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The Effects of Stimulus Intensity on the Cognitive P3 Evoked Response

Marilyn Louise Farnsworth Dille

A dissertation submitted in partial fulfillment of the  
requirements for the degree of

Doctor of Philosophy

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Abstract

The Effects of Stimulus Intensity on the Cognitive P3 Evoked Response

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Short-term memory problems are a normal part of aging but they can also indicate early signs of dementing diseases such as, Alzheimer's. The P3 cognitive evoked response is a technique thought to directly assess short-term memory function. However, it has not been shown to be sensitive to mild short-term memory disorders. The P3 procedure is not standardized and this lack of sensitivity can be attributed, in part, to stimulus related factors used to generate the response.

The purpose of Experiment 1 was to investigate the effect of increasing stimulus intensity on the P3 response. Many clinical populations cannot be counted upon to actively listen during the P3 discrimination task. It was hypothesized that the alerting effects of high stimulus intensity would cause a passive listener to generate a P3 response that was identical to an active listener. High intensity stimuli increased the prevalence of the P3 response. Additionally, the P3 latency shortened and the P3 amplitude was increased using high level stimuli. However, the P3 response obtained during passive listening was significantly different from the P3 response during active listening in young adults from the general population.

P3 responses obtained from these two listening strategies should not be compared, especially at low stimulus intensities.

The purpose of Experiment 2 was to compare equal and unequal relative toneburst intensities on the P3 measures. Hearing loss is a common finding among clinical populations with memory problems and can make the oddball tone unequal in loudness to the standard tone. It was hypothesized that changes in the salience of the discrimination task resulting from changes in the relative loudness of the tone pairs would change the P3 measures. It was found that the P3 response were less prevalent and longer in latency when subjects listened passively and the tonebursts were unequally intense, a listening condition common for individuals with dementia and hearing loss. Since a significant finding among clinical populations on whom the P3 might be applied is a prolonged or absent response, it is very important that the discrimination task be done at high intensity levels with the tones equally loud. If comparison are to be made between groups, both groups should be using the same listening strategy.

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## Chapter I Introduction

To understand the auditory information around us, many physiologic systems are required to work in a coordinated way. Sensitive hearing is required to accurately receive information. Attention is crucial to fully focus on events around us. Memory systems provide context and meaning to the auditory information. How these systems work in a coordinated fashion is not well understood. However, it is known that developmental immaturities, trauma and disease can disrupt these coordinated efforts impairing our ability to understand the events around us (Courchesne, 1978; Goodin, Starr, Chippendale, & Squires, 1983).

To understand any breakdown in information processing, an independent assessment of each system is important. Compensation techniques can then be taught that are more appropriately tailored to the needs of the individual. Currently, assessment of information processing is a difficult undertaking. Formulation of an assessment test is often based on theoretical models of each processing system and how other systems interact with it. Because of these theoretical models, neuropsychological assessments have been developed. These tests have improved the focus of assessments but many discrete functions proposed by these models are still not testable in isolation. For example, getting an accurate assessment of the short-term memory ability of a person who has an orientation or attention deficit is difficult. It is clear that how carefully a person attends to a given task will effect how well the task is carried out. Teasing apart the discrete function of one system when another system can affect the outcome measure makes the assessment more difficult. For example, assessing the effects of intensity in a system that behaves differently as a function of attention presents a complex assessment obstacle.

New measurement tools are now available for the neurophysiological assessment of information processing. These tools involve measuring electrical discharges in the auditory

nervous system in response to sound. These tools offer the advantage of observing discrete systems as they process information "on line". For example, it is now possible to measure discrete events as they occur in the auditory nerve, as they progress up the brainstem, and as they arrive in the auditory cortex. Electrophysiological measures are now available that are thought to reflect sensory memory and short-term memory processing separately: the mismatched negativity (MMN) response and the P3 cognitive response (Naatanen, 1990; Ruchkin, Johnson Jr., Canoune, & Ritter, 1990).

Neurophysiological assessments hold the potential for the independent measurement of information processing subsystems.

The discrete measurement of these subsystems to detect pathology, however, is still more of a potential than a reality. For example, the measure of short-term memory disorders using the P3 response has met with only limited success (Filipovic & Kostic, 1995; Verlager, Kompf, & Neukater, 1992; Vieregge, Verlager, Schulze-Rava, & Kompf, 1992). In part, the difficulty lies in the technique required to generate the response. This technique still requires the subject to be focused and attentive. This requirement can introduce a potential interaction that can effect the true measurement of short-term memory function. Thus, the contributions from other processing subsystems are reflected in the P3 response as well. Whether measured neurophysiologically (e.g., P3) or neuropsychologically (behaviorally), information processing still remains the sum of several subsystems operating cooperatively.

Peripheral processing (i.e., hearing sensitivity or frequency resolution) and attentional focus are known to influence the the P3 latency (Polich, 1989a; Polich, 1989b). Both could be thought of as "filters" through which the stimulus must pass prior to gaining access to short-term memory resulting in the P3 response. Peripheral hearing loss, for example, could make an otherwise audible signal barely audible. It is known that low level signals increase the latency of the P3 response, suggesting that access to short-term

memory is influenced by variables not solely related to short-term memory abilities. The characteristics of these "filters" need to be better understood. New knowledge in this area may eventually allow us to better understand the factors effecting the P3 response, leading to a P3 response that accurately reflects short-term memory processing alone.

The purpose of this study is to define some known influences on the P3 response exerted by other information processing subsystems so that the response can become a more effective measure of short-term memory abilities especially in a clinical population. Two known influences are attentional focus and peripheral sensitivity (Musiek, Baran, & Pinheiro, 1992; Polich, 1987a). In the first experiment, the hypothesis is that attentional focus on an auditory signal can be influenced in various ways. The most common way in normal listeners is to simply tell the subjects to pay attention to what they hear. This manipulation, however, works less well on subjects who cannot be counted on to follow directions e.g., subjects with dementia. In this clinical population, inattention rates may be high despite the instructions to listen carefully. Since it is known that high-intensity signals capture attention involuntarily (Scarf, 1989), a stimulus perceived as loud may make an inattentive subject pay more attention and behave more like an attentive subject. In this study, P3 responses were collected as a function of intensity in two conditions, inattentive and attentive, in normal listeners. In the first condition, the subjects were told to ignore the sounds that they heard. At the same time, a mildly-distracting alternative activity was provided. In the second condition, the subjects were directed to attend to the auditory signals by indicating when they were heard.

The second experiment focused on the potential influence of peripheral hearing loss on P3 measures. When an individual has hearing loss, loudness perception can be distorted and it is known that the relative loudness of the stimuli can effect the P3 measures (Polich, 1987b). Many clinical populations (e.g., dementia, Down Syndrome) on whom the P3 response has been targeted are at high risk for hearing loss (Gold, Lightfoot, &

Hnath-Chisolm, 1996; Polich, 1987b; Widen, Folsom, Thompson, & Wilson, 1987). It is the hypothesis of the second experiment that peripheral sensitivity is an important influence on the P3 response. A typical listening situation of persons with hearing loss was simulated for normal listeners while collecting the P3 response. Understanding and controlling the influences of attention and peripheral sensitivity on the P3 response enables the response to more accurately reflect the discrete function of short-term memory processing.

## Chapter II Review of the literature

The goal of this review is to further our understanding of how attentional and peripheral hearing loss affect the P3 response. The processing of auditory information requires the coordinated action of several systems. While short-term memory processing is thought to be primarily reflected in the P3 response, other systems of information processing can influence the response as well. These influences can slow down but they can also facilitate short-term memory processing. Control over these influences can be gained through stimulus parameters that are known to facilitate information processing. To better understand the interaction between these systems, a review of information processing models and the cognitive P3 response is necessary. Populations with short-term memory disorders are reviewed with particular focus on the occurrence of coexisting disorders such as, attention deficit and peripheral hearing loss. Finally, models are proposed to predict the interaction between the P3 response and the subsystems of attention and peripheral sensitivity. These models are then tested experimentally.

### A. Human Information Processing

One of the earliest models for human information processing was proposed by Broadbent (Broadbent, 1958). This model was developed to explain the processes of selective attention and memory capabilities in sensory processing. Broadbent proposed this model to explain how some stimuli are chosen for processing and storage while other stimuli are ignored or only minimally processed. A criticism of this model was the "pipeline" approach it took to sensory processing. That is, it suggested that information was passed along in a fixed order of sensation to short-term memory store and, then, to long-term memory store. Many information processing models have been proposed since this Broadbent model (Baddeley, 1990; Cowan, 1988; Naatanen, 1990) each refining the processes of storage, attention and sensation. To date, no particular model is widely

accepted.

One widely cited information processing model was proposed by Nelson Cowan (1988) and its simplified version is shown in Figure 1. Within the model are elements for brief (sensory), short-term, and long-term storage and for attentional focus. Each storage system is defined by its storage capacity and length of store. As the stimuli arrive, the brief store is used to hold a neural representation of the stimulus for up to a few hundred milliseconds so that further processing may proceed. Those stimuli that are not voluntarily processed, do not change over time, and have no alerting context or meaning to the person, are habituated i.e., no longer cause an effect. When a change occurs in the stimulus or when associations are made between the incoming stimuli and long-term memory, the attentional filter may intervene to select those signals for preferential processing. The final element of information processing is the effortful control of processing represented in the central executive. The central executive interacts with memory stores to select stimuli for rapid, preferential processing and to aid in the formulation of new associations within short- and long-term memory.

The components of information processing are closely associated and interact with one another to influence what is processed and how completely and quickly it is processed. Research has shown that features of the stimulus can influence the speed of processing by capturing the attentional focus. Clearly, components or systems involved in information processing influence one another in significant ways

## B. Attention and Hearing

No discussion of auditory assessment can avoid the topic of attentional influences on sensitivity and perception. Attentional focus is closely related to processing depth. That is, when attention is directed toward a sound, the listener is better able to remember and describe that sound. Naatanen (1990) reported on an experimental demonstration of this effect. Listeners were instructed to attend to a message in one ear while ignoring a

competing message in the other ear. Not surprisingly, when asked later what they heard, the information from the attended ear was elaborately processed including semantic attributes of the message while the ignored information was only sporadically retained with few semantic associations.

A further demonstration of the effect of attention on performance was provided by Tomporowski, Hayden and Applegate (1990) using young adults from the general population and adults with developmental delay. One feature of developmental delay is attention deficits. Both poorly maintained and poorly focused attention (vigilance and selective attention, respectively) can lead to poorer performance even in tasks seemingly unrelated to attention. In this experiment, both groups of subjects were asked to identify missing digits in a series of digits progressing at either a fast or slow background rate over a long time period (60 minutes). In order to perform well on this task, the subjects would need to retain portions of the series of digits to detect the missing digit. After training, both groups demonstrated the ability to do this task easily. There was no decrement in performance over the 60 minute session for the group from the general population at either the fast or slow presentation rate. Performance declined over the first 20 minutes regardless of the rate in the group with a developmental delay. The inability of individuals with a developmental delay to direct and sustain attention reduced their performance. Clearly, it is difficult to determine the function of one system when limited capabilities of another system have the potential to interfere with the measurement. This is an especially vexing problem when assessing populations with multiple handicaps.

Generally, attentional focus can be consciously controlled in normal listeners. But attention can also be "captured" without the conscious effort of the person. For example, a whole body startle reflex occurs following a loud sound. The intensity of the sound captures the attention of the individual leading to an immediate, involuntary reaction. This response is uniformly effective at eliciting a response across all populations except those

with hearing loss. However, this reaction quickly habituates. A sound that once caused a startle may not, after repeated exposures, elicit the same reaction (Northern and Downs, 1991). Attention is reallocated elsewhere. Another example of the influence of intensity on attention is the Stenger effect. This effect shows that when two sounds differing only in intensity are simultaneously presented, only the louder sound is perceived. Loud sounds are preferentially processed. Intensity appears to be an important stimulus feature in auditory processing. Thus, a means for controlling attentional allocation in populations less able to control their inattention rates may be found in the stimulus features themselves such as, intensity.

