower the probability of overload. Research at NAVPERSRANDCEN with EW operators has shown a wide range of individual differences in the performance of EW training exercises (Trejo, Kramer, & Humphrey, 1992). Novice or less experienced operators show overload-related performance decrements under conditions where expert operators continue to perform well. In addition, measures of brain function such as ERPs show clear differences between the way the brain processes information during normal and overload conditions. ERP signals from individual operators also vary considerably, indicating a wide range of processing capacity among operators. These observations suggest that experts develop a greater capacity to process task-related information than novices. This capacity may be inferred from performance under different levels of difficulty and confirmed with measures of brain function.

Scientific Background

Recent developments in cognitive science suggest that task performance may be evaluated on a continuum. When tasks are being learned or are inherently difficult, performance is purposeful, slow, deliberate, and under attentional control of the trainee. This type of performance is characteristic of tasks that produce heavy working memory or attentional loads. However, learning and practice may lead to deeper representations of task information and procedures, which simplify performance greatly.

For example, recognition of complex objects or patterns in a task such as EWs perform may depend on the development of cognitive knowledge structures such as associative networks or schemata (Morton & Bekerian, 1986). In associative networks, basic concepts are represented by nodes and the relationships between the concepts are represented by links between the nodes. Learning a complex object or pattern involves forming the nodes and reinforcing the links. Once learned, activation of any node, such as by seeing one of several features of the pattern, may lead to activation of the entire network. Depending on the strength of the links, some nodes may be more effective in leading to activation of the entire network.

Associative networks could be the basis for some EW expert-novice performance differences. For example, basic emitter attributes such as frequency, bearing angle, pulse-repetition interval, and platform type could be the nodes of an associative network. The congruence of particular values of these attributes would form specific instances of learned emitters. In expert operators, strong links between congruent features would lead to fast, automatic recognition of emitters. In novices, weaker or nonexistent links would force slower, serial searches through the database of emitters and lead to overload at low emitter densities.

The concept of a schema may also help to explain EW expert-novice performance differences. Schemata are unique knowledge structures which represent past actions and experiences. A schema does not necessarily represent a specific experience; instead, it is a generic prototype for stereotypical, scriptal experiences or actions (e.g., cashing a check, setting the table). Specific, fragmentary memory traces of past events are linked in some order to form an abstract schema. Schemata are always receptive to relevant sensory information and become activated when the information is received. Although several schemata may be activated, the one that offers the best match to the information being processed can switch off its competitors, leaving a single active framework for interpretation.

An example of a schema in EW operator performance is provided by the sequence of multiple "false contacts" caused by a "fly by" (a close, high speed pass over a ship) of certain aircraft. Having learned this schema through experience, the expert will recognize the sensory input as a single moving aircraft. The novice who has not yet formed this schema may interpret the contacts as a squadron of aircraft. For the expert, processing of this schema can be a fast, automatic recognition process, which involves low attentional and working memory demands. For the novice who does not recognize the pattern, processing would be slow, serial, and attentionally controlled.

The development of knowledge structures such as associative networks and schemata through training will reduce attentional and working memory demands of combat system operators. However, the time course of this development may not be apparent from simple measures of performance. For example, measures of classification accuracy for EW operators do not tell us what strategy or type of processing they use. Slower, attentionally controlled processing may lead to the same accuracy as that obtained through recognition of schemata or activation of associative networks. In simple laboratory tasks, measures of response time are used to distinguish between controlled and automatic processing styles. However, response times may be of less value in tasks, such as those the EW operator performs, where long response times are common or immediate responses are not always required.

Research on the physiological mechanisms involved in learning and memory has shown that the frontal cortex of the brain is activated when memorized information is used in the performance of a task. In a recent study (Squire et al., 1992), subjects were trained to memorize a list of English words and were then instructed to recall words aloud. Using positron emission tomography, cerebral blood flow to the right prefrontal cortex and the right hippocampal region increased during the memory recall task compared to flow during a baseline task in which subjects formed words at random from the word stems. Other research, using ERP methods, has shown that a negative voltage develops in the electric field over frontal and central areas of the scalp during recall and recognition of letters, words, pictures, and faces (Friedman, 1990a, 1990b; Mecklinger, Kramer, & Strayer, 1992; Noldy, Stelmack, & Campbell, 1990; Ruchkin, Johnson, Canoune, & Ritter, 1990; Ruchkin, Johnson, Mahaffey, & Sutton, 1988; Wijers, G. Mulder, Okita, & L M. J. Mulder, 1989). These voltages, known as *negative slow waves (NSWs),* increase with the amount of information stored in memory (memory load).

Data from a 1990 study performed by NAVPERSRANDCEN at the Naval Air Development Center, Warminster suggests that the voltage of NSWs increases during practice. Subjects (test pilots) viewed geometric symbols on a cathode-ray tube, decoded them into memorized numeric values, added a subset of these numeric values, compared the sum with a target value, and pressed one of two keys to signal that the sum was either more or less than the target value. ERPs elicited by the onset of the geometric symbols and were recorded over a half-hour session of task performance. Subjects were asked to return a week after the first session for a reliability retest. Response accuracy in the second session was about the same as in the first session but response time was about 10% faster. No obvious changes occurred for early components of the ERP (e.g. P1, N1, P2), but the voltage of a late (500 to1500 ms) frontal NSW was noticeably larger in the second session than in the first.

One explanation for these between-session differences is that subjects converted the computational problem into one of recognition through development of knowledge structures such as associative networks. The patterns of symbols were repetitive enough so that over many trials, some memorization occurred. Presumably, a recognition strategy is faster than the elaborate computational strategy, which led to the faster reaction times (RTs) observed in Session 2 than in Session 1. However, the recognition strategy might also impose a greater memory load (or at least a different kind of memory load) than the computational strategy, leading to larger frontal NSW voltages.

A positive ERP component known as P300 is also influenced by learning and memory. Unlike the frontal, NSW, P300 decreases in voltage with increasing memory load (Mecklinger, Kramer, & Strayer, 1992). The P300 is also very sensitive to information load, and serves as an indicator of overload conditions (Donchin, Kramer, & Wickens, 1986; Isreal, Chesney, Wickens, & Donchin, E., 1980; Kramer, Wickens, Vanasse, Heffley, & Donchin, E., 1981).

The voltage and latency of P300 waves associated with task stimuli changes systematically during training of complex tasks (Kramer, Schneider, Fisk, & Donchin, 1986). During early training, when performance is slow and attentionally controlled, P300 latency is long, reflecting long stimulus evaluation times. P300 amplitude during early training is very sensitive to stimulus probability effects and memory load. If the stimulus-response relationships of the task are consistent over time, then practice leads to a faster, automatic type of processing. P300s in highly experienced subjects occur at short latencies, reflecting short stimulus evaluation times. In well-practiced subjects, the P300 amplitude is also relatively insensitive to effects of varying stimulus probability and memory load.

The response of the brain to irrelevant or distracting stimuli is different during overload than during normal conditions. This was demonstrated in a recent study of EW operator performance (Trejo, Kramer, & Humphrey, 1992). EW operators listened to irrelevant auditory tones during normal and overload conditions of a training scenario. During normal conditions, the N1 and mismatch-negativity (MMN) components of the auditory ERP were well-defined. However, during overload conditions, the N1 and MMN voltages were attenuated.

Selective attention (SA) to a stimulus will increase the voltage of the N1 component in the ERP associated with it (Woods, 1990). Recently, attentional modulation of the MMN has also been observed (Trejo, Ryan-Jones, & Kramer, 1992). Exceeding the scope of SA may explain the changes in the ERP for irrelevant auditory stimuli observed during overload conditions. During normal conditions, attentional demands of the EW operator's task are so low that attention can shift from the visual and auditory stimuli of the EW system to other sights and sounds in the environment including the irrelevant tones. However, during overload conditions, the task demands will consume as much attention as the operator is able to focus on the task stimuli. Consequently, less attention will be given to irrelevant stimuli such as the tones, resulting in low-voltage ERPs. The pattern of changes in N1 and MMN that occurs during overload may serve as an index of the expertise level in an operator. Situations that produce overload in novices may not be challenging to experts.

Future Directions for Research and Development

The technical and scientific issues and results discussed in the preceding sections suggest several avenues for future research. First, we must determine whether assessing or predicting overload using ERP measures will be useful in adjusting the pace and difficulty of training scenarios to maximize learning rates and transfer of training. If so, then several practical issues arise. For example, continual training near or above a trainee's overload point could be ineffective, whereas training too far below the overload point could waste training time and lead to slow rates of skill acquisition. Optimal loads as a function of training time should be determined. In addition, training for transfer to operational situations should probably involve variable difficulty, including some exposure to overload. The duration and intensity of this exposure should be measured for post-hoc assessment of the effectiveness of training strategies in producing transfer of learning to operational conditions.

Two main goals of adaptive operator training are to reduce training time and increase transfer of training to demanding operational conditions. Adaptive training system prototypes should be developed to test whether these goals can be achieved. Such systems must allow researchers to adjust the sequence, frequency, and difficulty of training interventions so as to accelerate skill acquisition and enhance transfer of training. In such systems, traditional performance measures such as accuracy, response time, and declarative knowledge tests should be combined with ERP measures such as NSWs, P300, N1, and MMN. The combined measures could then be used to infer development of knowledge structures and strategies, assess task demands, and adapt simulator-based training to individual trainees. Using combined performance and ERP techniques may make it possible to assess a trainee's ability dynamically and to determine more accurately when he or she reaches a criterion level of performance. Ultimately, computerized adaptive training systems may be developed to perform training adaptation on line (in real time), further reducing training costs and enhancing transfer of training.

Initial areas of interest for such systems are EW and antisubmarine warfare. However, the potential for applications to air traffic control or other system operations (especially dual-use technologies, such as aviation and power plant operations) may also be appropriate.

References

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower, (Ed.), *Advances in Learning and Motivation: Vol. 8* (pp. 47-90). New York, NY: Academic Press.

Donchin, E., Kramer, A. F., & Wickens, D. D. (1986). Applications of brain event-related potentials to problems in engineering psychology. In M. G. H. Coles, E. Donchin, & S. Porges (Eds.), *Psychophysiology: Systems, processes, and applications.* Middleton, NJ: Till & Till.

Friedman, D. (1990a). ERPs during continuous recognition memory for words. *Biological Psychology, 30,* 61-87.

Friedman, D. (1990b). Cognitive event-related potential components during continuous recognition memory for pictures. *Psychophysiology, 27,* 136-148.

Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology, 17,* 259-273.

Kramer, A. F., Schneider, W., Fisk, A., & Donchin, E. (1986).The effects of practice and task structure on components of the event-related potential. *Psychophysiology, 23,* 33-47.

Kramer, A. F., Wickens, C. D., Vanasse, L., Heffley, E. F., & Donchin, E. (1981). Primary and secondary task analysis of step tracking: An event related potentials approach. *Proceedings of the 25th Annual Meeting of the Human Factors Society*, 43-47.

Mecklinger, A., Kramer, A. F., & Strayer, D. L. (1992). Event-related potentials and EEG components in a semantic memory search task. *Psychophysiology, 29,* 104-119.

Miller, G. A. (1956). The magical number seven plus or minus two: Some limits on your capacity for processing information. *Psychological Review, 63,* 81-96.

Morton, J., & Bekerian, D. (1986). Three ways of looking at memory. In N. E. Sharkey (Ed.), *Advances in Cognitive Science 1* (pp. 43-71). New York, NY: John Wiley & Sons.

Noldy, N. E., Stelmack, R. M., & Campbell, K. B. (1990). Event-related potentials and recognition memory for pictures and words: The effects of intentional and incidental learning. *Psychophysiology, 27,* 412-428.

Ricard, G. L., & Norman, D. A. (1975). *Adaptive training of manual control: Performance measurement intervals and task characteristics* (IH-252). Orlando, FL: Naval Training Equipment Center.

Ruchkin, D. S., Johnson, R. Jr., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: an event-related brain potential study. *Electroencephalography and clinical Neurophysiology, 76,* 419-439.

Ruchkin, D. S., Johnson, R. Jr., Mahaffey, D., & Sutton, S. (1988).Toward a functional categorization of slow waves. *Psychophysiology, 25,* 339-353.

Squire, L. R., Ojemann, J. G., Miezin, F. M., Petersen, S. E., Videen, T. O., & Raichle, M. E. (1992). Activation of the hippocampus in normal humans: A functional study of memory. *Proceedings of the National Academy of Sciences, 89,* 1837-1841.

Trejo, L. J., Kramer, A. F., & Humphrey, D. (1992). Differential workload sensitivity of early and late components of the auditory probe ERP. *Psychophysiology (Supplement), 29,* S70.

Trejo, L. J., Ryan-Jones, D., & Kramer, A. F. (1992). Attentional modulation of the pitch-change mismatch negativity. *Psychophysiology (Supplement), 29,* S71.

Wijers, A. A., Mulder, G., Okita, T., & Mulder, L. J. M.(1989). Event-related potentials during memory search and selective attention to letter size and conjunctions of letter size and color. *Psychophysiology, 26,* 529-547.

Woods, D. L. (1990). The physiological basis of selective attention: Implications of event-related potential studies. In J. W. Rohrbaugh, R. Parasuraman, & R. Johnson, Jr. (Eds.), *Event-Related Brain Potentials. Basic Issues and Applications* (pp.178-209). New York, NY: Oxford University Press.

Annotated Bibliography

Event-Related Potentials, Learning, and Memory

Barrett, S. E., Rugg, M. D., & Perrett, D. I. (1988). Event-related potentials and the matching of familiar and unfamiliar faces. *Neuropsychologia, 26*(1), 105-117.

ERPs were recorded from one midline and three pairs of lateral sites while subjects made same/different judgments on sequentially presented pairs of familiar or unfamiliar faces. During the interval between the first and second face, a slow wave (SW) was more negative over the right than the left hemisphere, particularly when the faces were familiar. Following the second face, two regions of the waveforms were more negative-going when this face did not match the identity of its predecessor. In the early region (< 160 ms), this effect was confined to posterior electrode sites and familiar faces. In the later region (> 250 ms), the match/nonmatch effect was widespread across the scalp and was evident for both familiar and nonfamiliar faces, although in the latency range 350 to 450 ms (encompassing the N400 component), it was greater in magnitude in the case of familiar stimuli. It is suggested that the SW asymmetries reflect the engagement of short-term memory mechanisms lateralized to the right hemisphere. The match-nonmatch differences are thought to reflect multiple processes, including the modulation of the N400 component. The sensitivity of this component to the familiarity manipulation is consistent with the hypothesis that the amplitude of N400 reflects an item's compatibility with currently activated memory representations.