Clearly, if inattention can adversely effect performance then directed attention should improve performance. Generally, in a cooperative population, attentional focus can be gained through specific instructions and motivational rewards. Highly sustained and focused attention is presumed in many neuropsychological tests of memory as well as auditory sensitivity tests. However, there are many populations who may understand the instructions or the intent of the task but cannot be counted upon to sustain attentional focus despite their willingness to do so. Therefore, their performance may vary as inattention rates vary. The hallmark of auditory development research is the large variability in the results when compared to a group of adults from the general population (Bargones & Werner, 1994; Greenberg, Wilson, Moore, & Thompson, 1978; Werner, Mancl, & Folsom, 1996; Widen, et al., 1987). Bargones and Werner (1994) and Werner, Mancl and Folsom (1996) attributed the majority of this variability to nonsensory factors including, higher inattention rates. This trend is also seen in aging research. Many investigators have proposed attention deficits to explain, at least in part, the observed memory deficits in normally aging individuals (Pfefferbaum, Ford, Roth , Hopkins, & Kopell, 1979; Verlager, Neukater, Kompf, & Vieregge, 1991) and in those with pathological aging processes such as, Alzheimer's disease (Cohen, O'Donnell, Meadows, Moonis, Stone, &

Drachman, 1995). Cohen et al. (1995) correlated the functional outcome for individuals at high risk for developing Alzheimer's disease with neuropsychological measures. He found that backward digit span, a cognitive measure of "focused attention" was, among others, significantly correlated with developing Alzheimer's. Backward digit span is the ability to repeat a group of digits in the reverse order from which they were given. As Alzheimer's progressed, backward digit span performance decreased. Here was evidence that attentional declines were part of the Alzheimer's disease progression. Since inattention can influence behavioral performance, caution must be used when interpreting the memory function results of a patient with an attention deficit.

Alzheimer's disease is a fatal, neurodegenerative disease with distinctive neuropathological features. It generally develops in the late adult years though the genetically-linked, early Alzheimer's disease develops in the middle adult years. Often, the first sign of Alzheimer's disease is increasing memory problems. As the disease progresses, cognitive decline, emotional instability, and increasing memory and orientation disorders emerge. Alzheimer's disease is the most frequent cause of dementia.

Aside from the obvious risk factor of aging, Alzheimer's disease is sporadic (Haass, 1996). Early onset familial Alzheimer's disease has recently been shown to have a genetic basis with defects linked to chromosome 21 (St George-Hyslop, Haines, & Roses, 1992). In addition, individuals with Down Syndrome (trisomy 21) also have a greatly increased risk for the neuropathological changes consistent with Alzheimer's disease (Van Broeckhoven, Backhovens, Cruts, De Winter, Bruyland, Cras, et al., 1992). While dementia is hard to measure in cognitively low functioning individuals, individuals with Down Syndrome frequently demonstrate the behavioral symptoms of Alzheimer's late in their relatively brief lifespan (Thase, Tigner, Smeltzer, & Liss, 1984) though this claim has been disputed by others (Devenny, Silverman, Hill, Sersen, & Wisniewski, 1996).

A definitive diagnosis of Alzheimer's disease can be obtained only at autopsy. The

typical clinical diagnosis is one of "probable" Alzheimer's disease and is obtained through neuropsychological testing for memory and cognition disturbances and the lack of radiological evidence for other brain lesions and diseases. The current set of diagnostic tools are mainly used to rule-out other possible causes. The ideal diagnostic tool would be one that identifies Alzheimer's disease especially in its early stages. This is especially important to the family because of the progressive, degenerative nature of the disease.

One technique used experimentally with Alzheimer's patients is the cognitive P3 response. The neurophysiologically-measured P3 response is a quick, simple procedure requiring only minimal patient cooperation. As such, it is ideal for the serial measurements that might be necessary with progressive diseases. It is thought to directly tap short-term memory function as it is being enlisted (Ruchkin, et al., 1990). Because it is a more objective procedure than current neuropsychological assessments of dementia, it should be less prone to fluctuations from variables such as, examiner and interpretation differences.

Unfortunately, the P3 response is relatively normal in the early stages of Alzheimer's (Verlager, et al., 1992). It appears best at revealing the disease in its later stages (Filipovic & Kostic, 1995). This reduced sensitivity to early dementia can be attributed to the large overlap in the P3 measures of latency and amplitude between individuals from the general population and those with developing Alzheimer's. The access time for short-term memory (P3 latency) and the attentional focus devoted to the task (P3 amplitude) are highly variable. Additionally, the procedures used to generate the P3 are not standardized. Since stimulus features such as intensity can effect processing time and attentional focus, it seems reasonable to assume that the insensitivity of the test may be due in part to poorly standardized procedures.

### C. The P3 Response

Auditory evoked cortical responses are large amplitude, long latency (100+ms post-stimulus) responses reflecting the cortical processing activity of an auditory signal.

Because of their large amplitude, cortical responses were among the first to be extracted from the ongoing EEG activity of the brain, as early as 1939 (Hall, 1992). Unlike the "short latency" responses occurring at 10-15 ms post-stimulus and used to assess hearing sensitivity, the cortical potentials reflect more the awareness and significance of an auditory signal. Cortical responses occurring at 100-250 ms post-stimulus are generally categorized as exogenous, originating from an external cause, because they reflect the arrival and obligatory processing of an auditory stimulus. Responses occurring at 250 ms and longer are more dependent on the significance of a stimulus and, so, are classified as endogenous. In the general population, the P3 response, an endogenous potential occurring at approximately 300 ms after some acoustic events, is evoked in an "oddball paradigm" in which two tones are presented differing only in one aspect, commonly frequency. One tone, the "standard," occurs frequently while the other tone, the "oddball," rarely occurs. It is the recognition of the rare tone from the train of frequently occurring standard tones that initiates the P3 response. The cortical functions of selective attention and memory are integral to the generation of the P3 response. These cortical functions are addressed in the information-processing model shown in Figure 1. As the auditory sensation arrives at the cortex, a neural "representation" of the stimulus is generated. This is referred to as a "sensory store" by Cowan (1988) and, variously, as "sensory memory," "stimulus trace," or "neuronal trace" by others (Das, Kirby, & Jarman, 1975; Naatanen, 1990; Woldorff, Hackley, & Hillyard, 1991). This memory is very quick to decay, lasting only as long as a few hundred milliseconds. Both effortful attention and involuntary (captured) attention can cause activation of short-term memory resources. The neural representation is then held longer, sometimes as long as several minutes so that further processing of the signal can occur (Cowan, 1988).

In light of this construct, the cognitive events reflected by the P3 response are thought to occur in the following sequence. The attention devoted to the standard tone

quickly habituates as each trace is "compared" with a stored trace in sensory memory and is found to be similar. Attention is not drawn to these frequently occurring events.

However, the occurrence of the oddball tone causes a neural mismatch with the stored representation in sensory memory. This "comparator" within sensory memory is thought to accomplish its task in one of two ways (Näätänen, 1990). The first is neural refractoriness. That is, the neurons responding to the standard tone remain in a refractory state while a "fresh" set of neurons would be activated by the oddball. Attention is drawn to this new set of neurons firing. This theory does not readily explain a response that can occur to an absent but expected tone. The memory trace theory suggests that a mechanism within sensory memory responds and encodes any difference between two separate but consecutive stimuli. A difference would then draw attention. The amount of attention devoted depends on many things including the significance and meaningfulness of the stimulus to the listener. If attention is drawn to the stimulus, a behavioral response is initiated, if necessary, and short-term memory is accessed and updated (Cowan, 1988; Whiting, Martin, & Stapells, 1998). The latency of the P3 response is regarded as the time it takes to access and update short-term memory while the amplitude of the response reflects, at least in part, the attentional resources devoted to the stimulus (Polich, 1987b; Vesco, Bone, Ryan, & Polich, 1993).

Unlike the auditory brainstem, the middle latency and, to some extent, the early cortical responses, the P3 response is the psychological event of discrimination and is, therefore, dependent on a subject who is cooperating with the discrimination task. The level of cooperation can be varied by the instruction given to the subject. During active listening, the most commonly used listening pattern, the subject is instructed to listen and respond by pushing a button or raising a finger when the oddball tone is heard. Passive listening is also used, especially in subjects with pathologies such as, dementia, that limit their ability to cooperate with active listening. During passive listening the subject is told

that tones will be heard but that nothing need be done. Less frequently, subjects are given an attention diverting task such as, solving a puzzle or reading a difficult passage from a book, as a distraction to the presentation of the tones. Like other evoked responses, computer averaging is necessary to reveal the P3 response against the background EEG "noise." Therefore, a minimal level of behavioral cooperation must be sustained throughout the testing session.

Multiple neural structures are thought to contribute to the P3 response. The P3 is best recorded along the midline scalp at Fz, Cz and Pz (re: 10-20 International Electrode System). Wood, Allison, Goff, Williamson, and Spencer (1980) obtained surface and depth recordings of the P3 during epilepsy surgery. Using precisely placed probes on the surface of the brain and deep within the cortex, they found that the response increased in amplitude and decreased in latency as subcortical structures were approached. This provided initial evidence that the P3 is not generated by bilateral cortical generators that "fused" at midline but rather that it arises from subcortical generators. Further, Halgren, Squires, Wilson, Rohrbaugh, Babb, and Crandall (1980) found the response reversed in polarity with probe insertions into the limbic system. A pattern of polarity reversal near a neural structure is evidence that the generator of the response has been found. (It is true that other generators not detected by the probe insertions may also contribute to the response.) The specific structures that produced the polarity reversal were the amygdala and hippocampus; structures believed to be integral to short-term memory function. The P3 response may then provide an opportunity to evaluate specific structures as short-term memory is accessed.

#### D. Factors Effecting the P3

There are many factors known to effect the P3 response. Generally these can be divided into four categories including, subject factors, stimulus factors, sensitivity factors, and attentional factors. The size of the effect is variable and is dependent, in part, on the

psychological significance of the factor.

### 1. Subject factors

The P3 paradigm has been used to explore cognitive and memory changes associated with development, aging, and pathology. In developmental studies, the P3 response decreased in latency until the mid-teen years at which time it stabilized until the end of the third decade of life (Courchesne, 1978; Pearce, Crowell, Tokioka, & Pacheco, 1989). This latency change most likely represents the completion of cognitive development (Berman & Friedman, 1995; Pearce, et al., 1989). Conversely, as humans age, the P3 response latency increases from the third decade through the eighth decade of life and beyond (Brown, Marsh, & LaRue, 1983; Coyle, Gordon, Howson, & Mearns, 1991; Picton, Stuss, Champagne, & Nelson, 1984; Polich, 1991; Verlager, et al., 1991). Verlager, Neukater, Kompf and Vieregge (1991) concluded that this change represents a generalized slowing of memory access rather than a delay from diminished sensory function. Many investigators have tried to quantify the increase in the P3 latency as a function of age. Polich (1991) concluded from a meta-analysis of 12 of such studies that a linear relationship exists between increasing age and the P3 latency. Since there is no standardized collection protocol to obtain the P3 response, the absolute values of the response across all 12 studies are quite variable. As Polich reviewed the studies, he suspected that the differing stimulus levels may be masking any consistent trends. It was only when he replotted the slope of the latency increase from each study as a function of stimulus intensity that he was able to show a stable and clear relationship between the P3 latency and increasing age. He found an average P3 latency increase of 1.3-1.4 ms/year beyond age 30. It appears that louder stimuli are more salient, receiving preferential processing and, so, relatively quicker access to short-term memory. Stimulus intensity, he noted, appeared to be a "critical determinant" in the discriminative task. This provided evidence that features of the stimulus such as, intensity, can interact with subject factors to

speed access to short-term memory by capturing attentional focus. Therefore, the intensity of a stimulus could be a critical feature in capturing the attention of a population that has poor control over its attentional focus. Such difficult-to-test populations may include those with Alzheimer's disease.

Many populations with known cognition and memory deficits have abnormal P3 responses. For example, the P3 response is increased in latency in patients with a confused mental state from head injury or drug overdose and in patients with psychological disorders such as, schizophrenia or depression (Goodin, et al., 1983; Verlager, et al., 1992). Goodin et al., found that as the confusion subsided and the patient's condition improved, the P3 latency shortened. Processing appeared to ease as cognition improved. Additionally, in subjects with dementing diseases such as, Alzheimer's disease, Huntington's disease and Parkinson's disease, the P3 latency increases and the amplitude decreases (Goodin & Aminoff, 1986). With these diseases, both memory and cognition are effected. In populations with developmental delay such as, Down Syndrome and Fragile X syndrome, the P3 latency is also increased and the P3 amplitude is decreased (Blackwood, St Clair, Muir, & Oliver, 1988; Muir, Squire, Blackwood, Speight, St Clair, Oliver, et al., 1988). Memory, cognition, and attentional deficits are well documented in these populations (Das, Divis, Alexander, Parrila, & Naglieri, 1995; Kay-Raining Bird & Chapman, 1994; Marcell & Armstrong, 1982). Clearly, those deficits associated with various pathologies that effect memory, cognition and attention have the potential to significantly and adversely impact the P3 measures.

## 2. Stimulus factors

Since the P3 response is obtained in a discrimination paradigm, changes in the stimulus that alter the discrimination task, making it easier or harder, can alter the response. For example, Polich (1989a) found that as the frequency difference between the oddball and standard tones was reduced, the P3 latency was increased and amplitude was

decreased. Papanicolaou, Loring, Raz, and Eisenberg (1985) and Polich (Polich, 1989a) found that as the intensity of the stimulus tones increased, P3 latency decreased but, in this case, amplitude was not effected. It seems that as the salience of the tones that is, the difference between the tones, is reduced, categorization of the tones is slowed and attentional resources are sometimes depleted. However, P3 latency can be stabilized if the salience of the discriminaiton remains high and attention to the task is manipulated. In this case, P3 amplitude is the variable most effected. Polich (1986) contrasted the standard from the oddball in two domains, frequency and intensity differences, and changed the attentional demands placed on his young adult control group. His subjects were asked to listen actively and passively as well as to solve a difficult word puzzle during the P3 discrimination task. In this study, he was interested in response changes that might occur as cognitive disabilities such as, Alzheimer's Disease, effected the ability of the patient to cooperate with the P3 task. Since P3 latency is the measurement of interest in the assessment of dementia, finding a paradigm that minimizes latency fluctuations due to attentional factors is important. Since the salience between the standard and oddball tones was high, P3 latency was stable suggesting that categorization of the tones remained easy regardless of the attentional demands placed on the subject. P3 amplitude decreased as attention to the task was diverted from active listening to solving a difficult word puzzle. It follows then, that in a population with poorly controlled attentional focus, salience of the tones becomes a critical feature the P3 response measures. To improve the P3 measures in this group, improving the salience of the stimuli would be important. There are many ways to do this but increasing the intensity of the tones would be a logical way. High intensities are naturally alerting. In populations with high inattention rates, higher intensity tones may more automatically capture and direct wandering attention improving the P3 measures.

### 3. Hearing sensitivity factors

In addition to stimulus factors, hearing loss is a major consideration in P3 testing.

Hearing loss can inadvertently effect the overall as well as relative audibility of the tones. If audibility is reduced, the perceptual task of discrimination becomes more difficult. When salience is reduced, categorization takes longer and more attention is required to maintain performance. The P3 measures are adversely effected. Martin, Sigal, Kurtzberg, and Stapells (1997) provided a clear demonstration of effects of decreased audibility on perception. Normally hearing subjects were asked to discriminate between two speech sounds: "ba" and "da." In quiet, behavioral discrimination was nearly perfect. As expected, the P3 latency was shortest and the amplitude was largest. However, when masking noise with a variable cut-off frequency was introduced and impinged upon the frequencies that were critical for the discrimination of the two speech sounds, the number of correct detections of the oddball ("ba") dropped indicating that the salience between the speech sounds was reduced. In turn, the P3 latency increased and the amplitude decreased, indicating an increase in processing time and depletion of attentional resources available for processing. Finally as the noise masked the critical frequencies for discrimination altogether, though both speech sounds were still audible, the behavioral discrimination of the oddball from the standard was near chance. Since both speech sounds were still audible, it was the contrast between them that was used to distinguish the standard from the target speech sounds. When this contrast was removed, the P3 measures suffered.

Similar to impinging masking interfering with the discrimination of speech sounds, various audiometric hearing loss configurations can also effect the discrimination of tones, changing the difficulty of the task and, thus, the P3 latency and amplitude. Hearing loss with a rising or falling audiometric contour will cause one of the tones to be perceived as louder if one tone is in the range of normal hearing and the other is in the range of hearing loss. In this case, the salience of the louder tone is increased. Polich (1987b) demonstrated that when the target was more intense, the P3 measures were not adversely effected. In this circumstance, the latency was short and the amplitude was large. He also

showed that when both the standard and target tones were reduced in intensity, such as might occur with a flat audiometric configuration, the P3 increased in latency and decreased in amplitude indicating that processing became more difficult. There are no published data regarding the P3 effects when the standard is louder than the target. Since it is often the case that the oddball tone is higher in frequency than the standard, a falling audiometric configuration, by far the most common configuration among the elderly, could cause this situation to frequently occur. There is every reason to think that task difficulty would be effected by this variation as well. However, the direction of the change in the task difficulty (more or less difficult) and the concomitant effect on the P3 measures is not known and is purely speculative at this point since it is the standard, the tone not responsible for the P3 response, that is more salient.

All of the individuals within a group should perceive the two tones similarly to obtain a response that can be compared meaningfully. While this may seem obvious, it is often overlooked in the P3 literature. In studies on aging and in studies using populations that are difficult to assess audiologically (developmentally delayed, demented), hearing is rarely reported as having been thoroughly measured. The reason for the lack of audiometric data may be that these populations usually require audiologic expertise for an accurate evaluation. Yet, these individuals are much more likely to have a hearing impairment (Gold, et al., 1996; Widen, et al., 1987). Gold et al., compared the prevalence of hearing loss among elderly patients with memory disorders and those with no symptoms of memory problems and found a greatly increased prevalence for hearing impairment among the group with memory disorders. In fact, 94% failed the hearing screening from the memory disordered group while only 40% failed from the elderly group without memory disorders. The fact that the group with memory disorders may have been harder to evaluate did not appear to bear on the findings since inclusion in the study required that all subjects must be able to do the procedures.

Individuals with Down Syndrome frequently exhibit cognitive changes, memory disorders and dementia as they age into their 4th and 5th decade of life (Thase, et al., 1984). The prevalence for hearing loss among adults with Down Syndrome is high; variously estimated to be 50-100% depending on age (Buchanan, 1990; Keiser, Montague, Wold, Maune, & Pattison, 1981; Marcell & Cohen, 1992; Widen, et al., 1987). Yet testing the hearing of this very difficult-to-test population requires special audiological expertise. Frequently, the hearing levels reported for these individuals are obtained electrophysiologically (Blackwood, et al., 1988; Muir, et al., 1988). While this might be an expedient testing method, it is not a hearing threshold test nor is it frequency specific. Electrophysiological methods are estimates of hearing within frequency ranges and can approximate true hearing levels only to within 20-30dB. Therefore, using these estimate measures cannot replace hearing threshold testing.

Clearly, the prevalence for hearing loss in those populations at risk for Alzheimer's disease is high. Since hearing loss may effect the salience of the discrimination and, therefore, the P3 measures, it is very important to know in advance that all subjects are perceiving the tones similarly. It is only then that P3 responses can be compared meaningfully for abnormalities.

#### 4. Attentional factors

The effects of attention on the P3 have been clearly documented. The P3 response has been collected under several attentional conditions in order to demonstrate these effects. Recall that in an active listening condition, the subject is instructed to listen for the oddball tone and to respond behaviorally (e.g., count silently, raise a finger, push a button). In the passive listening condition, the listener is told that sounds will be heard but to ignore them. To help with this, the listeners are usually instructed to daydream, read a book, or do some other form of quiet, mildly engaging activity. Thus in the active condition, attention is focused whereas in the passive condition attention is unfocused. A third condition exists

but is less commonly used in which the listener's attention is diverted by doing a very distracting activity such as, to solve a difficult word puzzle or to carefully read a passage and then be tested on the content of it.

As discussed earlier, Polich has studied the effects of attention on the P3 measures (Polich, 1987a; Polich, 1989b). In a direct comparison of the measures using active and passive listening, Polich (1989b) found that the P3 latency was not effected by the amount of attention paid to the task however the P3 amplitude was significantly reduced when the listener changed from active to passive listening. Since the P3 response was morphologically similar between the active and passive paradigms, Polich concluded that the response arising out of these very different attentional conditions was, in fact, the same (P3) response. In addition, he concluded that the passive listening condition should result in a P3 response even in populations that may not be able to fully cooperate with active listening. In this circumstance, the main effect would be a loss of P3 amplitude. This was a significant finding since it is the P3 latency that is the important measure in testing populations with dementia. P3 latency should be unchanged by passive listening.

It is known that the effect of inattention on the P3 response is a loss of amplitude (Polich, 1989b). It is also known that the intensity of the tones used to generate the P3 measures is a "critical determinant" in the P3 measures (Polich, 1991). The interaction between intensity and inattention on the P3 measures should be considered. When actively listening, Papanicolaou, Loring, Raz, and Eisenberg (1985) and Polich (1989a) found that intensity exerted only a small, though significant, influence on the P3 measures once audibility was achieved. In both studies, P3 latency was reduced with increases in intensity while amplitude was not significantly effected. These latency changes were small and Polich noted that they may reflect "processing preferences...by the human auditory system" (p. 278). At these suprathreshold levels, the sounds are easily heard and discriminated in adults with normal hearing and focused attention. No study was found

that used intensity as a variable during passive listening. Because of the alerting effects of intensity, it is not unreasonable to expect that the P3 measures may improve with increases in intensity during passive listening. This is an important consideration since a population with dementia cannot be counted on to fully cooperate with an active listening task. Some studies have even reported that during active listening, subjects with dementia have poorer behavioral performance (Blackwood, et al., 1988; Goodin, et al., 1983; Vieregge, et al., 1992). That is, subjects with dementia respond less frequently to the oddball tone when it is presented. It is known that unheard oddball tones do not generate a P3 response (Martin, et al., 1997). Higher intensities may enlist undirected attention causing a passive listener to behave more like an active listener. The result may be better behavioral performance so that the P3 measures could then be more meaningfully compared.

#### E. Models of possible outcomes

The effect of changing stimulus intensity while collecting the P3 response can be predicted. A number of studies have previously investigated these effects for cooperating, attentive listeners from the general population (Papanicolaou, et al., 1985; Polich, 1989a). Figure 2 displays the prediction model for the P3 response obtained on subjects from the general population using active listening. This model is derived from previous investigational findings. As a function of intensity for an attentive listener, a large amplitude P3 response would be obtained at intensity levels in which the two tone discrimination is easily audible (+30dB sensation level). If this model is accurate, the P3 amplitudes should remain stable across intensities while the P3 latency should decrease a small but statistically significant amount at higher levels. Behavioral performance measures (correct detection rates) would confirm that attention to the discrimination task was highly focused.

The alerting model shown in Figure 3 represents the predicted changes in the P3 response as a function of intensity increases when attention is not focused on the task.

(Note that the prediction model of Figure 2 is overlaid on the alerting model for reference.) When passively listening, the P3 amplitude will increase as intensity increases. That is, the inattentive listener will begin to have P3 responses that are more like an attentive listener. Previous studies suggest that when attention is changed from focused to unfocused, only amplitude will be effected (Polich, 1987a). This prediction model than adds to current knowledge by suggesting that intensity can interact with attention during passive listening to increase the P3 amplitude. At low intensity levels, the alerting model suggests that the tones will be easily ignored and that attention will be directed elsewhere, thus, low P3 amplitude will result. At high intensities, the stimuli will become more alerting and increasingly difficult to ignore. The higher P3 amplitudes reflect the increasingly higher priority that the higher intensity stimuli impose on auditory processing.

A second experimental manipulation proposed for this study is an investigation into the effect of changing the relative intensity between the tones to be discriminated. Since high frequency hearing loss is an extremely common finding among the elderly and since it is common to choose a high frequency oddball tone, it is very likely that the relative loudness of the oddball tone is lower for many elderly, memory disordered listeners. We know that during active listening when the discrimination task is done at a high level and the oddball tone is higher in intensity than the standard, the P3 measures are not adversely effected (Polich, 1987b). In this circumstance, the perceptual demands of encoding and categorization are not great. The salience of the two tones remains high. However, when both tones are at an equal but low intensity level, the P3 latency is increased and the amplitude is decreased. The P3 measures reflect the difficulty of the task. When the oddball tone is softer than the standard as proposed by this study, two possible outcomes could be predicted and are shown in Figures 4 and 5. The first prediction, shown in Figure 4, is the salient model. This figure shows P3 amplitude as a function of listening condition using unequal and equal intensity tones as the parameter. It is already known that when the

tones are equally intense, the effect of changing from active to passive listening will reduce the P3 amplitude (Polich, 1987a). This known effect is illustrated in the model as a reference. However, using unequally intense tones in which the oddball is less intense than the standard, the salient model suggests that the P3 amplitude will be reduced by only a very minor amount, perhaps not even significantly, in the passive condition. The effect of a lower intensity oddball tone will be to make that tone more salient because it is different in two domains: frequency and amplitude. The P3 measures, particularly amplitude, will be largely unaffected.