Bentin, S., Kutas, M., & Hillyard, S. (1993). Electrophysiological evidence for task effects on semantic priming in auditory word processing. *Psychophysiology, 30,* 161-169.

This study was designed to examine the influence of task (depth of processing) on ERP signs of semantic association during the processing of single spoken words. In one task, subjects made a series of independent lexical decisions and kept a running mental count of all pseudowords (Count Nonwords); in the other, subjects listened to a similar list of words in anticipation of a recognition memory test (Memorize).

Both tasks produced a reduction in the amplitude and peak latency of the N400 component when target words were preceded by semantically related words. This effect was only statistically significant in the Memorize task. The divergence between the waveforms in the Memorize task spanned a long epoch starting at about 300 ms and ending at about 900 ms, relative to stimulus onset. These results support the hypothesis that the amount of attention directed to semantic analysis appears to be important in determining the size of the N400 priming effect.

Bentin, S., & Moscovitch, M. (1990). Psychophysiological indices of implicit memory performance. *Bulletin of the Psychonomic Society, 28,* 346-352.

Skin conduction responses and ERPs were registered as evidence of a memory trace in explicit (requiring conscious recollection of past experience) and implicit (not requiring conscious recollection) tests of memory. Results indicate that ERPs may be related to the strength or accessibility of memory traces in repetition effects. This finding is congruous with the view that performance on both types of memory tests is influenced by a common trace that may be tapped at different levels of awareness as determined by the demand characteristics of the task and the retrieval operation they induce. Another explanation of the data may be that separate traces may mediate performance on the two tests, but that the two (or more) traces are reactivated by the stimulus and jointly and concurrently influence the ERP. The study arrived at no definite conclusions, but it demonstrated that psychophysiological measures are a possible source of information for investigations of implicit and explicit memory tests.

Bentin, S., & Peled, B. (1990). The contribution of task-related factors to ERP repetition effects at short and long lags. *Memory & Cognition, 18*(4), 359-366.

ERPs were recorded while subjects were performing two tasks to assess the relative contribution of task-related decision-making processes to the repetition effect. In the first task, subjects were required to make a lexical decision. The second task was a recognition memory task. The results of the study suggest that ERP modulations are sensitive to the postidentification effects of stimulus repetition and provide evidence that recovery of an episodic trace, probably related to decision making and/or stimulus categorization, contributes to the long-lasting repetition effect.

Berman, S., Friedman, D., & Cramer, M. (1991). ERPs during continuous recognition memory for words and pictures. *Bulletin of the Psychonomic Society, 29*(2), 113-116.

This study compared and contrasted the effects of stimulus modality (word vs. picture presentation of a concept), item repetition (old vs. new), and lag (the number of intervening items between first and second presentation) on the ERP and behavioral measures of picture and word processing. The results suggest that at least two brain generators are differentially activated by repetition. They also suggest that different information-processing mechanisms were applied in different regions of the brain to word and picture representations of the same concept.

Donchin, E. (1981). Surprise! . . . Surprise? *Psychophysiology, 18,* 493-513.

The nature of the psychophysiological enterprise is examined as it bears on the study of the endogenous components of ERPs. The view is taken that success in psychophysiology should be measured by the degree to which psychophysiological data can be used in elucidating the processes that underlie the behavioral product rather than by the enumeration of psychophysiological "correlates" of behavior. It is proposed that endogenous ERP components are best viewed as manifestations of the activities of "subroutines" invoked during the informational transactions of the brain.

A theoretical account of an ERP component consists of the specification of the functional role of the subroutine it manifests. Studies of the P300 components are examined for the contribution they make to the development of such a theory of the P300. Experiments focusing on P300 latency and amplitude are reviewed; it is concluded that P300 may be a manifestation of the processes whereby schemes (*see* "schemas," Introduction) are revised. The relationship between P300 amplitudes may predict the memorability of events. A preliminary test of this prediction is described.

Fabiani, M., Demetrios, K., & Donchin, E. (1986). P300 and recall in an incidental memory paradigm. *Psychophysiology, 23,* 298-308.

The results from this study confirm that the relationship between the amplitude of the P300 component and memory emerges more consistently when elaborate rehearsal strategies are not used. Subjects that used rote rehearsal strategies showed a stronger correlation between P300 and recall than did those that used more complex strategies. The data also support a "context updating" hypothesis that claims a process is invoked when events occur and create a need to revise the current representations in working memory.

Friedman, D. (1990a). ERPs during continuous recognition memory for words. *Biological Psychology, 30,* 61-87.

ERPs were recorded from 10 young adults during a version of the continuous recognition memory paradigm. Words were presented after lags of 2, 8, or 32 intervening items (equiprobable) following their first presentation. Subjects were required in each trial to make a choice: New (never presented previously) or old (previously presented) response. The old items elicited a late frontal negativity, whereas new words distributed a frontal positive SW. The amplitude of the frontal NSW is larger for the words correctly recognized as old on the first presentation than for those subsequently recognized as old on the second presentation. Also, the results of the data show the largest amplitude of the frontal NSW is for unrecognized old items. Since a positive SW has been interpreted as reflecting "further processing," the data suggest that such processing, possible similar to elaboration, enhanced the probability of subsequent recognition.

Friedman, D. (1990b). Cognitive event-related potential components during continuous recognition memory for pictures. *Psychophysiology, 27,* 136-148.

ERPs were recorded from 28 young adult subjects during a continuous recognition memory paradigm, with pictures as stimuli. Subjects were required to determine on each trial if the picture was "new" (never before presented) or "old" (seen previously). To assess differences between primary and secondary memory, old items were presented after lags of 2, 8, and 32 intervening pictures (equiprobable) following their first presentation. The results suggest that a negativity (Cz maximum) at 300 ms was the most likely candidate for the brain event reflecting the retrieval of the item from memory. There was also a long-latency negative component (800 to 1200 ms) was also most prominent for old and subsequently unrecognized stimuli which is consistent with other research by this author (Friedman, 1990a). One explanation offered is that the NSW found with old words is actually due to the presence of a positive SW elicited by the new words that is not present for the old words. In other words, it is a NSW because it lacks a positive SW element.

Gomer, F. E., Spicuzza, R. J., & O'Donnell, R. D. (1976). Evoked potential correlates of visual item recognition during memory-scanning tasks. *Physiological Psychology, 4,* 61-65.

To study the retrieval of information from memory, ERPs were recorded from subjects performing a memory-scanning task. Subjects were presented with a test stimulus (a letter) and were required to determine if it had been memorized previously and thus, make a choice

RT response accordingly. The results provide evidence for the argument that there is a template-matching stage in which the sensory input is evaluated with reference to specific memorized characteristics which define the critical stimulus dimension. The findings also extend the potential generality of this theory beyond the detection of simple sensory stimuli to complex cognitive tasks and stimulus events.

Johnson, R., Pfefferbaum, A., & Kopell, B. S. (1985). P300 and long-term memory: Latency predicts recognition performance. *Psychophysiology, 22,* 497-507.

This study investigated memory acquisition processes and the effects of repetition of long term recognition memory. Subjects were presented with a list of words ("targets") to be memorized (Study series) and were later tested for recognition on a word list consisting of target words mixed randomly with an equal number of new, distractor words (Test series). Processing time was measured by P300 ERP components and RT. P300s elicited for words later recognized, when words for the Study series were divided on a basis of recognition performance, were shorter than for words not recognized. The amplitude of the P300 increased with repetition of words in the Study series while maintaining a constant latency. During the Test series, P300 latency and RT decreased with repetition for both target and distractor words. Words that were recognized more consistently during the Test series elicited larger and earlier P300s than words that were recognized less consistently. The P300 amplitude and latency results from both the Study and Test series are interpreted as reflecting the increased discriminability of the target words as the memory trace increases in strength.

Karis, D., Fabiani, M., & Donchin, E. (1984). "P300" and memory: Individual differences in the von Restorff effect. *Cognitive Psychology, 16,* 177-216.

In a free recall paradigm, subjects were presented at each of two sessions with 40 lists each consisting of 15 words. One word in each list was "isolated" by changing its size. These isolated words were recalled more often and elicited larger P300s than did other words in the same position on the list. P300 for words recalled had a greater amplitude on initial presentation than did those not recalled, especially for subjects who used simple (rote) mnemonic strategies. For subjects who used more complex mnemonic strategies, P300 was not a reliable predictor of later recall, whereas a later "slow wave (SW)" component was. All subjects had a large P300 as the initial response to isolated items. The manner in which the relation between P300 amplitude and recall varied with the subjects' strategies provides information that can be used to develop, and assess, more detailed models of storage and retrieval than can be derived from an analysis of the subjects' reactions alone.

Kramer, A., Schneider, W., Fisk, A., & Donchin, E. (1986). The effects of practice and task structure on components of the event-related brain potential. *Psychophysiology, 23,* 33-47.

This study focused on the effects of, and the interactions between, practice and task structure on human performance. The development of automatic processing through consistent stimulus-response mapping (CM) was assessed by means of measures of RT and ERPs. The CM condition consisted of targets always selected from one category (1 to 9) and distractors chosen from another category (letters A to I). The valuable stimulus-response mapping (VM) condition consisted of both targets and distractors from the same category (letters A to I).

During the VM condition, there was a prolonged frontal negative ERP, which was larger for absent target trials than for targets present. Also, as the memory load increased, the amplitude of the negative ERP increased as well. During the CM condition, neither the memory size nor the response type affected the amplitude of the prolonged frontal negative ERP. The conclusion drawn to explain this phenomenon is that the difference in prolonged negativity as a function of stimulus mismatch may signify an increased need for the processing of mismatches when subjects are performing in the controlled processing mode. This study realized that these negative ERP components have provided information concerning processing of mismatches not easily obtained by traditional measures.

Lang, M., Lang, W., Uhl, F., Kornhuber, A., Deecke, L., & Kornhuber, H. H. (1987). Slow negative potential shifts indicating verbal cognitive learning in a concept formation task. *Human Neurobiology, 6,* 183-190.

This study investigated the possibility that event-related cerebral potential shifts would indicate a left frontal lobe involvement in verbal-cognitive learning tasks. In a concept formation paradigm, subjects learned by trial and error to transform letters into Morse codes. Subjects also participated in a control task with already known letter/Morse code combinations. In both tasks, a frontal negative potential shift occurred within the stimulus-response interval, although the shift was smaller in amplitude in the second task. In all conditions, fronto-medial (FCz, Cz) and fronto-lateral (F3 and F4) recordings showed a remarkable increase of negativity following stimulus 2 (S2) with short latency (about 500 ms). Amplitudes of the negative potential shift after stimulus 1 (S1) presentation increased in the course of the learning process in the frontal cortex (including Cz) and absent in the control condition.

Licht, R., Bakker, D. J., Kok, A., & Bouma, A. (1992). Grade-related changes in event-related potentials (ERPs) in primary school children: Differences between two reading tasks. *Journal of Clinical and Experimental Neuropsychology, 14,* 193-210.

ERPs were recorded from the left and right temporal and parietal sites of school aged children while they performed two reading tasks. The group of children were followed over a 3-year period, from Grade 1 to Grade 3. All ERP components show changes in amplitude as a function of grade: P240, N530, the parietal N150, and SW changed from no asymmetry to larger positivity over the right site, whereas N360 changed from symmetric amplitudes to larger amplitudes over the left hemisphere. There are also individual differences between the readers in that the proficient readers showed larger SW and N360 asymmetries and shorter vocal response times than did less proficient readers. In addition, a positive relationship was found between reading performance and ERP amplitudes over the left temporal hemisphere at Grades 2 and 3.

Mäntysalo, S., & Gaillard, A. W. K. (1986). Event-related potentials (ERPs) in a learning and memory test. *Biological Psychology, 23,* 1-20.

This study outlines a new paradigm to investigate the effects of learning and memory on ERPs. In the learning phase, subjects had to learn a sequence of 12 auditory consonant-vowel syllables. In the test phase, subjects had to detect and report a change in the learned sequence.

A positive SW reported at Pz and Cz was attributed to the updating of working memory. Fz was more negative than both Cz and Pz. Post-hoc, a negative SW was noticed at Fz for symbols located at the learned position, syllables not yet learned, learned syllables, and overlearned syllables. Although these NSWs were noticeable, none were statistically analyzed; thus, none were proven significant.

Mecklinger, A., Kramer, A. F., & Strayer, D. L. (1992). Event related potentials and EEG components in a semantic memory search task. *Psychophysiology, 29,* 104-119.

The study examined the relationship between EEG and ERP components as a function of memory load and response type. The subjects performed a semantic memory search task in which they matched word probes to category labels. There was a negative frontal SW which increased in amplitude with memory load. The NSW was reported at Fz for both target and nontarget stimuli with the nontarget stimuli resulting in larger amplitudes (of the NSW). The conclusion drawn is that the NSW reflects the extended process in working memory. There was also a significant interaction between the theta wave and the NSW. The explanation for this is that the frontal-central theta power reflects the difficulty of conceptual operations in working memory and is closely related to the changes in the NSW.

Morton, J., & Bekerian, D. (1986). Three ways of looking at memory. In N. E. Sharkey (Ed.), *Advances in Cognitive Science 1* (pp. 43-71), New York, NY: John Wiley & Sons.

This chapter is concerned with the structure of theories concerning human memory. The purpose is to make the nature of associative network theory and schema theories clearer. These theories differ not only in the formulations and terminology used, but also in the ease with which they handle different kinds of phenomena. An important, but often ignored point, is that a model or theory is within a framework. The important feature of a framework is that it is, in principle, not falsifiable. However, the models or theories within the framework are falsifiable. The advantage of having a framework is to enable a coherent debate with prior agreement about the definition of terms. Progress can only be made ultimately, however, when specific models are formulated which can be empirically tested.

An attempt to distinguish is made between those aspects of theories which have framework status and those that do not. Kernel assumptions, which define the framework, are distinguished from additional assumptions; this enables us to postulate a specific, falsifiable model. The authors attempt to contrast associative network and schema frameworks with the their own approach. By doing this, the authors demonstrate how different assumptions can lead to different theoretical commitments for explaining behavior. The feature of particularly stressed memory is the distinction between information that can be used as a cue for recall and information that can be recalled but not used as a cue.

Neville, H. J., Kutas, M., Chesney, G., & Schmidt, A. L. (1986). Event-related brain potentials during initial encoding and recognition memory of congruous and incongruous words. *Journal of Memory and Language, 25,* 75-92.