However, the less salient model, shown in Figure 5, predicts that making the tones unequally intense will make the discrimination task more difficult and reduce the P3 amplitude regardless of the listening condition: active or passive. In the less salient model, when unequally intense tones are heard (oddball less intense than standard), the P3 amplitude is adversely effected regardless of the listening condition. The P3 amplitude will be higher during active listening than during passive listening but neither will reach the amplitude values of equally intense tones. This model predicts that having an oddball that is lower in intensity will result in a lower P3 amplitude. In the case of high frequency hearing loss, the oddball tone may be perceived softer and so, harder to hear. The P3 amplitude will be lower because more attentional resources will be depleted by the more difficult listening task.

## INFORMATION PROCESSING MODEL

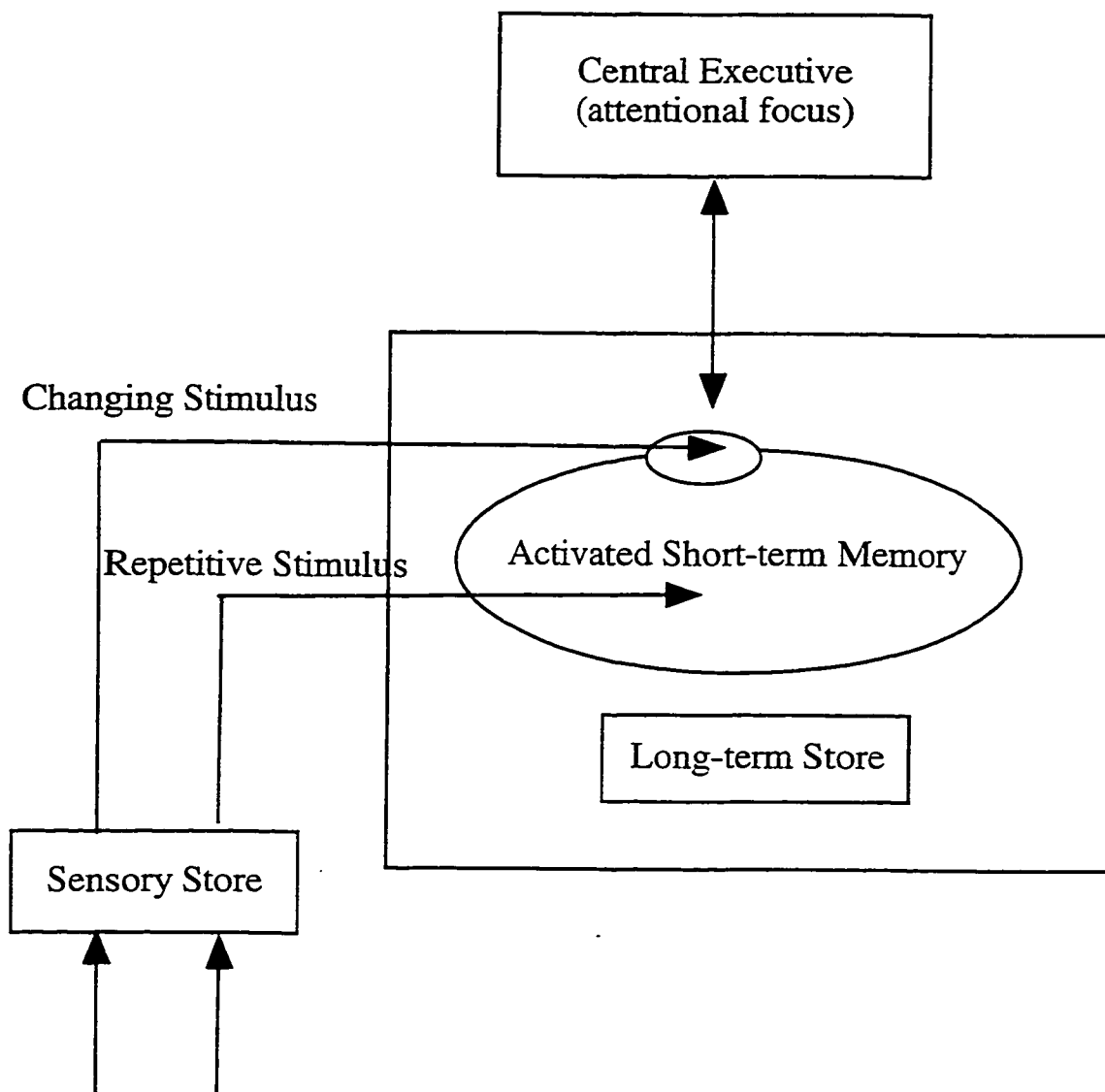


Figure 1. Simplified version of an information processing model proposed by Nelson Cowan. As sensation arrives, sensory store briefly holds the neural representation of the stimulus. The stimulus is then passed on to short-term memory, a subset of long-term memory. If the stimulus is new or changes, attentional focus is drawn to it.

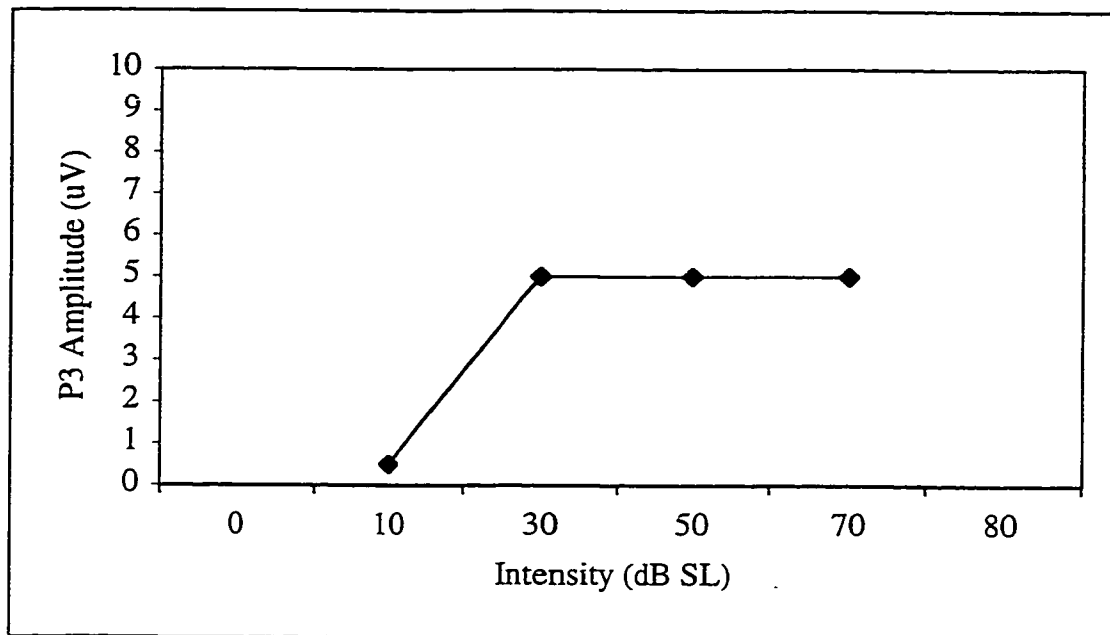


Figure 2. Prediction model for the P3 response amplitude as a function of stimulus intensity during active listening.

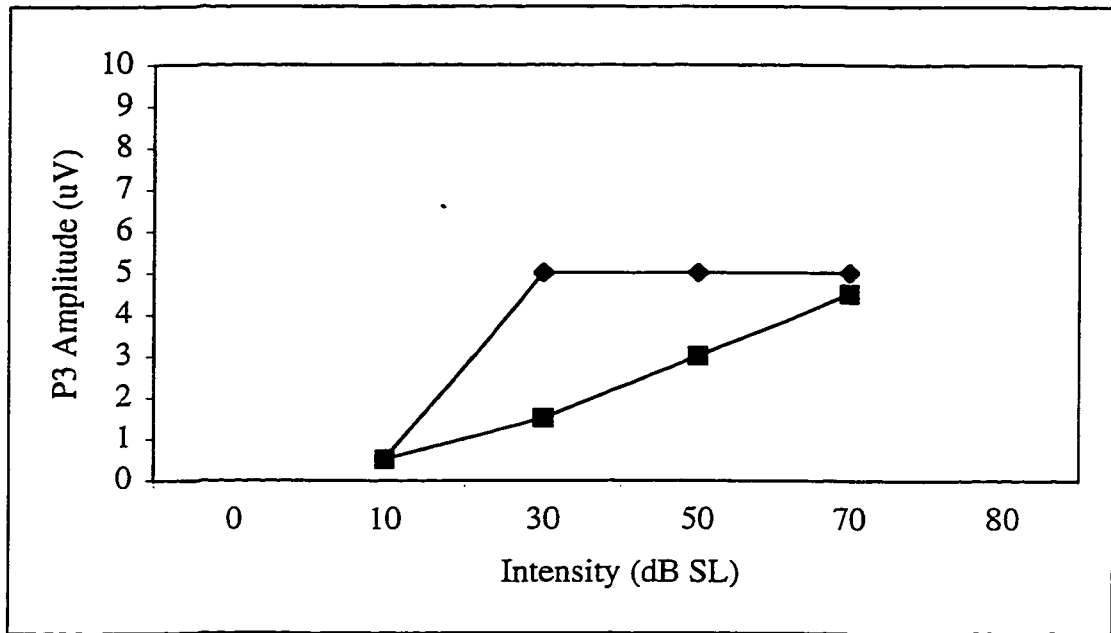


Figure 3. Alerting model. Proposed changes in the P3 response amplitude as a function of stimulus intensity. Active listening (filled diamonds) is shown with passive listening (filled squares).

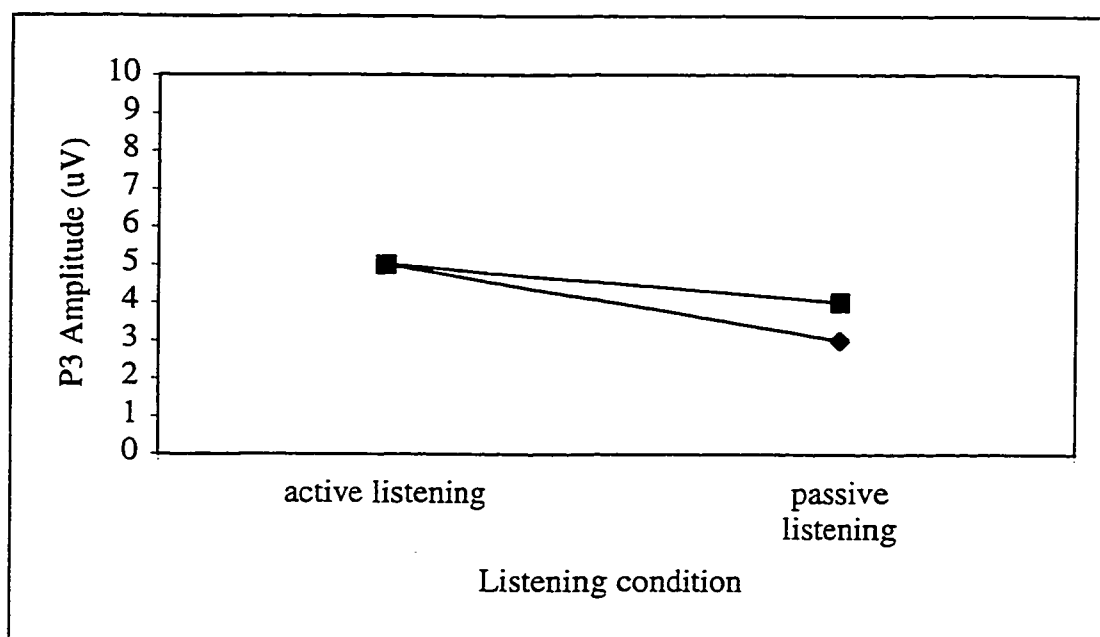


Figure 4. Prediction model for the effects on P3 amplitude of equal relative intensity (filled diamonds) and unequal relative intensity (filled squares) tonebursts as a function of listening condition. This model predicts that the unequal intensity tonebursts will be more salient during passive listening.

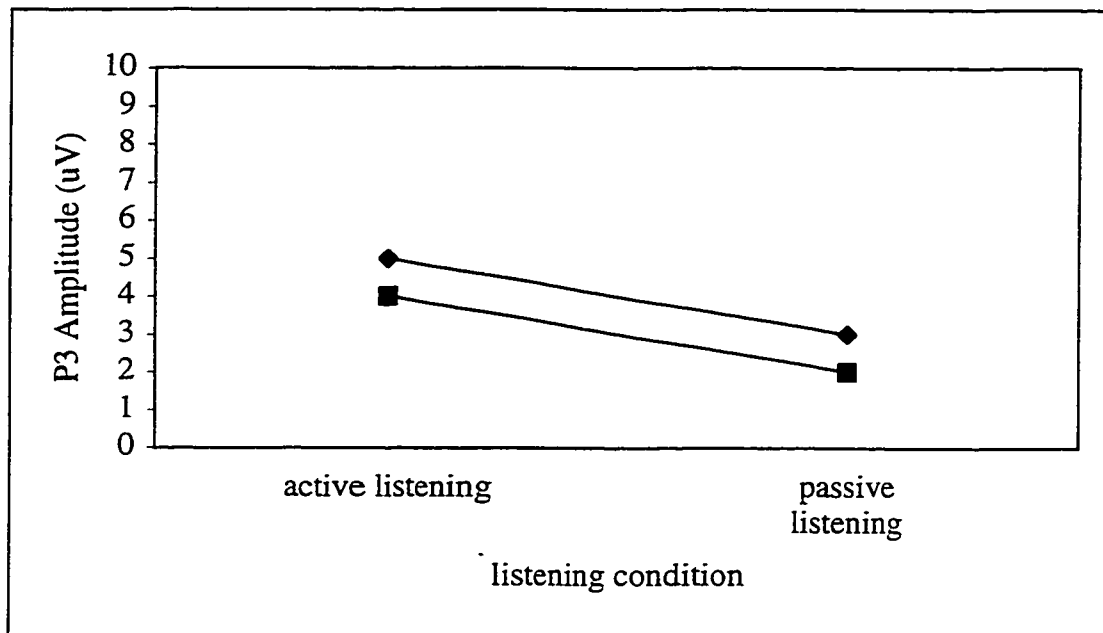


Figure 5. Prediction model for the effects on P3 amplitude of equal relative intensity (filled diamonds) and unequal relative intensity (filled squares) tonebursts as a function of listening condition. This model predicts that unequal intensity tonebursts will be less salient than equal intensity tonebursts regardless of listening strategy.

### Chapter III Statement of the Purpose

The purpose of this study is two-fold. The first experiment was designed to characterize the effects of stimulus intensity changes on the P3 response in two listening conditions that are commonly employed. Data were first collected when the subject was passively listening. That is, the subject was allowed to engage in a concurrent activity (watching TV) while the tonebursts were being presented. Next, the subject was instructed to actively discriminate between two tones by responding behaviorally (raising a finger) whenever one tone, the oddball, was heard. In both listening conditions, the intensity of the tonebursts was increased from 10 dB to 70 dB sensation level (SL) in 20 dB steps. Since it is already known that active listening will produce a larger amplitude, shorter latency P3 response than passive listening, the first experiment seeks to answer the following questions:

- A. Does increasing the intensity of the toneburst pairs change the P3 measures?
- B. Does increasing the intensity interact with the listening condition to change the P3 response?

The second experiment was designed to investigate the effects of unequal tone intensities on the P3 measures. Generally, the P3 evoked response is collected with both tonebursts at equal intensities. However, hearing loss could inadvertently effect the relative loudness of the tonebursts. Since hearing loss is a common occurrence in populations with memory disorders and, further, since the P3 measures are known to be influenced by the relative ease of the discrimination task, the potential effect of hearing loss on the P3 measures is the proposed purpose of the second experiment of this study. The second experiment of this study seeks to answer the following questions:

- A. Do unequal toneburst intensities change the P3 measures?
- B. What are the interactive effects of unequal toneburst intensities on the P3 measures

when the listening condition is varied?

The results of these experiments will add to our knowledge in two ways. First, the alerting effects of high intensity stimuli on the P3 response will be revealed. If high intensities stimuli can coerce a passive listener to generate a P3 response identical to an active listener, then the responses between these two very different listening strategies can be compared in clinical populations. Second, unequal intensity tone pairs are likely to be a common occurrence for listeners with hearing loss. This study seeks to reveal the effects of unequal tone pairs on the P3 measures. If the measures are adversely effected, compensatory techniques should be considered to prevent unequal stimulus intensity tone pairs.

## Chapter IV Methods

### A. General Methods

#### 1. Subjects

Twenty subjects were recruited from the university population to participate in both parts of this study. For inclusion in the study, all subjects 1) were 20-35 years of age, except for one subject who was 50 years of age. Since his P3 responses were within the range of the other subjects for both latency and amplitude and the trends of his response were similar to the other subjects, his responses were included in the data; 2) reported no major medical or psychological problems that required medication known to interfere with the P3 response; 3) had hearing within 20dB of audiometric zero for the frequencies 1000 Hz and 4000 Hz in the ear used for the study and 5) were able to perform the P3 task. Informed consent was obtained from each subject. Some subjects who participated in this study did so as a partial completion of a laboratory course requirement.

#### 2. General procedures

The general procedures were the same for both parts of this study. Each subject either received a pure tone hearing test for the frequencies 250-8000 Hz in both ears or, if their hearing had been recently evaluated, supplied a recent audiogram. The procedures used to collect the P3 response were commonly used procedures. The stimuli, presented monaurally, consisted of tonebursts of two frequencies: 1000 Hz and 4000 Hz. The toneburst had a duration of 20 cycles with a rise/fall time of 5 cycles and were presented at a rate of 1.5 tones each second. They were presented with an 80% probability that the tone would be 1000 Hz and a 20% probability that the tone would be 4000 Hz. Therefore, the standard toneburst was 1000 Hz while the oddball was 4000 Hz. A minimum of 80 artifact-free responses to the oddball tone were obtained and replicated for each experimental condition. Prior to each session (active or passive listening), the threshold for each toneburst was measured on each subject. All intensities for either toneburst were

adjusted in dB sensation level (SL) relative to this threshold.

Two attentional conditions were obtained. During the passive listening condition, the subjects were told they would hear two tones but they should ignore the sounds. Instead, they were given a video movie of their choice to watch. Closed captioning was used as a substitute for the movie sound. During the active listening condition, the subjects were told they would hear two tones and that whenever the higher pitched tone was heard, they were asked to raise a finger. They were asked to either close their eyes or fix their gaze on a visual target to minimize eye movement and blinking. A practice session was given if the subject was confused about which tone to respond to. Not only did the motor response aid in maintaining the subject's attentional focus but it allowed the examiner a means for determining the accuracy of the discrimination and the alertness of the subjects. It was often the case that the subjects became sleepy during the active paradigm. If the correct identification rate fell below 90%, the subject was given a break. Several breaks were sometimes given to individual participants.

### 3. Instrumentation

The P3 cognitive evoked response was obtained using the commercially available Nicolet Spirit evoked response signal averager. The Nicolet Spirit was used to both generate the stimuli and record the P3 response. The noninverting electrode was located at the vertex with the inverting electrode on the ipsilateral earlobe and the ground on the contralateral earlobe. In addition, an electrode was located at the lateral canthus of ipsilateral eye and linked to the inverting electrode. Prior to data collection, the subject was asked to blink approximately once each second and the artifact sensitivity of the equipment was adjust to reject any trace associated with an eyeblink. Since subject relaxation can improve throughout the data collection period, artifact rejection was often checked to determine if it could be lowered to improve the signal-to-noise ratio of the response. Electrode impedance was 10K ohms or less, preferably 5000 ohms. The EEG signal was

digitized and amplified 100,000 times. The low pass filter was set to either 30 Hz or 100 Hz while the high pass filter was set to 1 Hz or 5 Hz whichever filter setting allowed the timely collection of the P3 response. The timebase for the P3 response was 450ms post-stimulus.

#### 4. General Scoring Procedures for the Waveforms

The waveform complex of N1-P2-N2-P3 was identified for each subject however, only the latency and amplitude measures of P3 were used for analysis in this study. Latency was measured as the time (in ms) following the stimulus for the peak of the P3 response to occur. Amplitude was measured from the peak of the response to the following trough of the response. The initial and replication waves were added together offline in two ways. First, both waveforms produced by the oddball signal were simply added together to produce an averaged wave of that intensity and listening condition. Second, the standard was subtracted from the oddball waveform and these difference waves were then added to produce an averaged difference wave for that intensity and listening condition. Both sets of averaged waves for each intensity and listening condition were scored by two experienced examiners. One of the examiners was blind to the listening condition used to obtain the P3 response.

#### B. Methods: Experiment 1

The purpose of this experiment was to compare the P3 response amplitude in 4 intensity conditions in both passive and active listening conditions. Prior to each session, threshold for each toneburst was obtained so that the P3 response could be obtained at 10, 30, 50, and 70dB re: the each subject's sensation level for that toneburst. The first recording session was always done using passive listening while the second session was done during the active listening. Though research has shown that the responses can be obtained in either order (Polich, 1986), the passive listening was done first in case it proved difficult for a subject to ignore an oddball tone after being instructed to attend to it in

the previous session. In this experiment, eight experimental conditions existed (four intensities x 2 listening conditions). An analysis of variance (ANOVA) was planned for experiment 1 on the P3 measures of amplitude and latency for the main effects of listening condition and stimulus intensity and for their interactive effects.

### C. Methods: Experiment 2

The purpose of this experiment was to compare the P3 response obtained from stimuli of equal relative intensity to the P3 response obtained to stimuli of unequal relative intensity during both passive and active listening conditions. For the equal relative intensity condition, the data obtained at 70dB SL during active and passive listening from the previous experiment were used. For the unequal intensity condition, the standard toneburst remained at 70dB SL while the oddball toneburst was reduced to 50dB SL. There were two rationales for choosing these levels. First, the response morphology would be best at these high levels. Second, a 20 dB intensity drop over two octaves (1000 Hz to 4000 Hz) did not represent an overly dramatic slope of intensity reduction. Therefore, the listening condition that might be expected for an individual with presbycusis hearing loss was closely simulated. The P3 response from the unequal intensity tonebursts were obtained in both passive and active listening conditions. Therefore, four experimental conditions exist for this experiment (2 relative stimulus intensity levels x 2 listening conditions). An analysis of variance (ANOVA) was planned on the P3 measures for the main effects of listening condition and relative toneburst intensity and for the interaction of these main effects.

## Chapter V Results

### A. General Results

Prior to each recording session, a threshold for both tonebursts was obtained. The mean threshold for the 4000 Hz toneburst was 6.5 dB nHL with a range of 0-15 dB. The mean threshold for the 1000 Hz toneburst was 15.1 dB nHL with a range of 5-25 dB. Threshold was found using a standard ascending threshold search technique. No subject's threshold for either toneburst varied by more than 5 dB between sessions indicating high reliability of the threshold measures.

The P3 response was obtained in two conditions: an active and a passive listening condition. In the passive condition, the subjects were asked to ignore the sounds they heard and to watch a video. In the active condition, the subjects were instructed to listen to the two tones presented and to indicate by raising a finger whenever the oddball tone was heard. All subjects were cooperative with the procedure and a P3 response was obtained from each participant. Behavioral performance in the active condition was sampled frequently during the data collection. Even at low levels (10dB SL), whenever the oddball tone was presented, the subjects correctly detected the oddball tones at near perfect levels (>90% hit rate). In the passive condition, subjects were frequently asked at the end of the session about the sounds they heard. In general, remarks centered on the fact that the sounds were quite loud near the end of the session but often subjects were unable to remember much else about the tones they heard. The data and post-session comments suggest that all subjects followed the instructions to ignore the sounds.

All waveforms were double scored by two experienced examiners one of whom was blind to the listening condition. The agreement between the two examiners on the presence of the P3 response to each intensity condition was 90%. The P3 measures obtained from averaged difference waves were used in both experiments. The difference waveforms generally produced more clearly formed and identifiable P3 responses that were

more consistently scored by the two examiners. The added waveforms were used primarily as a confirmation that the P3 response was, indeed, obtained. However, in two cases, the added waveform produced more clearly identifiable P3 responses. In these two subjects, data from the added waveform were used.

Averaged difference waveforms from five subjects enrolled in this study were added together to show a representative P3 response obtained at the four intensity levels used. These particular subjects were chosen because their P3 latencies were similar (i.e., 300 ms,  $\pm 30$  ms). Since averaging waveforms with widely different latencies would obscure the P3 peak, waveforms in any average across subjects should have similar latencies. Figures 6 and 7 show these waveforms at each intensity level as a function of time post-stimulus. Figure 6 shows the waveforms from the passive listening condition and Figure 7 shows the waveforms from active listening as a function of time. The intensity used to obtain the response is noted beside the waveform. For clarity, the P3 response is marked on the 70 dB SL waveform.