ERPs were recorded while subjects read statements followed by words that were either semantically congruous or incongruous with the preceding phrase and during a subsequent recognition test. Congruous words yielded smaller N400s and better memory than did incongruous statements. In addition, the ERPs for correctly recognized old words were characterized by an enhanced late positivity (P650) relative to those elicited by correctly identified new words. A second experiment essentially replicated the results of the first. In addition, the amplitude of the late positive component (P650) elicited by final words on initial exposure was predictive of subsequent recognition; words that would be recognized later were associated with a larger P650 (whether they were incongruous or not) than were words that would not be recognized. These ERP data provide evidence that within 250 ms of the presentation of a congruous word and within 450 ms of an incongruous word, a significant portion of the brain processes which determine whether a word will or will not be recognized some time in the future have taken place. Also reported, was a late fronto-central NSW (500 to 1200 ms) for words subsequently not recognized.

Noldy, N. E., Stelmack, R. M., & Campbell, K. B. (1990). Event-related potentials and recognition memory for pictures and words: The effects of intentional and incidental learning. *Psychophysiology, 27,* 417-428.

ERPs were recorded under conditions of intentional or incidental learning of pictures and words and during the subsequent recognition memory test for these stimuli. There was a NSW at Fz during the recognition recall task for intentionally remembered. However, the ERP associated with the pictures (whether intentionally remembered or not) is a positive SW. This difference was explain by the theory that processing words becomes automatic whereas additional attention resources are needed for processing pictures. Thus, the automatic ability to learn words is a result of overlearning which does not occur for picture recognition. These data also support the theory from previous research that a late negative wave is thought to be especially sensitive to linguistic processing.

Paller, K. A., Kutas, M., & Mayes, A. R. (1987). Neural correlates of encoding in an incidental learning paradigm. *Electroencephalography and clinical Neurophysiology,* 67, 360-371.

This study examined the influence of semantic processing on memory and on ERPs. ERPs were recorded during an incidental learning paradigm in which recall and recognition were better for words initially presented in tasks requiring semantic decisions than for words in tasks requiring nonsemantic decisions. ERPs elicited during performance of these tasks were predictive of subsequent memory performance. A possible prediction is that the larger the P3 an item produces, the more likely it will be remembered. However, not all factors that alter P3 amplitude necessarily impact memory, and P3 and Dm (any ERP difference based on later memory performance) may be partially independent.

Parasuraman, R., Richer, F., & Beatty, J. (1982). Detection and recognition: Concurrent processes in perception. *Perception & Psychophysics, 31,* 1-12.

In two experiments, ERPs were recorded while subjects performed a simultaneous detection and recognition task. Ten subjects listened to pure tones in noise and reported both whether a target tone had occurred (using a 4-category confidence rating scale) and whether the target was one of two (Experiment 1) or four (Experiment 2) tones differing in frequency. The amplitudes of three ERP components were found to be differentially related to detection and recognition performance. The early N100 component varied with processing related only to detection, while the late P300 varied with both detection and recognition, and a later slow positive shift varied only with recognition and not with detection. While the latencies of both N100 and P300 increased for less confident target detections, there were no differences in the latencies of these ERP components between correctly and incorrectly identified targets. The results indicate that brain potential components can be used to disclose temporal features of the processing of a stimulus by the nervous system and support the view that detection and recognition are partially independent, concurrent processes in perception.

Rösler, F., Heil, M., & Glowalla, U. (1993). Monitoring retrieval from long-term memory by slow event-related brain potentials. *Psychophysiology, 30,* 170-182.

Slow ERPs of nine subjects were recorded in an experimentally controlled long-term memory retrieval task (the Fan paradigm) from electrode sites F3, Fz, F4, Cz, P3, and P4. In all retrieval conditions, a very pronounced DC-like negative potential appeared over the left frontal cortex. This negativity was switched on with the presentation of the probe stimuli and prevailed in some conditions throughout the total recording epoch of 14 seconds. Particular retrieval conditions became manifest in distinct SW effects. The amplitude of a bilaterally distributed frontal NSW increased when a more diversified associative structure had to be searched. The amplitude of another NSW, which peaked bilaterally over parietal areas, was affected by the type of concepts that had to be retrieved. The amplitude was larger with general concepts (category labels) and smaller with specific concepts (category exemplars). These results suggest that distinct strategies are invoked when subjects are required to draw conclusions about different contents stored permanently in an associative network. Many reasons and explanations for the frontal NSW are discussed. The main conclusion is that long-term memory retrieval is exceptionally potent for the evocation of slow potential shifts, particularly those over the frontal cortex.

Rugg, M. D., & Doyle, C. (1992). Event-related potentials and recognition memory for low- and high-frequency words. *Journal of Cognitive Neuroscience, 4,* 69-79.

ERPs were recorded while subjects performed a task requiring overt recognition memory to study the modulation of P600 by correctly identified "old" (previously studied) and "new" (not studied) high- and low-frequency words. The authors conclude that post-500 ms "old/new" ERP modulations in recognition memory tasks may reflect differences in old and new words' levels of relative familiarity, and the recognition memory advantage for low-frequency words may result from the higher level of relative familiarity engendered at test by previously studied low-frequency items.

Rugg, M. D., & Nagy, M. E. (1987). Lexical contribution to nonword-repetition effects: Evidence from event-related potentials. *Memory & Cognition, 15,* 473-481.

The modulation of ERPs by the repetition of orthographically legal and illegal nonwords was studied in two experiments to investigate the effects of repetition on lexical decision processes. A SW component of the ERP was found to be more negative for the first presentation and control conditions than for the second. The results support the idea that either ERP repetition effects are limited to items that can arouse significant activation within the lexical system or the positive going modulation of ERPs to repeated items to some degree reflects the attention of negativity generated as a consequence of the unprimed status of control and first presentation items. This finding is inconsistent with the idea that the effects of repetition, even over short time intervals, can be understood entirely in terms of the formation and retrieval of episodic memories of items' prior occurrences.

Sanquist, T. F., Rohrbaugh, J. W., Syndulko, D., & Lindsley, D. B. (1980). Electrocortical signs of levels of processing: Perceptual analysis and recognition memory. *Psychophysiology, 17,* 568-576.

ERPs were recorded to study the electrocortical manifestations of levels of perceptual processing and memory performance during a verbal comparison task and a following test of recognition memory. Subjects were required to determine if two words were the same or different according to an orthographic, phonemic, or semantic criterion. The results from this study indicate that the late positive components were larger when items were recognized and that they varied predominately with the type of judgment made in the phonemic and semantic tasks. The SW varied according to the type of comparison being made and was more frequent when items were recognized. The authors conclude that the SW component reflects the type of judgment performed on stimuli that vary most with comparison criterion. The negative component of the SW appears under conditions leading to relatively poor memory performance, whereas the positive SW component is related to better performance. The data suggest that ERPs characterize stimuli in terms of their later recognizability and that they can be related to the amount of associative activity evoked by the stimuli, which may result from different types of processing required by the various comparison criteria such as an index type of processing or a momentary state of memory system activity.

Smith, M. E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgments. *Journal of Cognitive Neuroscience, 5*(1), 1-13.

This study found that ERPs recorded during the course of a modified recognition memory task differ between stimuli that elicit a conscious recollection and those that only bring about a sense of familiarity. Previous studies have shown a dramatic difference in ERPs between items that have and have not been recently studied. This effect is referred to as the Memory Evoked Shift (MES). It entails a broad, positive-going, voltage shift of the ERP elicited by the old words relative to the new words, that usually begins about 350 ms or so following stimulus onset, and that lasts for 400 to 500 ms. When subjects reported that recognition decision were based on specific recollection of study episodes, the MES that accompanied these reports was larger in magnitude than when subjects reported making decisions based on feelings of familiarity, at least during the 550 to 700 ms time window. In contrast, old words that were not correctly recognized were not accompanied by a MES. These findings provide the first direct evidence that ERP differences between old and new words are closely related to subjects' recollective experience, and they have the potential to help relate that experience to the physiological mechanisms that generate it. Another finding shows that it is possible to predict future recognition of a word by the ERPs elicited while studying that word.

Smith, M. E., & Halgren, E. (1989). Dissociation of recognition memory components following temporal lobe lesions. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 50-60.

This study tested the argument that recognition decisions entail contributions from two component processes. One involves contextual retrieval of specific trace information and the other is an assessment of item strength. The retrieval component is most important when items have had only one prior presentation whereas the strength component is maximized when items have received repeated study. The unilateral anterior temporal lobectomy (ATL) in the language dominant (left) hemisphere is reported to impair the retrieval component but to have no effect on the strength component. The implication that the temporal lobe contributes to retrieval rather than strength during recognition is supported by simultaneous ERP recordings. In normal subjects, the large ERP difference between repeated and nonrepeated words does not increase with increasing study and is associated with contextual integration in other tasks. Thus, the lack of a repetition-induced ERP difference after left-ATL reported here provides converging evidence for a critical role of the temporal lobe in contextual retrieval during recognition.

Squire, L. R., Ojemann, J. G., Miezin, F. M., Petersen, S. E., Videen, T. O., & Raichle, M. E. (1992). Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proceedings of the National Academy of Science USA, 89,* 1837-1841.

Regional cerebral blood flow was studied using the $H_{2}{}_{15}O$ method while normal subjects performed four similar tasks involving three-letter word beginnings (stems). Prior to each task, subjects studied a list of words. Local blood flow was then monitored during a 40-second period while subjects (1) silently viewed word stems; (2) completed stems to form the first words to come to mind, but the stems were not the beginnings of any study words (baseline); (3) completed stems and half of them could form study words (priming); or (4) tried to recall study words, and half of the stems could form these words (memory). There are three major findings:

1. The memory task engaged the right hippocampal region when the memory task was compared to either the baseline or the priming condition. The right hemispheric locus suggests that performance is driven by the visual characteristics of the words rather than by semantic or phonetic analysis.

2. In the priming-minus-baseline comparison, there was reduction in blood flow in the right posterior cortex.

3. Right prefrontal cortex was activated in the memory-minus-baseline condition.

The results provide evidence for selective activation of the human hippocampal region in association with memory function. The results also lead to a suggestion about the neural basis of repetition priming: Following presentation of a stimulus, less neural activity is required to process the same stimulus.

Sutton, S., & Ruchkin, D. S. (1984). The late positive complex. *Annals of the New York Academy of Science, 425,* 1-23.

This article reports that there may be many more components in the scalp-recorded ERP than were originally thought to be. This may mean that, in reviewing earlier work dealing with ERPs, it cannot be determined what components were related to the experimental variables because of many of these ERP components overlap in time and space. The positive side to these recent developments is that it is now known that P3b and SW can relate quite differently to behavioral variables. Decision time, which was thought to have occurred at P3 latency, can now be assumed on the basis of recent findings to occur earlier, at the N2 component. The separation of the formerly unitary contingent negative variation (CNV) into several components makes it more possible to develop unique functional roles for each of the components. A similar development has occurred with the separation of the poststimulus negativities into several components. The constructs for various components are still unclear, but the field has better tools at its disposal for making them more precise. Finally, the multiplicity of components, which appears overwhelming initially, provides us with more degrees of freedom in attempting to relate electrophysiological activity to behavior. A number of investigators have commented that the complexity of factors that enter into behavior could not be reflected in the relatively few ERP components the authors were dealing with. Now that more components are being distinguished, the likelihood increases that it will be possible to obtain ERP correlates of more of the dimensions involved in behavior.

Tecce, J. J., Cattanach, L., Yrchik, D. A., Meinbresse, D., & Dessonville, C. L. (1982). CNV rebound and aging. *Electroencephalography and clinical Neurophysiology, 54,* 175-186.

This study tested 35 young (18 to 32 years), 38 older (55 to 69 years), and 23 elderly (70 to 85 years) individuals in two CNV paradigms: (1) a constant foreperiod RT task, consisting of a light flash-tone-key press sequence (control trials) and (2) a divided-attention (DA) (50% letters) task in which two types of trials occurred randomly—no-letters trials and letters trials. In the DA task, all three groups showed significant decreases in frontal, central, and parietal late CNV amplitudes during letters trials. In no-letters trials, young and older subjects showed significant elevations in late CNV amplitude (rebound effect). Early CNV amplitude was decreased in all groups when the short-term memory task was presented. The oldest group also showed a paradoxical reduction in early CNV when the task was omitted. This suggests an age-related sluggishness in switching from a divided to an undivided attention set. The frontal brain areas appear to mediate, in part, this weakened capacity of the elderly to switch attention. The robustness of frontal P3 amplitudes in both older age groups suggests that orienting and/or dishabituation processes may hold up with aging.

Wijers, A. A., Mulder, G., Okita, T., & Mulder, L. J. M. (1989). Event-related potentials during memory search and selective attention to letter size and conjunctions of letter size and color. *Psychophysiology, 26,* 529-547.

This study tested the different ERPs during memory searches. The tested levels were stimulus relevance, memory load, and stimulus discrimination. A fronto-central NSW was found for relevant, target stimuli when four target letters presented (memory load 4). These results are consistent with previous research suggesting that this reflects a serial control process. The negative centrally maximum shift associated as a function of memory load was found in previous research to generalize to irrelevant stimuli. The NSW also lasted longer for nontarget stimuli than for target stimuli. The authors concluded that a nontarget stimulus takes longer to be processed in a memory search because the search is rechecked if the target is not found or it may reflect a different mental process occurring.

Electroencephalogram States in Learning and Task Performance

Bird, E. I., & Wilson, V. E. (1988). The effects of physical practice upon psychophysiological response during mental rehearsal of novice conductors. *Journal of Mental Imagery, 12*(2), 51-64.

The ability of novice conductors to see a mental image and the changes in psychophysiological activity associated with mental rehearsal (MR) as a function of physical practice at the beginner's level of conducting skill were examined in this study. Two specific responses were investigated: (1) changes from baseline to MR periods and (2) physiological patterning during MR and the actual task. Psychophysiological correlations and correlates of performance were also investigated. The psychophysiological responses used were electromyogram (EMG) levels of the right deltoid muscle, surface finger temperature, left hemisphere EEG, and heart rate (HR). It is suggested that the MR patterns of EMG and especially EEG reflect actual performance during learning of the motor skill. The results were such that the more skilled novices and the instructor exhibited more frequent and exact EEG pattern similarities in the pre- and post trials. Therefore, if MR were taught, the configurations of EMG and EEG patterning could serve as a guide to progress in skill acquisition and to techniques for MR training and performance enhancement.