#### B. Experiment 1. P3 response changes with intensity increases

The P3 response was collected at 4 intensities (10, 30, 50, 70 dB sensation level or "SL") and in two listening conditions (passive and active). The experiment was designed to investigate the alerting effects of intensity on the P3 response when a normal listener was asked to attend or to ignore the auditory stimuli presented. The likelihood of obtaining a P3 response on any subject was significantly higher for active listening than for passive listening. In addition, the likelihood of obtaining a response significantly increased at higher intensities regardless of whether subjects were actively or passively listening. Table 1 depicts the number of P3 responses obtained at each intensity level and for each listening condition. Despite the near perfect behavioral performance at low (10 dB SL) stimulus intensity levels in the active condition, P3 responses were obtained from only 50% of the subjects at this level. However, the response was not obtained from any subjects in the

passive condition at this level. At 30 dB SL in the active condition, the response was obtained in nearly 75% of the subjects. Conversely, the response was still absent in 75% of the subjects at this level when passively listening. It was not until the stimulus level reached 50 dB and 70 dB SL in the passive condition that the response was reliably obtained in young normal adults. A significance test for the difference between proportions, a nonparametric procedure following Bruning and Kintz (1987), was performed to determine if the number of responses was significantly different between active and passive listening across each intensity. A significant ( $p < 0.05$ ) difference was found at 10, 30 and 50 dB SL indicating it was significantly more likely at lower intensities for the P3 response to occur in active listening rather than in passive listening.

Table 1. Prevalence of P3 response as a function of intensity during active or passive listening

Intensity (dB SL)	Passive listening	Active listening
10*	0/20	10/20
30*	6/20	14/20
50*	16/20	20/20
70	20/20	20/20

\* $p < 0.05$

Figures 8 and 9 show the results of the P3 amplitude and latency measures, respectively, obtained as a function of intensity with the listening condition as a parameter. An analysis of variance (ANOVA) was performed on both the P3 latency and amplitude measures for the main effects of intensity and listening condition and for their interaction. Because the P3 responses were frequently absent at low levels, the ANOVA was done on the data collected at high levels only (50 dB and 70 dB).

As expected, the main effect of listening condition [ $F(1,15)=24.09$ ,  $p < 0.0001$ ] on

the P3 amplitude was found. Additionally, a significant effect of stimulus intensity [ $F(1,15)=5.47$ ,  $p<.003$ ] was also found. However, the interaction between these main effects was not significant [ $F(1,15)=.3$ ,  $p<.48$ ]. A similar pattern of effects was seen on P3 latency. The main effects of listening condition [ $F(1,15)=7.31$ ,  $p<.01$ ] and intensity [ $F(1,15)=17.89$ ,  $p<.001$ ] were both significant while the interaction between the two main effects was not [ $F(1,15)=2.52$ ,  $p<.13$ ].

### C. Experiment 2. P3 response changes with unequal tone intensities

This experiment focused on the question of what changes might be expected in the P3 response when the stimuli were at unequal relative intensities. Normally, the tonebursts generating the P3 response are at equal intensities. Many of the target populations on whom the P3 technique is applied are at high risk for hearing loss. If the hearing thresholds of these populations are not carefully defined prior to testing, the relative loudness of the tonebursts may be different for these individuals. This experiment was designed to demonstrate the effect of obtaining the P3 response when the oddball toneburst was at a lower intensity than the standard toneburst.

The P3 response was collected in both the active and passive listening conditions when the standard tone was held at 70 dB SL and the oddball tone was reduced to 50 dB SL. These P3 measures were then compared to the P3 measures obtained in Experiment 1 when both tonebursts were 70 dB SL. Figures 10 and 11 show a representative averaged difference waveform to unequal intensity tonebursts summed over 5 subjects who had similar latencies. Figure 10 was obtained during a passive listening condition while Figure 11 was obtained during active discrimination.

Table 2 shows a comparison between the number of responses obtained when the P3 was collected in the active and passive listening condition and the tonebursts were either at unequal and equal intensities. The test for differences between proportions was again used to determine if the number of response obtained to unequal toneburst intensities was

significantly different than to equal intensity tonebursts despite the listening strategy. It is already known from Experiment 1 that listening strategy is a significant variable. A significant interaction was found in the passive condition with unequal toneburst intensities. That is, there were significantly fewer P3 responses to unequal intensity tonebursts when the subject was passively listening than to equal intensity tonebursts regardless of listening condition.

Table 2. Prevalence of P3 response obtained with equal and unequal intensities during passive or active listening

	Condition	Number of Responses
Unequal intensity (70/50)	Passive	16/20*
Equal intensity (70/70)	Passive	20/20
Unequal intensity (70/50)	Active	17/20
Equal intensity (70/70)	Active	20/20

\* $p < 0.05$

Figures 12 and 13 show the P3 measures as a function of listening condition when the tonebursts were equal or unequal in intensity. Figure 12 shows the effect on the P3 amplitude while Figure 13 shows the effect on the P3 latency. An analysis of variance (ANOVA) was carried out to determine if the P3 measures of latency and amplitude were effected by the relative toneburst intensities. Six subjects failed to generate a P3 response in one ( $n=5$ ) or both ( $n=1$ ) listening conditions in this part of the study. As expected, the main effect of listening condition significantly effected the P3 amplitude [ $F(1,13)=23.93, p < .0002$ ] and latency [ $F(1,13)=8.04, p < .01$ ]. The P3 response was larger in amplitude and shorter in latency when the subject actively listened for the oddball toneburst. In addition, the main effect of relative stimulus intensity significantly effected the P3 amplitude [ $F(1,13)=6.67, p < .02$ ]. However, it did not effect latency

[ $F(1,13)=3.94, p<.06$ ]. There was a marginally significant ( $p<0.052$ ) interaction between intensity and listening condition [ $F(1,13)=4.55, p<.052$ ] on P3 latency indicating that latency was significantly longer for unequally intense tones when listening passively. No interactive effect was found between listening condition and relative intensity on P3 amplitude.

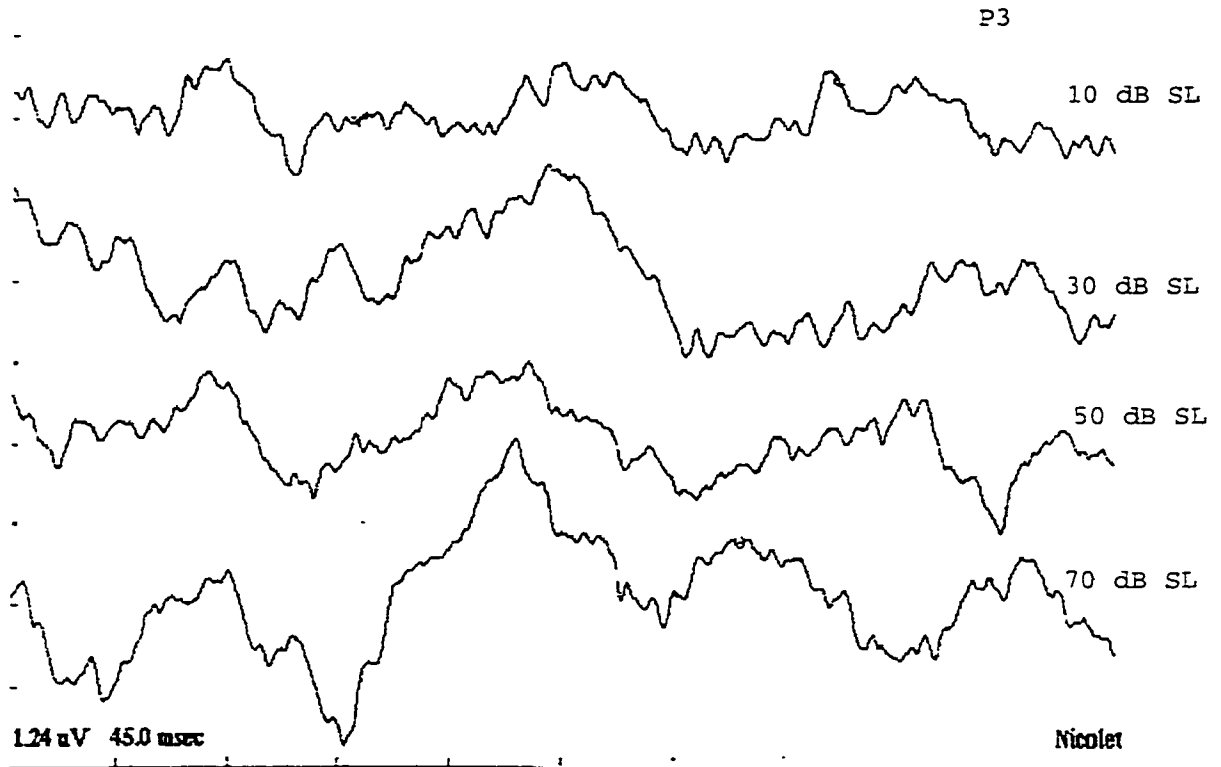


Figure 6. Passive listening P3 waveforms. Summed averaged difference cortical responses including the P3 response from 5 subjects with stimulus intensities from 10-70 dB SL in 20 dB steps. Responses were obtained in the passive listening condition. Timebase is 450 ms.



Figure 7. Active listening P3 waveforms. Summed averaged difference cortical responses including the P3 response from 5 subjects with stimulus intensity from 10-70 dB SL in 20 dB intensity steps. Responses were obtained in the active listening condition. Timebase is 450 ms.

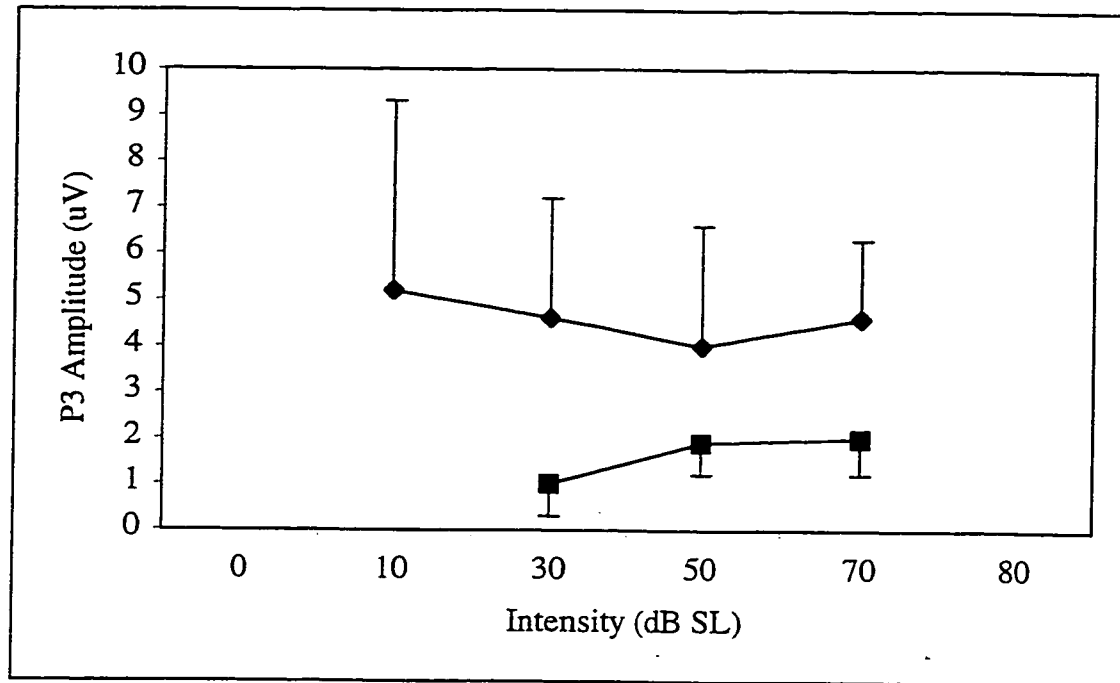


Figure 8. Results of P3 amplitude changes as a function of increasing stimulus intensity. Active listening (filled diamonds) and passive listening (filled squares) conditions are the parameter. Error bars represent +/- one standard deviation.