Bosel, R., Mecklinger, A., & Stolpe, R. (1990). Changes in spontaneous EEG activity indicate a special kind of information processing in concept learning. *Biological Psychology, 31,* 257-269.

The hypothesis that the power of α_1 component of EEG reflects the mental processes that combine features and matches them to a concept in the mind was tested in subjects that were required to match visually presented objects with a concept built up by hypothesis and to respond by pressing a yes or no key. An increase in power of the α_1 was recorded prior to the execution of a yes response, when subjects could match their hypothesis positively with combined features of the presented object. The α_1 spectral power was also larger after the presentation of disconfirming feedback than after confirming feedback. It is suggested that α_1 power provides an index for a special kind of information processing (exploration), which usually precedes a specific kind of reaction (important yes choices in concept features matching). The spectral power of α_2 EEG is larger after confirming feedback than after disconfirming feedback which could be interpreted in terms of general processing demands imposed during task performance.

Crews, D. J., & Landers, D. M. (1993). Electroencephalographic measures of attentional patterns prior to the golf putt. *Medicine and Science in Sports and Exercise, 25,* 116-126.

The purpose of this investigation was to determine the attentional focus patterns associated with golf putting performance. Highly skilled golfers (N = 34) were assessed using EEG measures of the motor and temporal cortices during the 3 seconds prior to the golf putt. Players completed forty, 12-foot putts and performance was measured in cm error from the hole. Three measures of EEG were analyzed: Slow shift, 40 Hz, and relative power spectrum; representing readiness to respond, focused arousal, and general cortical activity, respectively. All three EEG measures suggested a decrease in left hemisphere, motor cortex activity as the player prepared to putt. Relative power measures also showed significant increases in right hemisphere activity in both the motor and temporal cortices. During the last second preceding the putt, increased right hemisphere alpha activity correlated with and predicted less error. An important distinction occurred in the alpha band. In the motor cortex, left hemisphere, alpha increased significantly over time while in the temporal cortex, right hemisphere, alpha increased as subjects approached stroke initiation. Differences that existed between the attentional patterns from the present study and past sport studies may relate to the use of one versus two hands to initiate the response.

Floru, R., Cail. F., & Elias, R. (1985). Psychophysiological changes during a VDU repetitive task. *Ergonomics, 28,* 1455-1468.

The study investigated the relationship between performance and physiological measures, specifically EEG and HR, during a simulated realistic data-entry task on a visual display unit (VDU). Performance (correct entries, errors, omissions) and the physiological measures were recorded during the 120 minutes required to complete the task. A progressive decline of performance in the first hour of work was followed by a significant rebound. Behavioral responses were associated with corresponding EEG arousal changes whereas HR showed a progressive decline. There is some evidence indicating that different EEG frequency bands are more sensitive to SA requirements than HR which is more related to diffuse arousal changes. The EEG pattern accompanying the rebound of performance supports the auto-arousal hypothesis assuming that a cerebral compensatory effort occurs in mental repetitive tasks.

Jausovec, N. (1985). Hemispheric asymmetries during 9-year-olds performance of divergent production tasks: A comparison of EEG and YSOLAT measures. *The Creative Child and Adult Quarterly, 10,* 233-238.

Two groups (High Creative [HC] and Low Creative [LC]) of 9-year old children were given the "Your Style of Learning and Thinking (YSOLAT)," Children's Form A to measure hemispheric preference. EEGs were recorded from each subjects while they performed verbal and figural divergent production tasks. EEG results indicated that during problem-solving HC individuals showed greater hemispheric integration than LC individuals did. During task performance, LC individuals showed right hemispheric asymmetries. YSOLAT results were just opposite to those obtained with EEG. More right hemispheric answers were chosen by HC individuals than LC individuals. Differences between both kinds of measures indicate that the questionnaire's statements may be influenced by conformity-nonconformity choices.

Krieger, D., & Dillbeck, M. (1987). High frequency scalp potentials evoked by a reaction time task. *Electroencephalography and clinical Neurophysiology, 67,* 222-230.

The hypothesis that neural cell populations which produce high frequency scalp potentials also mediate visual task performance was studied by examining the relationships between bursts of 20 to 150 Hz scalp EEG and parameters of performance during visual RT tasks. It was shown that (1) muscle artifacts were not the primary source of identified EEG bursts, (2) the mechanism which produces the bursts may be similar to both rabbit olfactory bulb and human neocortex, (3) visual task performance may be mediated by the brain areas which produced the bursts, and (4) burst activity varied with changes in performance.

Lang, W., Lang, M., Kornhuber, A., Diekmann, V., & Kornhuber, H. H. (1988). Event-related EEG-spectra in a concept formation task. *Human Neurobiology, 6,* 295-301.

Event-related spectra of short EEG epochs were investigated in a concept formation paradigm. In this task, subjects had to learn to transform letters into Morse code. Changes in the Theta-MPD (mean power density) were closely related to all three variables of task performance: (1) Theta-MPD increased from the resting state to the state of information processing and response selection, (2) Theta-MPD separated experimental tasks and controls, as well as (3) successful learners from less successful ones. These changes of Theta-MPD were obtained in recordings of the fronto-medial midline and at fronto-lateral sites (F3); there were no differences of this parameter in parietal recordings. The increase in Theta-MPD may be caused by the an increase of task complexity or "cognitive load" in the performance of a concept formation task as compared to its control. Some additional control structure is recommended to achieve control of the desired behavior, especially when the task is novel or complex. These control structures have been related to the frontal cortex. Furthermore, it is well established that purposeful, goal-directed actions are driven by motivational and intentional mechanisms and that the frontal lobe is critically involved in such actions.

The relationships between the Theta-rhythm and task complexity, work speed, verbal cognitive learning, effort in a cognitive performance, and the level of visuospatial and of verbal discrimination performance are discussed as is the possibility that the early parietal alpha-attenuation reflects mechanisms of directing attention towards the presentation of external stimuli.

Changes in Alpha-MPD only varied between states of rest and states of performance, but there were no significant effects of factors such as condition or success in task performance.

Mecklinger, A., Kramer, A. F., & Strayer, D. L. (1992). Event related potentials and EEG components in a semantic memory task. *Psychophysiology, 29,* 104-119.

This study examined the effects of memory search and related processes on both time and frequency domain components of electroencephalographic activity, More specifically, we were interested in the relationship between EEG and ERP components as a function of memory load and response type. Subjects performed a semantic memory search task in which they matched word probes to category labels. Consistent with previous studies, RT increased and accuracy decreased with increasing memory loads. A negative component of the ERP (N400) was found to reflect semantic mismatch: N400s were larger for the nontargets than for the targets. Two ERP components were found to be reciprocally related to memory load. P300 decreased and NSW increased in amplitude with increases in the size of the memory set. These two ERP components were reflected by different components in a Principal Components Analysis. The power in the theta band (5 to 7HZ) also increased as a function of memory load and appears to be functionally and topographically related to the NSW in the ERP. It is argued that both measures are jointly determined and reflect the difficulty of the conceptual operations during memory search.

Murphy, P., Maurek, P., & Lakey, W. (1976). Effects of simultaneous divergent EEG feedback from both cerebral hemispheres on changes in verbal and spatial tasks. *Biofeedback and Self-Regulation: Abstracts of Papers Presented at the Annual Meeting, 1,* 337-338.

Two groups underwent training in EEG feedback. Group 1 underwent five 21-minute sessions to increase their right and decrease left brain EEG frequencies. Group 2 received the same training sequence, but to decrease right and increase left brain EEG frequencies. All subjects received identical presentations of verbal multiplication problems and Minnesota Paper Formboard items, before and after training, via slide projector. Results show that the two groups are significantly different in verbal-spatial pre-post training variability. Group 1 produced more variable verbal than spatial changes; Group 2 produced the opposite pattern. Alpha training of the appropriate hemisphere provided for either task increments or decrements, while beta training locked in the processing at the pretest level. Success in producing left brain alpha was related in a strong positive fashion to verbal task enhancement. A mixed design analysis of variance on integrated EEG shows Group 1 to have a significantly more aroused cerebral state in the right hemisphere than Group 2. One other link to training was a significant positive correlation between session-to-session frequency decrement and increased integrated EEG values on the posttest.

Tyson, P. D. (1987). Task-related stress and EEG alpha biofeedback. *Biofeedback and Self-Regulation, 12,* 105-119.

The hypothesis that high-amplitude alpha is sensitive to the manipulation of contingent stress was tested by manipulating conditions known to influence stress, such as the distribution, predictability, and controllability of stressful stimuli, and number of tasks performed. Forty subjects were divided into stress and nonstress groups. Within each group, one half had the dual-task of anticipating and increasing alpha activity. The other half was initially instructed to only anticipate alpha and, later, had the dual task of anticipating and controlling alpha. No feedback training was included to distribute the task-related stressor and [to allow] the assessment of self-control. All of the stress manipulations significantly influenced the effects of stress on alpha production. The dual-task subjects produced less alpha and less self-control than did training with control phased in after subjects learned to anticipate alpha. Without stress, phased-in control produced highly significant increases in alpha production and self-control without feedback.

Event-Related Potentials and Cognition: Attention, Imagery, and Mental Workload

Alho, K. (1992). Selective attention in auditory processing as reflected by event-related brain potentials. *Psychophysiology, 29,* 247-263.

ERPs were measured in order to attempt to understand the two kinds of SA mechanisms in processing negativity: Intermodal SA and intramodal SA. The late processing negativity reported may be associated with frontal brain functions participating in the control of attention or it may reflect further processing of attended stimuli. A more prominent later processing

negativity component is elicited by attended auditory stimuli during intramodal SA than during intermodal SA. This may indicate that the frontal control functions, (e.g., maintenance of an attentional trace in the auditory cortex) may have a more important role when auditory stimuli are selected among other auditory stimuli and a more precise stimulus selection is needed than when auditory stimuli are selected among stimuli of other modalities.

Bentin, S. (1987). Event-related potentials, semantic processes, and expectancy factors in word recognition. *Brain and Language, 31,* 308-327.

Electrophysiological activity was recorded at 16 scalp locations during a word recognition task in order to investigate the effect of expectancy factors of ERPs. This study reported a negative fronto-centro potential, which had a larger amplitude for the nonwords condition than the words condition. The results are due to an increased negative potential to unexpected words and to nonwords rather than an increased positive potential to primed words. This investigation supports the idea that lexical activity is associated with negative potentials related to a more general process of lexical access and/or stimulus identification.

Berman, S. M., Heilweil, R., Ritter, W., & Rosen, J. (1989). Channel probability and Nd: An event-related potential sign of attention strategies. *Biological Psychology, 29,* 107-124.

ERPs were recorded in a two-channel SA paradigm designed to assess the effects of channel probability on processing negativity. A late negative frontal component was reported at Fz. This component is interpreted as reflecting either further processing after the stimuli are matched with rehearsed characteristics or the rehearsal re-update process itself. It was also explained that the Nd500 long latency (maximum at Fz) cannot be attributed to MMN or to the N2b: An alternative answer is that it may be due to the stimulus changes.

De Jong, H. L., Kok, A., & Van Rooy J. C. (1988). Early and late selection in young and old adults: An event-related potential study. *Psychophysiology, 25,* 657-671.

This study investigated differences in processing between young (18 to 24) and old adults (65-75) in a combined visual selection-memory search paradigm. For attended stimuli at Fz, younger subjects had larger negative ERPs for the nontarget trials than for target trials, and four target stimuli (memory load 4) had larger ERPs than two target stimuli (memory load 2). The reverse was true for the older subjects: At Fz attended stimuli, target trials had more negative ERPs than did nontarget trials and memory load 2 had more negative ERPs than memory load 4 (however, even though more negative, the negative amplitude never crossed into the negative quadrant). For unattended stimuli at Fz, older subjects had more negative amplitudes for nontarget trials than for target trials (again not passing into the negative quadrant), whereas there was no significant difference for the younger subjects. For the younger subjects, there was a NSW at Fz which was positive at all other topographic locations. The older subjects had larger positive SWs than did the younger subjects at all topographic locations. High memory loads were found to reduce positive ERP components in both older and younger subjects. The RTs and error rates suggest a speed over accuracy strategy in the older subjects, especially under high processing loads. It is also suggested that older subjects have accumulated less evidence about the presence of a target than younger subjects. The presence of the SW is present until the end of the epoch in older subjects on nontarget trials,

but not on target trials, suggests that they process the attended trials until they respond or until the end of the epoch as a result of gathering less information on the target. The overall conclusion is that the older adults do not seem able to reach a confident decision within the time period given.

Elbert, T., Lutzenberger, W., Rockstroh, B., & Birbaumer, N. (1984). Slow brain potentials invoked by voluntary movements and evoked by external stimulation: Common principles. In R. H. Nodar, & C. Barber (Eds.), *Evoked Potentials II* (pp. 435-440). Boston, MA: Butterworth.

The negative slow brain potential (readiness potential) precedes a voluntary action from .5 to 3 seconds. The larger the expected movement is, the larger the readiness potential. This component is enhanced when subjects guess the improbable feedback of their voluntary response and when this feedback is unpredictable. The processing itself reduces the potential and thereby manifests itself by a reduction in negative or positive respectively. When discussing other associations with the readiness potential, the author mentions that the frontal readiness potential is probably related to the early, frontally predominant slow potential component, which is thought to represent the initiation of timing and contingency evaluation processes.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components II: Error processing in choice reaction tasks. *Electroencephalography and clinical Neurophysiology, 78,* 447-455.

RTs and ERPs of correctly performed and incorrectly performed trials were studied in a bimanual choice reaction task. In a focused attention (FA) condition, the stimulus modality was constant (visual or auditory); in a DA condition, the modality was varied at random from trial to trial. Stimulus- and response-triggered averages were computed from the midline EEG leads. In error trials, the ERP amplitude was reduced in the P300 range (300 to 500 ms) and enhanced in the SW range (500 to 700 ms) compared to correct reaction trials. Difference plots between the ERPs (incorrect minus correct reaction trials) revealed a large fronto-central negativity which the author calls an "error negativity" (N_E) and a parieto-occipital SW. These components appeared larger in the response-triggered averages. The authors believe that these components reflect two different stages of error processing. After auditory stimuli, the N_E peaked much later for DA than for FA, which supports the idea of an asymmetrical allocation of processing resources to the disadvantage of the auditory modality in our DA condition. Auditory stimuli also resulted a in delay of P300 and N_E, whereas visual stimuli did not. The N_E latency was influenced much more by attention than was the P300 latency. The N_E was assumed to represent an automatic mismatch between overt responses and the outcome of the response selection process.

Farah, M. J., Peronnet, F., Gonon, M. A., & Giard, M. H. (1988). Electrophysiological evidence for a shared representational medium for visual images and visual percepts. *Journal of Experimental Psychology: General, 117*(3), 248-257.

An imagery-perception interaction experiment was performed to determine whether mental imagery involves the activation of representations in the visual system. ERPs were recorded during the experiment and an effect of imagery was seen within 200 ms following stimulus presentation, at the latency of the first negative component of the visual ERP, directly over the visual cortex. This finding provides support for the claim that mental images interact with percepts in the visual system proper and hence that mental images are themselves visual representations.

Friedman, D., Brown, C., Vaughan, H. G., Jr., Cornblatt, B., & Erlenmeyer-Kimling, L. (1984). Cognitive brain potential components in adolescents. *Psychophysiology, 21,* 83-96.

ERPs were recorded in a cross-sectional study from 70 adolescents ranging in age from 11 to 18. A paradigm was used in which background, standard auditory events (66% occurrence) were randomly replaced by either a change in pitch or a missing stimulus, each occurring 17% of the time. All subjects at Fz had a frontal NSW which was larger in amplitude for relevant stimuli than for irrelevant stimuli; younger subjects had larger NSWs. In the absence of any stimulus-locked activity, the NSW appears as a long-duration, prolonged waveform lasting until the end of the recording epoch. A parietal positive SW was reported to have differentiated among levels of accuracy; whereas, the frontal NSW differentiated between the target and the standard stimuli at all levels of stimulus probability. The frontal SW was found during the reading and word detection conditions. The possibility that the frontal NSW could really be an early CNV was investigated and later dismissed since the comparison showed that these two potentials had distinctly different scalp topographies.

Grillon, C., Courchesne, E., Ameli, R., Elmasian, R., & Braff, D. (1990). Effects of rare nontarget stimuli on brain electrophysiological activity and performance. *International Journal of Psychophysiology, 9,* 257-267.

The effects of nontarget stimuli on task performance and electrophysiological activity were assessed in 16 subjects that performed RT experiments under three conditions. The subjects were required to press a button when they detected a rare target stimuli among frequent nontarget stimuli. The nontarget stimuli differed in each condition. In one, the nontargets consisted of "standard" stimuli (900 Hz). Deviant nontarget stimuli of either constant (700 Hz) tones or novel sounds were used in the other two conditions. Both the rare target and nontarget stimuli elicited P300 responses. Behavioral (RT) and electrophysiological data (ERPs) show that stimuli that followed standard stimuli were processed differently compared to stimuli that followed deviant nontarget stimuli. In the conditions containing deviant nontarget stimuli, the P3b to the target stimuli was smaller and later, and the mean RT longer than in the condition with no deviant stimuli. These behavioral and electrophysiological changes induced by the deviant nontarget stimuli are discussed with reference to two factors, distraction and increased level of task difficulty. It is suggested that each of these factors is differentially sensitive to the novelty of the rare deviant stimuli.

Hansen, J. C., & Hillyard, S. A. (1984). Effects of stimulation rate and attribute cuing on event-related potentials during selective auditory attention. *Psychophysiology, 21,* 394-405.

The goal of this study was to learn how attentional selectivity is influenced by variations in stimulus delivery rate. Auditory ERPs were recorded while subjects attended to a sequence of tones of one frequency ("target" tones) and ignored others of a different frequency and spatial origin ("standard" tones). Tone pips were delivered in random sequences in one condition while tone pedestals (tones of brief increments in intensity) were delivered continuously at two frequencies in another condition. The tone pips and pedestals were presented at interstimulus intervals (ISIs) which varied in length during the experiments. The major finding was that the broad negative ERP component (Nd) was elicited earlier (40 to 90 ms) when the ISIs were shorter. This finding was interpreted as a sign of a faster and more efficient rejection of attended-channel stimuli from further processing when stimuli were delivered more rapidly. However, the Nd wave did not differ in latency or amplitude between the tone pip and pedestal conditions at corresponding ISIs, suggesting that a high rate of information delivery is a more important factor in accelerating Nd onset than is the continuous reinforcement of the sensory cues that define the two classes of input.

Humphrey, D., Sirevaag, E., Kramer, A. F., & Mecklinger, A. (1990). *Real-time measurement of mental workload using psychophysiological measures* (NPRDC-TN-90-18). San Diego, CA: Navy Personnel Research and Development Center. (AD-A221 462)

The utility of ERPs as real-time measures of mental workload was investigated. Several measures of the P300 and SW amplitude of ERP components were recorded while subjects performed two tasks (a six-gauge monitoring task and a mental arithmetic task) both separately and together and at various levels of difficulty. Results support the hypothesis (that ERPs are useful as real-time measures of mental workload) with achievement of classification accuracies of 85% with 25 trials. A number of avenues for further exploration are discussed.

Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology, 17,* 259- 273.

A visual tracking task was performed while performing a concurrent task in which tones were covertly counted. The P300 component of the ERPs elicited by the tones was examined to determine the extent to which its amplitude was affected by variations in the forcing-function bandwidth, or difficulty, of the tracking task. P300 decreased in magnitude when tones were counted in conjunction with the performance of the tracking task, relative to a single-task counting condition. Increasing tracking difficulty failed to reduce P300 amplitude further. A second experiment obviated the possibility that movement-related potentials caused the P300 attenuation resulting from the introduction of the tracking task. In Experiment 3, subjects performed a RT task in conjunction with tracking in order to establish the validity of the tracking difficulty manipulation. The results are interpreted in terms of a theory of functionally-specific processing resources.

Kok, A. (1978). The effect of warning stimulus novelty on the P300 and components of the contingent negative variation. *Biological Psychology, 6,* 219-233.

This experiment evaluated the effects of stimulus and response probability on the P300 and components of the CNV in three different reaction tasks. The study reports a frontal NSW. The author takes this opportunity to determine if the NSW and the CNV are the same components. Based on the concept that the stimuli are novel, the early negative component of the CNV that has been referred to as "early CNV" or "O-wave" is a frontal manifestation of the SW part of ERP. The early CNV is determined by informative value of stimulus 1 (S1), and can be considered as the SW part of the ERP to S1. The late CNV is an event preceding negative shift that strongly related to the motor requirements of stimulus 2 (S2).

Kok, A. (1990). Internal and external control: A two-factor model of amplitude change of event-related potentials. *Acta Pscyhologica, 74,* 203-236.

This study critically examines the contributions of ERP measures in mental craniometry research. The present model cannot easily account for frontal NSWs elicited by warning stimuli in forewarned RT tasks. The amplitude increases after intense, novel, or informative warning stimuli. It is hypothesized that this frontal NSW represents parallel activation of two processing modes: External control and internal control. It is also possible that the negative potential shift represents simultaneous activities of these neural generators. For example, increased memory load is associated with an increase in sustained negativity and with increased amplitude for nontarget stimuli but not target stimuli. This internal processing mode (associated with selective inhibition of thalamic structures leading to suppression of distracting events in the environment) is activated by voluntary attention to difficult mental operations (i.e., memory search, mental rotation, and visual search) or motor preparation and is associated with increased sustained negativity of ERPs at the frontal and central electrode sites.

Kramer, A. K. (1990). *Physiological metrics of mental workload: A review of recent progress* (NPRDC-TN-90-23). San Diego, CA: Navy Personnel Research and Development Center. (AD-A223 701)

This report reviews research on physiological metrics of mental workload performed in the last decade. The focus of the review is on measurement techniques that have potential for fundamental explanation of mental workload and for use in operational environments. The techniques are examined within a framework of measurement criteria. These criteria include: Sensitivity, diagnosticity, intrusiveness, reliability, and generality of application. Over 200 articles are covered by the review. Measures reviewed include: EEGs, ERPs, magnetoencephalograms, positron emission tomography, electrooculogram (EOG), cardiovascular measures, pupillometry, respiratory measures, and electrodermal measures.

Kramer, A., Schneider, W., Fisk, A., & Donchin, E. (1986). The effects of practice and task structure on components of the event-related brain potential. *Psychophysiology, 23,* 33-47.

The present study focused on the effects of, and the interactions between, practice and task structure on human performance. The development of automatic processing through CM was assessed by means of measures of RT and ERPs. The subjects performed a visual search task in which they responded by pressing a button whenever a probe matched a memory set item. The variables manipulated in the study included the number of memory set items (1 or 4), the task structure (CM or VM), and the probability of occurrence of a memory set item (.2 or .8). Set size had a significant effect on RT in both CM and VM conditions prior to practice and in the VM condition following extensive practice. P300 latency mirrored RT, suggesting that the development of automatic processing substantially reduced stimulus evaluation time. The commonly observed relationship between probability and P300 amplitude, with large P300s elicited by infrequent events, was found in the VM conditions but not in the CM condition after practice. Two different negative components were affected by stimulus mismatch. The N200 component behaved in a similar manner during automatic and controlled processing. However, a late frontally negative component was sensitive to the degree of mismatch only during controlled processing.

Kramer, A. F., Wickens, C. D., Vanasse, L., Heffley, E. F., & Donchin, E. (1981). Primary and secondary task analysis of step tracking: An event-related potentials approach. In R. C. Sugarman (Ed.), *Proceedings of the 25th Annual Meeting of the Human Factors Society*, 43-47.

The utility of the ERPs for the evaluation of task load was investigated. Subjects performed a discrete step tracking task with either first or second order control dynamics. In different conditions, the subject covertly counted auditory probes, visual probes, or tracking target steps presented in a tracking task without a secondary task. In the auditory condition, an increase in the difficulty of the primary task produced a decrease in the amplitude of the P300 elicited by the secondary count task. The introduction of the primary task in the visual condition resulted in an initial reduction in P300 amplitude but increasing task difficulty and P300 amplitude was obtained in the step conditions. Furthermore, this effect did not require that the step changes be counted. The results are addressed in terms of the relative advantages of primary and secondary ERP workload assessment techniques.

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory & Cognition, 11,* 539-550.

ERPs were recorded while subjects silently read several prose passages presented one word at a time. Semantic anomalies and various grammatical errors had been inserted unpredictably at different serial positions within some of the sentences. There was a NSW for both terminal and intermediate words at all sites for semantically incongruent words and a positive SW for semantically congruent words. Closed class ("function") words elicited a larger negative component at Fz and Cz than did open class ("content") words. The authors conclude that a large negative component is specific to words that are unexpected or inappropriate in semantic content and suggest, that grammatical aberrations are processed in a different fashion (either qualitatively or quantitatively) from such semantic deviations. This study also indicates, that there seems to be a sensitive indicator of relationship between a word and its context and that whereas content words generally bear reference and carry the major semantic information load, function words provide syntactic structure by signaling relationships between content words.

Kutas, V., Van Petten, C., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences. *Electroencephalography and clinical Neurophysiology, 69,* 218-233.

This paper is an overview of the lateral distribution of ERPs recorded during silent reading in seven different experiments. Both single word and cross-sentence averages revealed the presence of several ERP asymmetries. The P1, P2 and a negativity between 300 and 500 ms were found to be larger over the right than left hemisphere. The authors conclude that asymmetric negativity is due primarily to the contribution of the N400 elicited by all content words. The degree of N400 asymmetry is affected by neither the rate of sentence presentation nor the ratio of congruent to incongruent sentences but is quite sensitive to family history of left-handedness. In contrast, the P1 and P2 asymmetries were uninfluenced by lexical class or familial sinistrality.

Lindholm, E. (1981). *Physiological and dual task assessment of workload during tracking and simulated flight* (AFOSR-TR-82-0714). Bolling Air Force Base: Air Force Office of Scientific Research.

HR, skin conductance, and ERPs were recorded during a visuomotor task of moderate complexity (tracking) and one of high complexity (simulated aircraft carrier landing). The tasks were first performed alone, then in combination with a tone discrimination task at two levels of difficulty in usual dual task fashion. The results of the dual task showed that subjects treated the tone discrimination task as "secondary." The physiological measures provided much more detailed interpretations and descriptions of training effects (practice), tone task information processing, individual differences, and visuomotor task control parameters than was possible by analysis of secondary task performance. This proves that the physiological method of measurement is preferred over the dual task method because of its nonintrusive nature and the greater detail of results afforded by the former method.

Lindholm, E., Cheatham, C., Koriath, J., & Longridge, T. (1984). *Physiological assessment of aircraft pilot workload in simulated landing and simulated hostile threat environments* (AFHRL-TR-83-49). Brooks Air Force Base: Air Force Human Resources Laboratory.

Two experiments were conducted in which the physiological responses (HR, skin conductance responses, ERPs, and eye movements) of naive subjects and Air Force rated pilots were measured while they flew aircraft simulators to assess pilot workload. The study concluded that HR was the most preferable measure because of its accuracy in tracking workload changes and its ease of measurement and quantification. ERPs display a significant potential as a measure of central nervous system activity and seem to indicate brain events relevant to information processing and decision making. It is possible the N2 component depicts a process more closely related to decision-making than does the P3.

Lindholm E., Ruppel, M., & Buckland, G. H. (1979). *Attention and task complexity as indicated by physiological indices* (AFHRL-TR-79-47). Brooks Air Force Base: Air Force Human Resources Laboratory.

The purpose of this study was to develop physiological measures of pilot attention and workload for use in flight simulation research studies and in future flight simulation training programs and equipment. HR, skin conductance, eye movement, and cortical evoked response were studied as measures of attention and arousal in both choice RT and letter matching tasks. For the choice RT tasks, the faster responses were in general associated with increased measures of arousal as indicated by HR, skin conductance, and evoked potential amplitude. There was no general arousal effect produced for the letter matching tasks; however, the cortical evoked response varied systematically and reliably with task difficulty and RT. In this regard, simple decisions evoked short latency, low amplitude brain waves, while more difficult decision evoked longer latency, higher amplitude brain waves.

Loveless, N. E. (1975). The effect of warning interval on signal detection and event-related slow potentials of the brain. *Perception & Psychophysics, 17,* 565-570.

The amplitude of a slow potential wave in the EEG was examined during performance of a signal detection task under several fixed intervals between warning signal and critical signal. It was observed that the probability of detecting the critical signal decreased as the interval increased and that this effect was due to a change in sensitivity rather than a change in criterion. The time-course of the change in sensitivity was related to that of the slow potential wave, which peaks shortly after the warning signal and then declines over a period of several seconds, and is interpreted as a component of the orienting response. It is suggested that the mechanism whose function is reflected in this wave also accounts for some effects of foreperiod duration and warning signal characteristics in RT tasks.