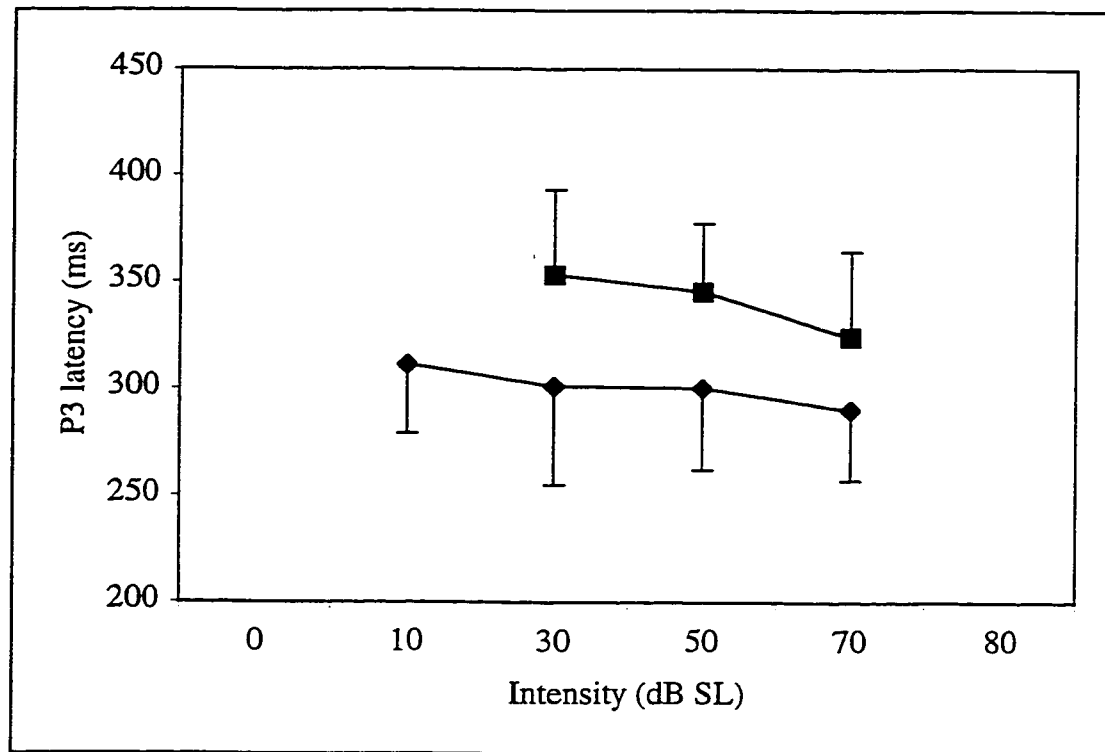


Figure 9. Results of P3 latency changes as a function of increasing stimulus intensity. Active listening (filled diamonds) and passive listening (filled squares) are the parameter. Error bars represent +/- one standard deviation.

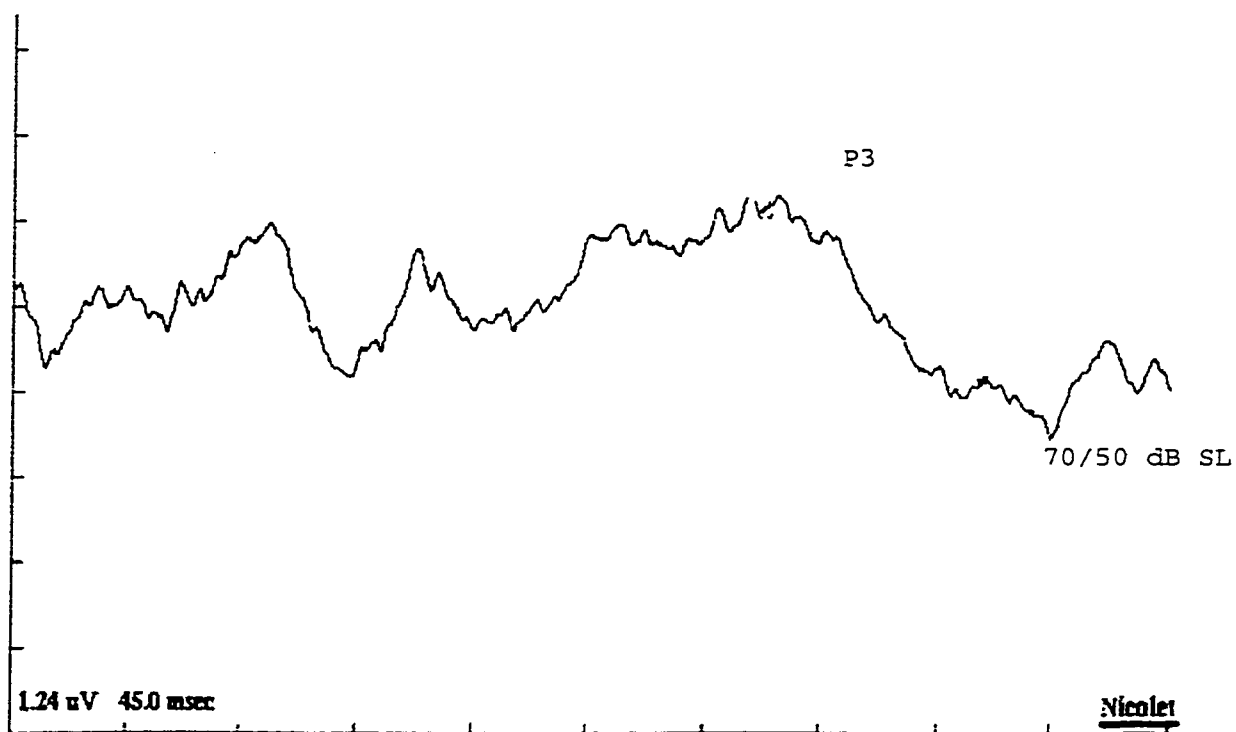


Figure 10. Passive listening unequal intensity P3 waveforms. Summed P3 responses from 5 subjects obtained during passive listening. The stimuli were at unequal relative intensities. The standard toneburst intensity was 70 dB SL while the oddball toneburst was at 50 dB SL.

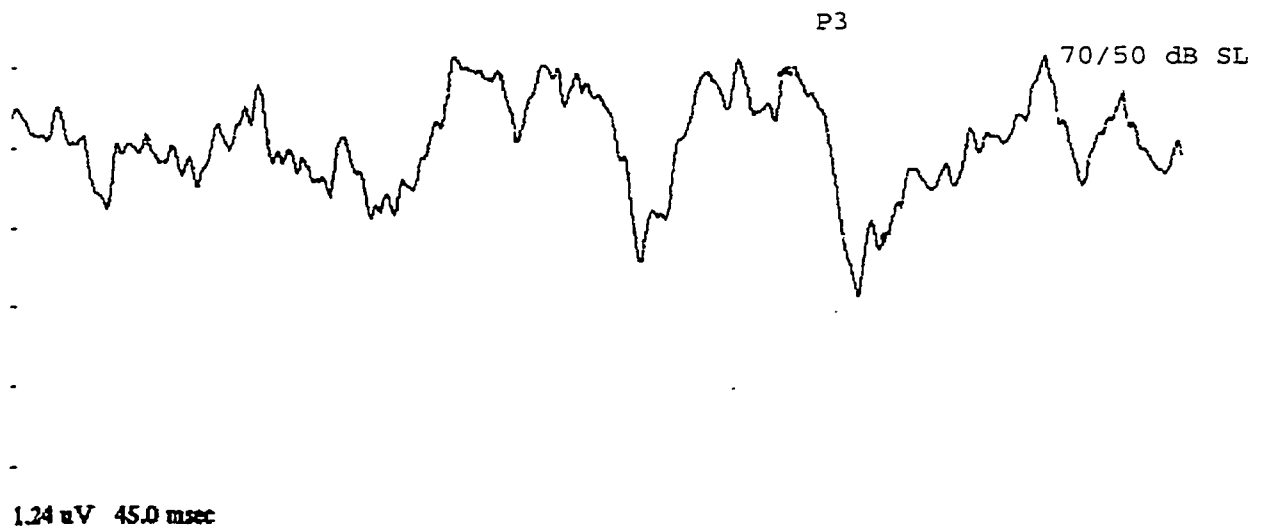


Figure 11. Active listening unequal intensity P3 waveforms. Summed P3 responses from 5 subjects obtained during active listening. The stimuli were at unequal relative intensities. The standard toneburst intensity was 70 dB SL while the oddball toneburst was at 50 dB SL.

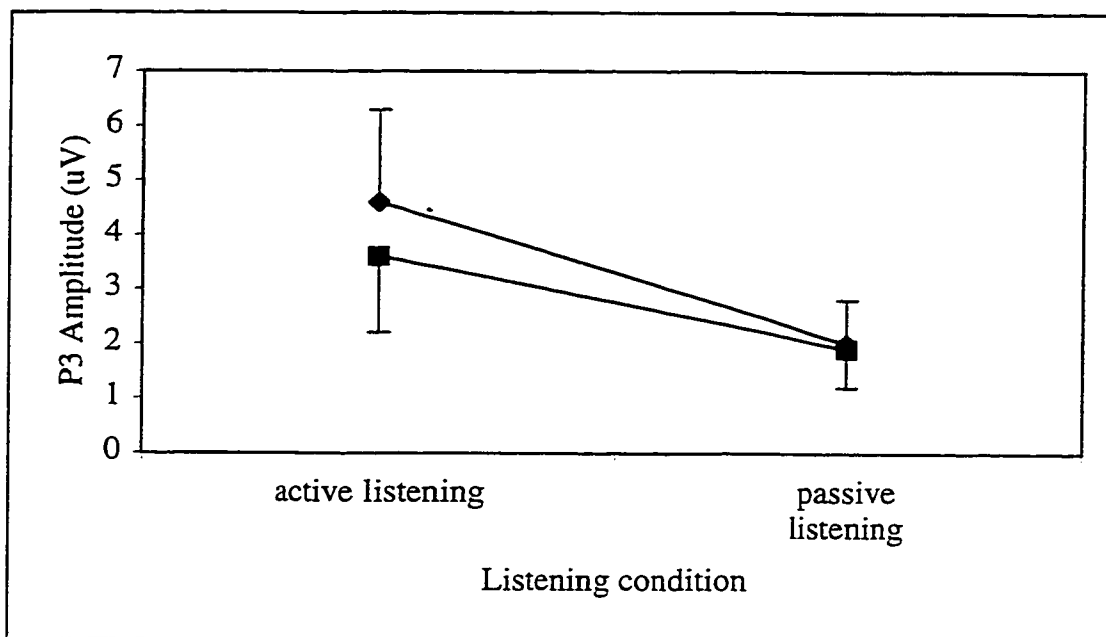


Figure 12. Results of P3 amplitude changes as a function of listening condition. Equal relative toneburst intensities (filled diamonds) and unequal relative toneburst intensities (filled squares) are the parameter. The error bars represent +/- one standard deviation.

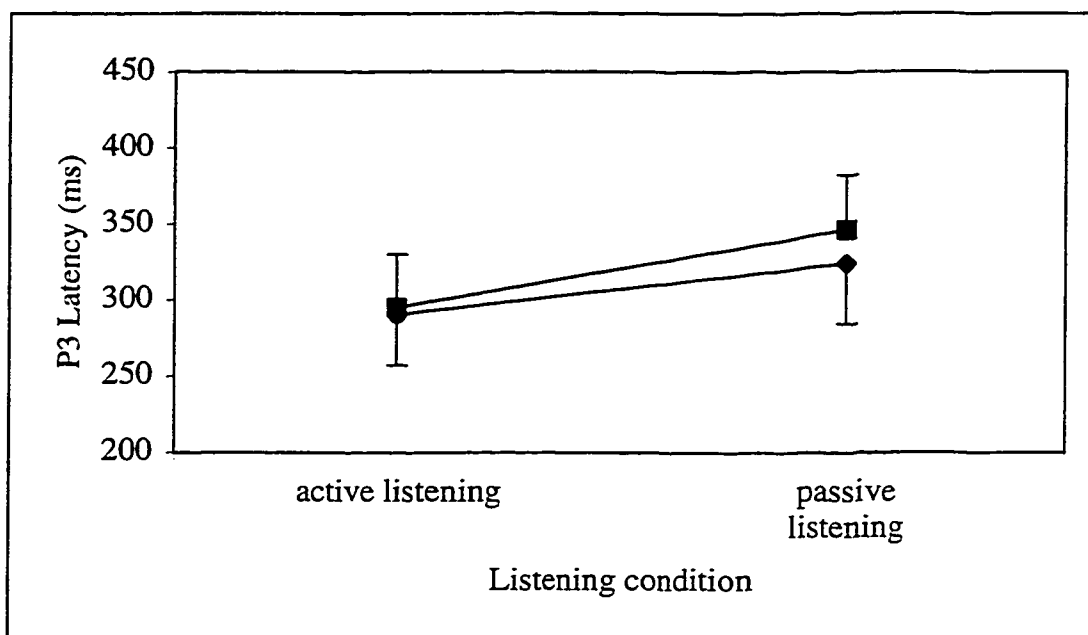


Figure 13. Results of P3 latency changes as a function of listening condition. Equal relative intensity toneburst (filled diamonds) and unequal relative intensity toneburst (filled squares) are the parameter. The error bars represent +/- one standard deviation

## Chapter VI Discussion

The primary purpose of Experiment 1 was to discover if the alerting effects of stimulus intensity could be used to improve the P3 measures so that meaningful comparisons between clinical patients and normal subjects could be made. The literature reports that persons with clinical conditions affecting comprehension or motivation become increasingly less able to carry out the active listening required in tasks during the recording of the P3 response (Cohen, et al., 1995; Muir, et al., 1988). Since high intensity signals have an alerting effect (Greenberg, et al., 1978; Scarf, 1989), it was hypothesized that high intensity stimuli would improve the P3 measures so that an individual unable to attend to the active listening task i.e., a passive listener, would generate P3 responses that were similar to an active listener.