Loveless, N. E., & Sanford, A. J. (1974). Slow potential correlates of preparatory set. *Biological Psychology, 1,* 303-314.

A simple RT task was performed under the classical normal, sensory and motor "set" instructions. Computer averaging of the EEG confirmed that slow potential changes during the foreperiod may be analyzed into two components: An orienting response following the warning signal ("O wave") and an expectancy wave anticipating the reaction signal ("E wave"). The orienting response was not affected by instructions, but the amplitude of the expectancy wave was proportional to changes in the level of preparatory set as inferred from RT. Interaction between this effect and the intensity of the reaction signal suggests that the expectancy wave reflects shifts of the criterion governing the intensity required to initiate a response.

Loveless, N. E., Simpson, M., & Näätänen, R. (1987). Frontal negative and parietal positive components of the slow wave dissociated. *Psychophysiology, 24,* 340-345.

The so-called "slow wave" of the ERP is composed of a slow frontal negative shift and a slow parietal positive shift which usually are both present or both absent in records. A persistent question has been whether these slow shifts are generated by the same cerebral process or by two cerebral processes which tend to be evoked in very similar ways; that is, whether these two slow shifts can be dissociated. The present paper demonstrates such a dissociation. By recording these shifts to very infrequent auditory stimuli deviating in pitch from the frequent homogeneous stimuli of the sequence, a multitude of such data was obtained which permitted the identification and measurement of the slow frontal negative and the slow parietal positive shifts at the level of *single trials.* These data reveal no positive relationship between the amplitudes of the two shifts. Rather, the results show an opposite tendency; that is, a large frontal negative component was often associated with a small parietal positive component (or none) and vice versa.

McCallum, W. C. (1987). Some recent developments in ERP research related to cognitive function. In C. Barber, & T. Blum (Eds.), *Evoked potentials III: The Third International Evoked Potentials Symposium* (pp. 56-71). Boston, MA: Butterworth.

This chapter gives a general overview of recent ERP research through 1987. Most of the research is covered in this annotated bibliography. The author found that: Trials at which an object moves rapidly and over long distances elicit a larger negative shift at Fz than do those moving slowly and shorter distances; also, as the number of targets are increased, the amplitude of the NSW increases as well; the frontal NSW appeared during target stimuli; frontal NSWs are the clearest discriminators of task-relevant target stimuli; and as task demand increases, so does the amplitude of the negativity. Another issue discussed, but not fully resolved, is whether or not a NSW is actually the same component as an "early CNV"; late NSWs appear in situations that have been manifestations of an orientating responses often under the guise of an early CNV.

McCallum, W. C., Curry, S. H., Cooper, R., Pocock, V., & Papakostopoulos, D. (1983). Brain event-related potentials as indicators of early selective processes in auditory target localization. *Psychophysiology, 20,* 1-17.

To establish the stages of brain processing in an auditory stimulus localization task, ERPs were recorded from 24 normal subjects listening to brief white noise stimuli in a free-field situation from front, back, left, and right loudspeakers. The subject's task was to respond to "target" stimuli from one designated speaker. Performance varied as a function of sound location, stimuli in the front/back dimension being more difficult to localize than those in the left/right. There was a late negative component at Fz with an increased amplitude for the target stimuli decreasing for rare nontarget stimuli and even more so for frequent nontarget stimuli. The negative component serves to distinguish rare nontarget stimuli from frequent nontarget stimuli. The overall conclusions are that the relative weighting to be attached to attentional bias and feature detection remains equivocal. The indication is that a critical target property—in this case location in auditory space—can be identified by the brain at a very early stage of processing, provided that the selection demanded is not close to the limits of discriminability.

Näätänen, R. (1988). Implications of ERP data for psychological theories of attention. *Biological Psychology, 26,* 117-163.

The contribution of ERP research to understanding human SA is evaluated. A closely related issue, the starting point of the present treatment, involves the nature and extent of automaticity in information processing. The MMN component of the ERP suggests that the basic, obligatory, processing of the physical features of auditory stimuli is unaffected by the direction of attention. These data also reveal a possible mechanism for attention switching to stimulus change occurring in the unattended input, observed by cognitive psychologists. The N1 wave of the ERP might in turn provide a database for explaining similar attention switches to stimulus onsets after breaks in stimulation and to offsets of long-duration stimuli. With regard to SA, the processing negativity might make it possible to delineate the central principle of stimulus selection in attention, a goal probably inaccessible to nonphysiological attention research. In the visual modality, cognitive psychologists have found that spatial attention is more fundamental and powerful in stimulus selection than any other form of visual SA.

Consistently, ERP data show that the exogenous components in vision are enhanced by spatial SA but not when attended and unattended stimuli are not spatially separated. Also, ERP data (the P3 wave) give support to certain forms of resource-allocation theories of attention. In addition, with regard to the currently popular distinction between automatic versus controlled processing, these data strongly suggest that extended consistent-mapping training does not lead to a "genuine" automatization of a search process in the sense of independence of a limited-capacity system.

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of component structure. *Psychophysiology, 24,* 375-425.

In this study of human auditory evoked potentials, a CNV developed preceding relevant but not irrelevant stimuli. It is probable that the effects of prior preparation are manifest only when the task is particularly demanding (e.g., a difficult sensory discrimination rather than a simple button press). The attended stimuli had a larger amplitude than the unattended stimuli. It is suggested that the later negativity is from processing negativity in the frontal region or that frontal negativity is present only when the within channel task is quite difficult.

Okita, T. (1981). Slow negative shifts of the human event-related potential associated with selective information processing. *Biological Psychology, 16,* 29-47.

ERPs to random sequences of tones delivered to the right and left ears were recorded during a pitch discrimination task which required subjects to attend selectively to one ear at a time and respond to occasional "target" tones in that ear. A negative shift with a larger amplitude for attended stimuli than for unattended stimuli was reported at both Fz and Cz in all conditions. The negative shift lasted longer than the actual decision process. The conclusions regarding the negative shift were that: The onset latency of the negative shift can be an index for the initiation of operations after the decision that the stimulus belongs to a relevant class; the negative shift or processing negativity jointly reflect the activity of frontally located, modality-nonspecific generators associated with (voluntary) orienting to a relevant input and the activity of modality-specific generators associated with further processing of the stimulus; and the attention-related negative shift recorded predominantly from the frontal area can be regarded as continuously reflecting such momentary changes of the arousal capacity system in Kahneman's capacity model of attention and mental effort.

Okita, T., Konishi, K., & Inamori, R. (1983). Attention-related negative brain potential for speech words and pure tones. *Biological Psychology, 16,* 29-47.

ERPs were recorded during performance of a SA task in which speech words and pure tones were dichotically delivered at random. To estimate the attention-related negative shift, ERPs to unattended stimuli were subtracted from ERPs to attended stimuli. The difference waves for both nontarget words and tones demonstrated a biphasic wave form: A fronto-centrally distributed component with a peak latency at about 165 ms and a more frontally focused component which peaked about 300 ms. The scalp distributions, differential experimental manipulations, and developing time-courses suggest that the early negativity manifests the auditory discrimination activity of a task-relevant stimulus for deciding whether it is a target or not, whereas the late negativity reflects modality-nonspecific activation processes which may be associated with "momentary effort" or "orienting" triggered by detection of the task relevancy. Neither the early nor late components, however, presented hemispheric asymmetry corresponding to linguistic processing.

Parasuraman, R. (1980). Effects of information processing demands on slow negative shift latencies and N100 amplitude in selective and divided attention. *Biological Psychology, 11*, 217-233.

The influence of information processing demands on auditory ERPs in selective and DA was examined by varying the stimulation rate and target difficulty in a two-channel discrimination task. Subjects were required to detect targets in either one or both ears (channels) in a series of tones presented randomly to both ears. The result was a small but significant increase in amplitude for a slow negative shift for more difficult targets: The amplitude of the slow negative shift was fronto-centrally focused being larger at Fz than Cz (but not significantly larger). The author claims that the slow negative shift is most likely modality specific and that it reflects the "voluntary" attention to stimuli found to be relevant and demanding further processing.

Picton, T. W., & Hillyard, S. A. (1988). Endogenous event-related potentials. In T. W. Picton (Ed.), *Human event-related potentials EEG handbook* (rev. ed.) (Vol 3, pp. 361-426). New York, NY: Elsevier Science Publishers B. V. (Biomedical Division).

This chapter is a review of and support for much of the present research in the field of ERPs. One study mentioned suggests that the SW reflects the need for further procession of difficult-to-detect stimuli because the less confident the subject is regarding his/her detection of the target, the larger is the negative, frontally distributed SW amplitude. In support of this, the author points out that the SW seems to vary with the amount of processing required for a perceptual decision to the extent warranted either by experimental demands or the lack of sensory decisions by the subject. The conclusions are that: A late NSW in the frontal regions may be involved in the initiating or supervising of particular kinds of memory search, or NSWs may be associated with the initiation of extra processing that cannot begin until some information is obtained from an unexpected stimulus (since late negative waves are also reported in tasks that do not require semantic processing).

Rockstroh, B., & Elbert, T. (1990). On the relations between event-related potentials and autonomic responses: Conceptualization within a feedback loop framework. In J. W. Rohrbaugh, R. Parasuraman, R. Johnson, Jr. (Eds.), *Event-related brain potentials: Basic issues and applications* (pp. 89-108). New York, NY: Oxford University Press.

This chapter examines the relationship between ERPs and EMG. The CNV component of ERPs is correlated with blood pressure and HR. In the CNV, the ERP becomes gradually more negative and then drops as soon as a response occurs. Typically a CNV component is associated with standard conditions but not with distractor conditions. The amplitude of late negative shift or "terminal CNV" is sensitive to both the relevance of anticipated events and its response requirement, with or without a motoric component; this sensitivity is called "cerebral potentiality." In support of this, the author also mentions that the "terminal CNV" is sensitive to speed or accuracy, but not to muscle tension during the ISI.

Rohrbaugh, J. W. (1984). The orienting reflex: Event-related potential manifestations of the orienting reflex. In R. Parasuraman, & D. R. Davies (Eds.), *Varieties of attention* (pp. 350-371). Orlando, FL: Academic Press, Inc.

This chapter is an overview of the characteristics and explanations of the orienting reflex. The orienting reflex (also referred to as the "O wave" of the CNV component or the SNW2) is uniformally negative but, is most predominant at the frontal or central sites. It can be elicited even in nonsignal conditions and is a function of intensity in both signal and nonsignal situations. It is greater for low-probability stimuli than for high-probability stimuli. This orienting reflex is most frequently elicited by a warning stimulus. It is usually more enhanced if the foreperiod is long enough to overlap with anticipatory activity but can still be seen with a short foreperiod. The author also discusses that the comparison of the "O wave" following the warning stimulus with that generated in response to nonpaired stimuli, on a number of amplitude, temporal, and topographic criteria, indicates almost certainly that the two are identical responses. They also respond alike to a number of task, modality, and intensity properties. The O wave is distinctly asymmetrical in its bilateral representation; the asymmetry predominates at the frontal sites and lasts for 3 seconds or more. The asymmetry is confined to the SNW2, therefore suggesting that it is not an artifact. Regarding habituation, most have found no decrement, a growth in amplitude, or an anticipated habituation which may eventually return to original level amplitude or stronger. As for what can be explained by the study of the O wave, the author reports that it is most often associated with changes in the sensory and motor performances.

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1976). Brain wave components of the contingent negative variation in humans. *Science, 191,* 1055-1057.

In a CNV paradigm with two stimuli paired at an ISI of 4 seconds, two distinct waveforms having functional and topographic differences are observed. An early wave is maximal over the frontal cortex and is elicited by the warning stimulus. A later wave, maximal over the motor cortex, precedes the imperative stimulus and is identified with preparation for motor response. The CNV may be two or more separate processes combining in unrecognized proportion. Other reports show that CNV assumes two distinct and nonoverlapping phases when the ISI extends beyond 1 to 2 seconds. Phase I is a broad negative wave peaking within +/- 1 seconds after the warning stimulus. Phase II is a second negative shift which appears before the imperative stimulus if the ISI is constant and the responding speed is emphasized (there is an inverse relationship between the late wave and RT).

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1978). Cortical slow negative waves following non-paired stimuli: Effects of task factors.*Electroencephalography and clinical Neurophysiology, 45,* 551-567.

ERPs were measured for subjects in each of eight conditions: 1st and 2nd passive listening conditions; count stimulus condition; pitch discrimination condition; probability of occurrence condition; relevance and probability of occurrence conditions; and omitted stimulus condition. A NSW was reported to be maximal at Fz. The NSW was frontally located for the 2nd passive listening condition but was positive for the 1st passive listening condition. The negative after-wave was found to be sensitive to instructionally created task conditions. The possibility of the

association between the negative after-wave and a CNV is explored but not confirmed. In all cases, the waves reached their maximum peak at frontal sites and persisted as long as 2 seconds. Compared to no-task conditions, instructions simply to count stimuli produced a seven-fold increase in amplitude. Further enhancement was obtained by requiring a difficult pitch discrimination or by embedding the counted target stimuli in a train of more frequent nontargets. Separate conditions using simultaneous trains of visual and auditory stimuli trains (each train having both rare and frequent stimuli) established that the enhancement occurred only for stimuli in the designated target modality.

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1979). Cortical slow negative waves following non-paired stimuli: Effects of modality, intensity and rate of stimulation. *Electroencephalography and clinical Neurophysiology, 46,* 416-427.

Using a simple stimulus counting task, negative after-waves following single (unpaired) stimuli were investigated under a variety of stimulus conditions. Responses were obtained to tones at three intensities, to light flashes at three intensities, and to tones at three rates of presentation. The acoustic stimuli led to a negative after-wave that peaked at frontal sites around 500 or 600 ms, and then trailed off to a more central scalp representation. This negative after-wave was increased in amplitude by slowing the rate of stimulus presentation. In comparison, no appreciable or sustained after-wave was elicited by visual stimuli. No significant effects in the negative after-wave were associated with intensity, either for visual or for acoustic stimuli. When analyzed by Principal Components Analysis, the negative after-waves were shown to comprise in all cases two underlying factors, although the factors contributed less to the total waveform for visual stimuli than for acoustic stimuli.

Two interpretations for the negative after-wave are contrasted. One considers it to be an integral feature of the auditory evoked potential. A second interpretation, more compatible with the data obtained here, links the negative after-wave with nonspecific activation processes. There was an attempt to equate the negative after-wave with an early CNV; however, CNV is usually affected by intensity where in this study, the negative after-wave is not.

Rösler, F., & Heil, M. (1991). Toward a functional categorization of slow waves: Taking into account past and future events. *Psychophysiology, 28,* 344-358.

This study measured ERPs in relation to mental computational tasks and load on working memory. The math computations are associated with a positive frontal SW especially at Fz for division tasks. The remember trials produced substantially larger positive potential at Oz than did subtraction or division (500 to 2000 ms) and at Pz during memorization. Working memory load was more associated with a positive SW than a NSW and remembering was associated with a posterior positive SW. Also reported was a NSW, which was associated with the anticipation of subsequent stimuli. The conclusion was that this study demonstrates how functionally distinct SWs can be disentangled by a systematic manipulation of events which either precede or follow the SW activity. Moreover, it shows that recording epochs must be of considerable length, if the functional significance of SWs is the objective of research.

Rösler, F., Schumacher, G., & Sojka, B. (1990). What the brain reveals when it thinks: Event-related potentials during mental rotation and mental arithmetic. *The German Journal of Psychology, 14*(3), 185-203.

Slow ERPs (i.e., amplitude shifts prevailing for at least a few hundred milliseconds in the EEG) seem to be specific correlates of cognition. Previous work has suggested three hypotheses: (1) Tasks differing in quality are accompanied by topographically distinct SWs, (2) the amount of load imposed on the system becomes manifest in the amplitude gradient of a particular SW pattern, (3) tasks for which distinct processing stages are to be assumed for psychological reasons seem to be accompanied by systematic shifts of the SW pattern.

This experiment's results give support to these predictions. Ten male subjects had to solve mental rotation and mental arithmetic problems presented in a random sequence. The difficulty of both types of problems was a varied systematically. ERPs were recorded at midline from frontal and parietal cortex (Fz, Pz), and with two bipolar electrode pairs from left and right temporal and parietal cortex, respectively (T3-T4, P3 -P4). The results reveal clear between- and within-task differences of SW activity. Mental arithmetic is associated with a frontal positive component that increases in amplitude with increasing difficulty of the problems. Mental rotation, on the other hand, is associated with a parietal negative component, the amplitude of which increases with the increasing angular disparity of two images that have to be compared. Moreover, the decision in the mental rotation task on whether two images are identical or mirror images of each other becomes manifest at lateral electrodes and in a later time epoch than the rotation effect. These SW changes all appeared during the operational phase proper, that is, after the presentation of the relevant information and before the subject committed an overt response. The data suggest that SW activity might be a useful supplement to behavioral data if the objective of research is the exploration of mechanisms of human information processing.

Ruchkin, D. S., Johnson, R., Jr., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: An event-related brain potential study. *Electroencephalography and clinical Neurophysiology, 76,* 419-439.

This study measured ERP activity during short-term memory storage and the process of retaining information in working memory. A frontal NSW was reported at the highest memory load level but was completely absent from the search task (even as a function of memory load). There was a task-specific increase in amplitude for this frontal NSW. The discussion concludes that the frontal negative SW is associated with retention rather than the acquisition operations and the amplitude reflects performance effort not efficiency.

Ruchkin, D. S., Johnson, R., Jr., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology, 25,* 339-353.

This study is concerned with slowly varying, long-duration brain ERP components, referred to as SW activity. SW activity can be observed in the epoch following P3b, suggesting that it reflects further processing invoked by increased task demand, beyond the processing that underlies P3b. This experiment was designed to distinguish SW activity related to specific types of task demands which arise during difficult perceptual (pattern recognition) and

conceptual (arithmetic) mental operations. The study concludes that SWs are elicited under the following eight conditions: (1) difficult conceptual operations required, (2) semantic judgments/incidental memorization, (3) complex mnemonic memorization, (4) memory search, (5) retrieval of memory from abstract information, (6) learning occurs in stimulus sequence-generating rules, (7) processing low probable stimuli in a Bernoulli sequence, and (8) mental rotation. Some examples and explanations of SWs are: SWs increase as a function of task demand and/or improved process efficiency; the topographic differences in SWs may reflect the nature of additional processing; NSWs are associated with scanning and mental imagery; the SW at Fz becomes more negative as the task becomes more conceptually easy, but becomes more positive as the task becomes more perceptually easy (however, these results are not significant); the late SW reflects conceptual processing not perceptual processing.

Shelley, A. M., Ward, P. B., Michie, P. T., Andrews, S., Mitchell, P. F., Catts, S. V., & McConaghy, N. (1991). The effect of repeated testing on ERP components during auditory selective attention. *Psychophysiology, 28,* 496-510.

ERPs were recorded for subjects during a study of the long-term repetition effects on human auditory ERPs. Subjects performed the same multidimensional (location, pitch, and duration), auditory, SA task in which they were to attend to a tone that varied along the dimensions and detect a prespecified target that was a combination of those dimensions. The task was performed six times at 1 week intervals. The findings were not very conclusive, but they did provide practical implications for designing future SA experiments. For instance, highly practiced subjects should not be used for investigating the functional significance of the late frontally distributed processing negativity, and any study that requires repeated testing of subjects to study the effects of different treatments or conditions should use a repeated measures design that includes an initial recording session that is excluded from comparisons of treatment effects.

Simons, R. F., Rockstroh, B., Elbert, T., Fiorito, E., Lutzenberger, W., & Birbaumer N. (1987). Evocation and habituation of autonomic and event-related potential responses in a nonsignal environment. *Journal of Psychophysiology, 1,* 45-59.

This study sought to determine whether or not a specific ERP component is elicited by the orienting response (OR). Two experiments were conducted which induced orienting and habituation by presenting a novel stimulus and repeating its presentation at long and irregular intertrial intervals. At the end of the habituation series, a pitch or intensity change was introduced to elicit response recovery or dishabituate the response to the subsequent initial stimulus. Skin conductance (SC), alpha blocking, and, to a lesser extent, HR reflected these manipulations. It was hoped that the slow potential (O-Wave) would constitute an ERP component of the OR, but the O-Wave was actually smallest or even positive on early trials and grew larger until it reached an apparent steady state level. The P300 responded to the initial stimulus presentation and habituated to steady state responding very quickly, but it did not prove sensitive to the change in stimulus characteristics. It was concluded that while traditional notions of orienting are still applicable to some measures (e.g., SC, HR and alpha blocking), the complexity of ERPs seems to require a decomposition of the OR into more basic processes before relationships between specific ERP components and aspects of the OR can be elucidated in any detail.

Simson, R., Ritter, W., & Vaughan, H. G., Jr. (1985). Effects of expectation of negative potentials during visual processing. *Electroencephalography and clinical Neurophysiology, 62,* 25-31.

ERPs were recorded during several RT tasks: Simple RT; oddball choice RT; a condition in which subjects were told stimuli would change infrequently, but they did not (the LIE condition); differential responding to two equiprobable stimuli that were randomized in one condition and alternated in another condition. Subtracting ERPs elicited during simple RT from those elicited during the other condition, enhanced a negative component, NA, relative to simple RT, in all the other RT tasks. The data of the LIE condition indicate that NA was enhanced by the expectation that unpredictable stimulus changes would occur, even when they did not. The data of the 50/50 alternating RT condition indicate that stimulus changes by themselves enhance NA, even when they are predictable. There appear to be several deflections that comprise NA.

NA was obtained with a variety of subtractions that balanced stimulus probability, the structure of the stimulus sequence, and task instructions. Similar results were obtained whether subjects made a finger lift response or counted stimuli.

Sommer, W., & Schweinberger, S. (1992). Operant conditioning of P300. *Biological Psychology, 33,* 37-49.

In this study, an experimental group of subjects was rewarded for producing large P300 amplitudes and was compared with a yoked control group which was rewarded on a random basis. During training, the experimental subjects increased both the amplitude of the P300 and of a subsequent frontal NSW relative to the control group. The frontal, NSW was larger for targets than nontargets. The experimental subjects were more negative at Fz and more positive at Pz than the control subjects toward the end trials. The frontal NSW showed a three-way interaction between group, training block, and electrode site. At Fz, the NSW got larger over blocks or at least stayed constant for the experimental group, whereas the control groups' amplitudes got progressively smaller over blocks. In the initial random feedback condition, there was no group difference for either P300 or NSW. One possible explanation for this is that uptraining did not really affect the stimulus-specific processes but rather helped maintain a general responsiveness in the experimental group. However, the questionnaire responses do not support this hypothesis as neither group indicated a loss of interest in the study over time.

Stuss, D. T., Sarazin, F. F., Leech, E. E., & Picton, T. W. (1983). Event-related potentials during naming and mental rotation. *Electroencephalography and clinical Neurophysiology, 56,* 133-146.

The biphasic late negative wave (Nx-Ny) evoked during the naming of pictures of objects was investigated in a series of experiments. The monitoring of several possible non-cerebral generators indicated that these components were probably cerebral in origin. The Ny wave differed in scalp distribution from the preceding CNV. It was unaffected by stimulus duration or by stimulus repetition. The Nx-Ny complex occurred in both a naming task and a mental rotation task. The SWs following the biphasic negative wave differed significantly between these two tasks. In the mental rotation task, there was a large prolonged negativity in both parietal regions. The Nx wave (at approximately 250 ms) of the biphasic complex may represent the initial registration of the stimulus. The Ny wave (at approximately 420 ms) does not appear to be specifically related to semantic processing. Rather, it may index some process involved in initiating the further evaluation of a complex stimulus. The SWs that follow the biphasic negative complex may reflect the actual perceptual processing of the stimulus. Three other important results are: (1) the orienting wave ("O wave") usually habituates with stimulus repetition; (2) response latency was longer in Nx-Ny waves, suggesting that the waves occur during stimulus evaluation rather than during the memory filing operation following stimulus evaluation, and in general; (3) high confidence in responses resulted in larger NSW amplitude.

Sutton, S., Ruchkin, D. S., Munson, R., Kietzman, M. L., & Hammer, M. (1982). Event-related potentials in a two-interval forced-choice detection task. *Perception & Psychophysics, 32,* 360-374.

In an attempt to elucidate the nature of the subject's strategy in a two-interval forced-choice auditory detection task, ERPs were studied at two intensities which yielded mean accuracies of 82% and 98%. A NSW was reported at Fz with greater amplitude for signal presentation, hi-intensity, and first observation than for absent signal, lo-intensity, or second observations. The Fz was also reported to be sensitive to information load. The findings suggest that the various aspects of processing, which are presumably reflected by the different components, are all affected by the properties of the task which result in focusing primarily of signal presence.

Trejo, L. J., & Kramer, A. F. (1992, June). *ERP indices of performance signal detection, running memory, and computation.* Paper presented at the Fourth Annual Convention of the American Psychological Society, San Diego, CA.

ERPs were recorded from eight experienced male Navy technicians with training and experience in monitoring electronic displays during three radar monitoring tasks (signal detection, running memory with letters, and computation) to determine the extent to which measure of ERP components account for normal fluctuations in human performance. The variance reflected by ERPs due to task-relevant and irrelevant probe stimuli was also studied. Several conclusions were drawn: (1) ERP measures accounted for a large fraction (up to 69%) of the variance in performance quality; (2) relevant-stimulus ERP measures were much more effective and reliable predictors of performance than irrelevant-stimulus ERP measure; (3) measures of ERPs constructed from running means of 10 epochs were good indices of performance in all tasks and much better than single-epoch measures; (4) individual differences in the success of ERP measures as indices of performance were large; in particular, no consistent pattern in the set of predictors that entered the models was seen across subjects. Future research will address more realistic tasks, cross-modality probe stimuli, and individualized, adaptive models (e.g., neural nets) for prediction of performance from ERP data in real time.

Trejo, L. J., Kramer, A. F., & Humphrey, D. (1992). Differential workload sensitivity of early and late components of the auditory probe ERP. *Psychophysiology (Supplement), 29,* S70.

The hypothesis that early and late components of irrelevant probe ERPs would be differentially sensitive to levels of difficulty of a simulated real-world task was tested. More specifically, it was speculated that P300 would reflect the transition from baseline to low workload conditions while N100 would provide a graded index of workload demands.

In a baseline condition subjects responded to one of two deviant events in a train of standard (1500 Hz, .80 probability) and deviant (1000 Hz & 2000 Hz, .10 probability each) tones. In the low and high workload conditions subjects were instructed to ignore the tones as they detected and classified visual events as friendly or hostile. Difficulty was manipulated by varying the visual event frequency and difficulty of classification.

EEG from Fz, Cz and Pz and horizontal and vertical EOG was recorded as subjects performed the tasks. Components measured included N100, P200, N200, P300 and MMN. N100, P200, P300 and MMN each decreased in amplitude from the insensitive to the transition from the low to the high workload condition. In fact, the P300 was literally abolished in the low workload condition. This same pattern of results was found for the N200 component. On the other hand, N100 and the MMN decreased monotonically from the baseline, to the low workload, to the high workload condition.

These data suggest a differential change in the efficiency of early (e.g. N100, MMN) and late attentional processes (e.g. P300) with increases in the difficulty of a simulated real-world monitoring task. Additionally, our data suggest that the MMN is no invariant to attentional demands.

Trejo, L. J., Ryan-Jones, D., & Kramer, A. F. (1992).Attentional modulation of the pitch-change mismatch negativity. *Psychophysiology (Supplement), 29,* S71.

Recent findings have questioned the assumption that the MMN is insensitive to attentional demands. In the present study we examine the degree to which MMNs elicited by changes in frequency are sensitive to the direction of attention.

To that end subjects were presented, via headphones, with a monophonic mix of two auditory streams. One stream was an interesting story while the other stream consisted of three different tones, two of which occurred infrequently (1000 & 1400 Hz, with .10 probability each) and one which occurred 80% of the time (1200 Hz). In one condition (attend tones) subjects were instructed to respond to one of the deviant tones and ignore the story while in the other condition (attend story) subjects were instructed to respond to a target word in the story and ignore the tones.

EEG was recorded from Fz, Cz and Pz sites, referenced to averaged mastoids. Vertical and horizontal EOG was also recorded. Subjects average ERPs were computed for each of the tones (nontarget deviant, target deviant, standard) and difference waves, subtracting the standard from the nontarget deviant, were computed separately for the periods between 100 and 180 ms (DN1) and 200 to 300 ms (DN2).

Amplitudes of N100, P200, and P300 were significantly lower in the attend-tape condition than in the attend-tones condition. The magnitudes of these differences ranged from .4 to .8 μV. Analyses of DN1 and DN2 followed the same pattern, being reduced in the attend story condition by .6 and .5 μV respectively. Comparisons with the average ERPs indicated that the DN1 arose from differences in the N1 component, but the differences in DN2 appeared to be related to the MMN. This conclusion was also supported by the absence of an effect for the N200. These data support the idea that MMN is sensitive to attentional modulation. More specifically, the pitch-change MMN is attenuated when attention is directed away from the eliciting stimuli within a single auditory location.

Wijers, A. A., Okita, T., Mulder, G., Mulder, L. J. M., Lorist, M. M., Posesz, R., & Scheffers, M. K. (1987). Visual search and spatial attention: ERPs in focussed and divided attention conditions. *Biological Psychology, 25,* 33-60.

ERPs and performance were measured in divided and FA visual search tasks. In FA tasks, to-be-attended and to-be-ignored letters were presented simultaneously. Display load, mapping conditions and display size were varied. RT, P3b-latency, and negativity in the ERP associated with controlled search all increased with display load. Each of these measure showed selectivity of controlled search, in that they decreased with focusing of attention. An occipital N230, on the other hand, was not sensitive to focusing of attention, but was primarily affected by display load. ERPs to both attended and unattended targets in FA conditions showed an N2 compared to nontargets, suggesting that both automatic and controlled letter classifications are possible. These effects were not affected by display size. Consistent mapping resulted in shorter RT and P3b-latency in DA conditions, compared to varied mapping conditions, but had no effect in FA conditions.

Woods, D. L. (1990). The physiological basis of selective attention: Implications of event-related potential studies. In J. W. Rohrbaugh, R. Parasuraman, & R. Johnson, Jr. (Eds.), *Event-Related Brain Potentials. Basic Issues and Applications.* (pp. 178-209). New York, NY: Oxford University Press.

SA has different effects on visual ERPs, depending on the attribute attended. For example, when subjects attend to stimuli in the periphery, "exogenous" ERP components, those elicited by the same stimuli when attention is directed elsewhere, are enlarged. In contrast, when the subject attends to stimulus color, "endogenous" components, not present in the ERP to nonattended stimuli, appear to be added to the ERP.

Unlike the negative enhancement of ERPs seen with auditory attention, both positive and negative components of ERPs to objects in attended positions in space can be enlarged, including the occipital P120-140 component (latencies for this component range from 120 to 140 ms in different studies) and the fronto-parietal N170-190 component (sometimes seen at occipital sites some 20 to 30 ms later than "parietal electrodes.") The P120-140 usually show a bilaterally symmetrical enhancement, while the contralateral enhancement of endogenous slow potentials, including a broad negative component, the N190-280 and a variable positivity, the P300-500. These enhancements are not the result of a redirection of gaze.

Some important implications for future ERP research on SA are: SA engages processing in multiple brain areas; SA engages multiple processes; Attention to different stimulus features engages selective processing in different brain areas; Attention engages modality-specific processes; Attention modulates exogenous responses and invokes endogenous brain processes; SA does not modulate sensory impulses prior to their arrival at the cortex; The earliest ERP signs of SA reflect the establishment of a preparatory set; Attention inhibits the processing of nonattended inputs; Novel stimuli are processed equivalently whether attended or not; The aperture of short-latency ERP attention effects is wide; SA involves a comparison of the features of the current stimulus with those of previously presented stimuli; The latency of SA effects changes with task difficulty; and SA involves the parallel analysis of stimulus features.

Adaptive Training

Cote, D. O., Williges, B. H., & Williges, R. C. (1981). Augmented Feedback in adaptive motor skill training. *Human Factors, 23,* 505-508.

Two studies were used to assess the need for augmented feedback in adaptive training situations. In each study, a two-dimensional pursuit tracking task was used for both training and transfer of a complex perceptual motor skill. Students learned using either fixed difficulty or adaptive training techniques. There were no reliable effects due to the augmented feedback training or transfer, but subjects performed better in transfer when they used adaptive training than fixed difficulty training.

Gaines, B. R. (1974). Training, stability and control. *Instructional Science, 3,* 151-176.

This paper presents a system-theoretic approach to the analysis of the problem of training. It is formally related to the control of an abstract dynamic system, the "adaption automaton" of the trainee. The utility of this formulation and the possibility of basing real training strategies upon it are discussed. It is argued that further constraints upon the automaton are both necessary, and available, in so far as the theory corresponds to practical reality. The minimal constraints generate an extended theory in which training is related to the stability of the adaption automaton. More practical constraints lead to theoretical foundations for strategies of "feedback" or "adaptive" training. Corresponding to each set of constraints, a "training theorem" is proved which demonstrates that the constraint is adequate to lead to a simple universal training strategy.

Gopher, D., Williges, B. H., Williges, R. C., & Damos, D. L. (1975). Varying the type and number of adaptive variables in continuous tracking. *Journal of Motor Behavior, 7,* 159-170.

This study investigates the implications of adapting stimulus and response variables, the effect of varying the number of adaptive variables, and the evaluation of adaptive techniques in training for transfer of changing task conditions. Subjects performed a two-dimensional pursuit tracking task for five 3-minute training sessions. In the factorial design resulting in eight experimental conditions, three variables (frequency of the forcing function, ratio of acceleration to rate control, and control stick sensitivity) were either fixed or adaptive. A transfer and retention task in which the tracking situation changed periodically was used to evaluate the ability of subjects to adjust to change. Each adaptive variable was analyzed separately in training. The highest rate of adaptation in frequency occurred when frequency was the only adaptive variable. The rate of adaptation in acceleration was greater early in training when frequency also adapted. More adaptation occurred in gain when another variable also adapted. During transfer subjects trained adaptively generally showed more stable performance in the changing task situation. No reliable differences among conditions appeared in retention.

Johnson, D. F., & Haygood, R. C. (1984). The use of secondary tasks in adaptive training. *Human Factors, 26,* 105-108.

The purpose of this study was to demonstrate the feasibility of conducting adaptive training by adapting primary-task difficulty on the basis of secondary-task performance. Adaptive-training was shown to be more effective than fixed training. The results concluded that adaptation of primary-task difficulty based on secondary task performance is a straightforward method of conducting adaptive training. Also, the use of secondary-task criterion can impede primary-task adaption. The use of the individually yoked method (fixed-training subjects were individually yoked to the adaptive-training subjects) ensures that task difficulty is equal for both sets of subjects.

Lintern, G., & Gopher, D. (1978). Adaptive training of perceptual-motor skills: Issues, results, and future directions. *International Journal Man-Machine Studies, 10,* 521-551.

This article reviews the assessment of adaptive training (AT) as a method for teaching control skills and establishes a conceptual framework that will allow a detailed analysis of adaptive manipulations and their influence on skill acquisition. An examination of the major studies in adaptive training reveals that support for the application of AT to applied motor skill training is lower than expected. A detailed analysis of motor skill theory and research shows that AT may be an effective training device. This article outlines several empirical tests that may enable a more effective analysis of adaptive training.

Ricard, G. L., & Norman, D. A. (1975). *Adaptive training of manual control: Performance measurement intervals and task characteristics* (IH-252). Orlando, FL: Naval Training Equipment Center.

The relationships between the measurement of trainee performance and the parameters of the simulated airframe of an adaptive, aircraft roll-control, training task were examined as an extension of the findings of a previous study. Five values for the performance measurement interval (PMI) were chosen to bracket the roll rate time constant of the simulator's lateral transfer function, and an acquisition-then-transfer experimental design was used to assess trainee skill development. A previous study suggested a 20-second PMI as appropriate for a roll control task. Data from this study confirm this and also reinforce the contention that relations exist between rules of the adaptive logic and parameters of the simulated airframe. Another conclusion is that poor acquisition task performance is a result of a short PMI requiring more trials to acquire the roll-control skill elevating their training cost.

Several recommendations are discussed for future studies:

1. Vehicular dynamics should be considered when parameters are selected which define the action of an adaptive training system.

2. A long PMI (20 seconds) for the measurement of longitudinal control should be used for roll control assessment.

3. As the acquisition of roll control is a relatively easy task, investigators of aircraft control who have to select an axis to activate would do well to choose the longitudinal one. The time trainees need to produce criterion pitch-control performance is the largest contributor to the costs of training aircraft dynamic control skill.

4. Acquisition and transfer performance may be related to parameters of the adaptive system. A final confirmation of these relations should be obtained in a 2-axis control task where PMIs are factorially combined with different phugoid frequencies. A wide spread of phugoids would probably be needed to produce differences in trainee performance, and the parameters of the 2-axis task transfer functions should be chosen accordingly. It is recommended that the necessary spread should be achieved by the different experimental conditions representing a real aircraft at different points in its flight envelope.

Savage, R. E., Williges, B. H., & Williges, R. C. (1982). Empirical prediction models for training-group assignment. *Human Factors, 24,* 417-426.

Two sample regression equations were used as empirical predictor models to improve the efficacy of the choice to train someone with adaptive training or fixed training. The use of the regression approach to match subjects to the type of training reduced training time almost 50%, compared to random assignment. There was a 40% reduction in the variability in training time with the use of the empirical prediction models for assignment. This reduction could be important when training periods are time constrained. These results do not suggest that the training type selected for an individual student was optimal, only that it was the better of the two techniques available.

Smirnov, S. A., & Kolovskaya, I. B. (1990). Dynamics of reactions of nonspecific and somatic activation during biofeedback training. *Neuroscience and Behavioral Psychology, 20,* 5-11.

This study confirms that the training of adaptive biocontrol is a form of instrumental conditioning. The dynamics associated with the indices of respiration, electromyographic activity of the hand muscles, HR, and EEGs during training of voluntary upward and downward regulation of skin resistance and skin temperature were studied. The data indicate that the initial stage in adaptive-biocontrol training is connected with the involvement of systemic activational reactions displaying similar characteristics during the regulation of different parameters, skin resistance and skin temperature, both when these parameters are raised and when they are lowered. The manifested activational shifts constitute a nonspecific reaction characteristic of training and extinguishing during the gradual specialization and reinforcement of the biofeedback skill. Also, individual learning strategies and a fairly broad spectrum of visceral processes, which could be involved when learning voluntary control of vegetative parameters, showed that involvement of systemic reactions is not a necessary condition for learning adaptive biocontrol.

Williges, B. H., Roscoe, S. N., & Williges, R. C. (1973). Synthetic flight training revisited. *Human Factors, 15,* 543-560.

Review of the critical issues in the development and use of synthetic flight trainers shows a need for a broader application of simulation to meet the new demands of pilot training,

certification, and currency assurance in air transportation. Adaptive training is suggested as an improvement over fixed in synthetic flight training. Examples of adaptive training include: Automatically increasing the average amplitude of the forcing function for a tracking task as a student learns; requiring a student to handle more and more subtasks simultaneously in accordance with his or her immediately preceding performance; and introducing new and different tasks as old tasks are mastered. Other recent training innovations discussed are computer-assisted instruction, cross-adaptive measurement of residual attention, computer graphics, incremental transfer effectiveness measurement, and response surface methodology.

Williges, R. C., & Williges, B. H. (1978). Critical variables in adaptive motor skills training. *Human Factors, 20,* 201-214.

This paper evaluates critical variables dealing with the performance measurement procedure, the choice of the adaptive variable, and the appropriate adaptive logic. The results of a series of laboratory studies are reviewed, and several suggestions for additional research as well as a general model of instruction are discussed. It is recommended that adaptive training (AT) use stimulus-related variables rather than response-related variable. Adaptive logic is desirable because it manipulates levels of difficulty in three ways: (1) It provides progression in two dimensions either to a new task or a new task stressor, (2) it can use two remedial branching strategies, and (3) random exercise presentation can be used. AT individualizes motor skills instructions. Matching instructional strategy and individual characteristics are reported to be critical for optimal training. Effective motor skills training should also involve multivariate performance measurement schemes which manipulate stimulus-related adaptive variables in connection with closed-loop adaptive logic models that are optimized for individual-differences.

Wood, M. E. (1969). Continuously adaptive versus discrete changes of task difficulty in the training of a complex perceptual-motor skill. *Proceedings of the 77th Annual Convention of the American Psychological Association, 4,* 757-758.

Adaptive training utilizes measures of subject performance to adjust automatically the difficulty of the perceptual-motor task being practiced. Through the use of this technique it is possible to vary some measure of task difficulty as a function of subject performance while maintaining some overall level of practice error constant. This is in contrast to the nonadaptive situation in which task difficulty is set at a constant level and subject error is free to vary. Because level of error can be taken as an indicant of taskload, the adaptive procedure is particularly appealing in that it provides some measure of experimental control over levels of taskload.

In the adaptive studies reported to date, major emphasis has been given to a continuously adaptive training situation in which some medium level of subject error or subject taskload is maintained constant on a moment-to-moment basis. In those studies which tested the efficiency of this approach, it has been shown that this technique can be superior to (1) training on the criterion task itself, or (2) training at arbitrary levels of increasing fixed difficulty. However, no comparison of training effectiveness has been made between a continuously adaptive task and a task which employs increasing levels of fixed difficulty which increase in magnitude at the same rate as the continuously adaptive task to set a schedule of difficulty change for fixed practice, comparisons can be made between the two approaches.

The purpose of this study was to compare two methods of training naive subjects in a two-dimensional, second-order tracking task using adaptive training techniques. The first method employed an automatic, self-adjusting technique which allowed task difficulty to vary during practice while maintaining subject error at a constant average level of medium magnitude. The second method employed increasing levels of fixed difficulty during practice which corresponded to the session-to-session median difficulty of the continuously adaptive group.

Glossary

ATL	Anterior Temporal Lobectomy
CM	Consistent Stimulus-Response Mapping
CNV	Contingent Negative Variation
DA	Divided-Attention
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electrooculogram
ERP	Event-Related Potential
EW	Electronic Warfare
FA	Focused Attention
HC	High Creative
HR	Heart Rate
ISI	Interstimulus Interval
MMN	Mismatch-Negativity
MPD	Mean Power Density
MR	Mental Rehearsal
NAVPERSRANDCEN	Navy Personnel Research and Development Center
NSW	Negative Slow Wave
OR	Orienting Response
PMI	Performance Measurement Interval
RT	Reaction Time
SA	Selective Attention
SC	Skin Conductance
SW	Slow Wave
VDU	Visual Display Unit
VM	Valuable Stimulus-Response Mapping
YSOLAT	Your Style of Learning and Thinking (Children's Form A)

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