### Experiment 1

#### A. Does increasing the intensity of the tonebursts change the P3 measures?

The findings of Experiment 1 indicate that the P3 measures are affected by the intensity of the tonebursts in three significant ways: the prevalence of the P3 response was greater, the latency was shorter and the amplitude was larger at higher intensity levels.

##### 1. P3 prevalence as a function of intensity

The results from Experiment 1 show that the P3 response were significantly more likely to occur with each 20 dB increase in intensity from 10-70 dB SL. This was true regardless of the listening condition. Half of our subjects did not generate a P3 response at the lowest stimulus level (10 dB SL), even in the active listening condition despite the fact that their behavioral performance indicated that they consistently heard the oddball tone. Even at 30 dB SL, the response was present in only 70% of our young adult subjects during active listening. It was not until 50 dB SL that the P3 response was obtained

reliably in all of our subjects during active listening.

This pattern of increasing P3 response prevalence as a function of stimulus intensity was repeated for passive listening as well. However, higher stimulus intensities were required to assure the response. It was not until 70 dB SL that a reliable response could be obtained during passive listening on all of the young adults subjects. Differing sensitivities to the stimulus are unlikely to have contributed to this difference since threshold (0 dB SL) was obtained at the beginning of the each recording session and all subsequent stimuli were adjusted in dB re: each individual's sensation level.

There are reports in the literature that low level intensities had successfully generated the P3 response in all subjects (Papanicolaou, et al., 1985; Polich, 1989a). These studies focused on the changes in the P3 measures with changes in stimulus parameters such as, intensity. Neither study indicated that a threshold for the stimulus was obtained or that a criterion for inclusion in the study was the presence of the response at low intensities. Therefore, the findings of this study, that the P3 response was less prevalent at low levels, is in conflict with the findings from other studies that did not report a reduction in the prevalence of the response. The active listening tasks and the recording parameters were similar between studies so that these difference are unlikely to explain the discrepant findings. However, the high pass filter setting used in our study (5 Hz) was different from the settings used in the Papanicolaou et al. (0.5 Hz) and Polich (0.01Hz) studies. It has been reported that a filter setting of 1 Hz and above may filter out low frequency neural activity contributing to the P3 waveform (Musiek, et al., 1992). Regardless, several times during each recording session, lower filter settings were attempted but it never happened that our filters could drop below 1 Hz without an inordinately high artifact rejection rate and a significant increase in recording time. The filter setting chosen in this study was chosen for two reasons. It is a setting advocated by some authors (Hall, 1992; Musiek, et al., 1992) and it allows the timely recording of the

response. Several times during each recording session, lower filter settings were attempted but it never happened that the filters could drop below 1 Hz without inordinately high artifact rejection rates and a significant increase in recording time. Nevertheless, it does not seem reasonable that the filter setting of 5 Hz would differentially filter out neural activity at low levels and not at high levels. This difference between studies does not seem to explain our findings of a lower prevalence of the response at low levels. At this point, the reduction in the prevalence of the response cannot be accounted for except as a stimulus intensity related difference. This is an important finding and suggests that stimuli used to evoke the P3 response need to be at high levels, especially if the response must be evoked during passive listening.

The P3 response has been applied to subjects with dementia and other clinical conditions that affect comprehension and motivation. In the interpretation of this response, the most important diagnostic measure is latency since increased latency indicates a problem with short-term memory updating. However, the absence of the response also has been deemed a significant finding related to pathology (Goodin, et al., 1983; Muir, et al., 1988). The present study shows that the intensity of the signals must be considered as an important variable when the presence of the response is used as a diagnostic indicator. This becomes an especially important consideration when patients with significant clinical conditions are no longer able to follow the instructions or provide the concentration necessary to carry out the active listening task and thus, must have the response evoked passively. Moderate-to-high intensity signals are more successful at evoking the P3 response during active listening but only the highest intensity used in this study was found to coerce the response from subjects who were passively listening.

## 2. P3 latency as a function of intensity

The P3 measure of importance in the assessment of most clinical conditions involving memory and comprehension is latency. It is this measurement that is effected by

increasing short-term memory problems (Filipovic & Kostic, 1995; Polich, 1986). The P3 response was found to be significantly shorter in latency at higher intensity levels regardless of the listening strategy employed. For both passive and active listening, the P3 response decreased in latency as the stimulus intensity increased from 50 to 70 dB SL. This finding is consistent with previous investigations into the effect of stimulus intensity during active listening. No study was found in the literature on the effects of stimulus intensity during passive listening. Although it had been predicted that P3 latency would be comparable for active and passive listening at the highest intensity level (70 dB SL), latency values were shorter for active listening than for passive listening at comparable intensities showing that even at high intensities, active listening speeds short-term memory updating.

### 3. P3 amplitude as a function of intensity

Previous studies have found that the P3 amplitude is not effected by intensity increases during active listening (Papanicolaou, et al., 1985; Polich, 1989a). No previous report in the literature has chronicled P3 changes during passive listening as a function of intensity. In this study, the P3 amplitude was significantly increased with increases in stimulus intensity from 50 to 70 dB SL regardless of whether the subject was listening actively or passively. The question of whether amplitude increased from 10-30 dB and from 30-50 dB could not be answered because too few responses were obtained at these levels.

The differences between the results of this study and previous studies might be explained on the basis of methodology. First, the current study equated sensitivity differences between subjects by finding threshold for each toneburst and obtaining the P3 response at the four sensation levels which were the same for all subjects. Both Papanicolaou et al. and Polich used intensity levels in dB sound pressure level (SPL). Since the range of normal hearing is 0-20 dB, differences in sensitivity among young adults with normal hearing could allow the discrimination task to be done at very different

levels. Since this study shows that amplitude does vary with intensity level, using an absolute level such as SPL, without regard for the individual sensitivity of the subjects will very likely introduce variability into the P3 amplitude measure that may obscure any amplitude-intensity trends.

Second, the waveforms collected in the current study were averaged over 80 presentations of the oddball tone. There may be counterproductive aspects to averaging over a series of 80 stimuli in that habituation may occur and reduce the absolute amplitude over many presentations (Musiek, et al., 1992). However, the number of presentations should not differentially change the P3 amplitude as a function of intensity. If the habituation effect does occur, it should have the same effect on P3 amplitude for both high and low intensity tones.

Finally, a third difference between the present study and previous studies concerns the strategies used to present tonebursts of varying sensation levels. In the present study, tonebursts were presented in an ascending order from low to high. Previous studies have used a randomized sensation level strategy. This procedural difference between studies may have influenced results in terms of P3 amplitude related to intensity changes.

P3 procedures are not standardized and, further, many of the variations across commonly-used procedures are assumed to be of little consequence to the test outcome. However, this study has shown that some procedural decisions can have a significant impact. The stimulus intensity can exert an influence over whether a P3 response is evoked at all. If the stimulus used is sufficiently intense to evoke the response, this study has found that the intensity level chosen has a unique effect on the P3 amplitude and latency. Finally, variations in the stimulus intensity between subjects will contribute variability to the P3 measures reducing the sensitivity of the test to memory and cognitive disorders.

The P3 amplitude measurement is frequently adversely affected by memory

disorders such as, dementia (Cohen, et al., 1995; Muir, et al., 1988). It has been reported that in serial measurements of the P3, responses could not be confidently identified because the amplitude was too low (Muir, et al., 1988). Therefore, finding ways to maximize the P3 amplitude are of primary importance. In the current study and in others, the P3 amplitude has been found to be lower for passive listening than for active listening (Polich, 1987a; Polich, 1989b). Therefore, when a passive listening technique is necessary, the present study shows that a higher stimulus intensity will increase the P3 amplitude.

Verlager, Kompf and Neukâter (1992) reported that the P3 measure was insensitive to mild short-term memory disorder such as, early dementia, in part because the response was too variable. According to Verlager et al., the overlap between the P3 measures obtained from the general non-impaired population and those individuals with short-term memory impairment was too great to reliably detect the disorder. The literature to date reveals no study that has recommended a P3 latency or amplitude value that could be considered clinically significant for short-term memory impairment. These results suggest that careful consideration of stimulus intensity and its potential effects on the reliability of the diagnostic findings is an important part of the procedures for P3 applications in diagnosing dementia.

As shown by the present study, stimulus intensity differences between subjects can introduce variability in the P3 measures in young, non-impaired adults. In addition, the perceptual effect of stimulus intensity should be considered. For example, a high intensity stimulus pair presentation is alerting and becomes difficult to ignore, even in subjects instructed to listen passively. This study showed that the likelihood of obtaining the P3 response improved, the latency of the response shortened and the amplitude increased at high stimulus intensities regardless of listening strategy. A frequent comment from the subjects after completing the passive listening portion of this study was that the stimuli became very loud. This, and similar comments about the perceived loudness of the

stimulus, are interpreted to mean that the salience of the stimulus increased thus drawing more cognitive resources to it. For an individual with a cognitive disorder who cannot be counted on to reliably comprehend and perform an active listening task, intensity will be a crucial variable in capturing and directing attention.

This study has shown that high intensity stimulus presentations are likely to change the P3 responses evoked from a passive listener so that responses are more similar to responses obtained from an active listener. More specifically, during passive listening high intensity stimuli improve the likelihood the P3 response will be generated, shorten the P3 latency and increase the P3 amplitude. However, despite this "improvement," P3 responses obtained from a passive listener remain substantially different from responses obtained during active listening. Comparisons made between individuals from the general population and individuals who may not fully understand or be able to cooperate with the active listening task should be made cautiously, especially if the stimuli are presented at low intensity levels. Further, if the individual is only able to cooperate with passive listening, this study shows that removing the alerting effects of stimulus intensity during passive listening and then comparing these P3 findings with individuals who were listening actively will further reduce the sensitivity of the measurement to mild short-term memory disorders. A better comparison would be between P3 measures obtained from high stimuli tone pairs with all subjects listening passively.

B. Does increasing the intensity interact with the listening condition to change the P3 response?

The hypothesis of this question was that as a function of intensity, the P3 amplitude would increase more during passive listening than during active listening. It was proposed that the mechanism for this would be the alerting effect of intensity during the inattentive, passive listening condition.

### 1. P3 prevalence

The results of this study showed that intensity significantly interacted with the listening condition to generate a P3 response. The P3 response was present at moderate-to-high intensities during active listening. During passive listening, the P3 response was generated only at the highest level. When listening passively, high intensity stimuli are needed to consistently generate the P3 response.

### 2. P3 latency

There was no interaction found between listening condition and intensity on the P3 latency. This finding was contrary to findings by Polich (1989b). In a previous study (Polich, 1989a), it was reported that intensity increases significantly shortened the P3 latency during active listening. In a later study Polich then compared the P3 measures during active and passive listening and reported that while the P3 response amplitude decreased during passive listening, the response was unchanged in latency (Polich, 1989b). However, the procedure used in that study to generate the response was different from the procedure used in the present study. Polich devised a procedure, the "passive sequence paradigm," that used a discrimination task in which the oddball was always put into one of 4 sequence positions (out of 10 available positions). In addition, a 4-6 second silent period was inserted between sequence block presentations. Expectancy for the oddball was very likely increased by this procedure. Polich then increased the amount of distraction (solving a timed word puzzle) during the session in an attempt to mimic cognitive dysfunction. While the P3 amplitude was significantly decreased by changing from active to passive listening, P3 latency was unchanged by the listening condition or the amount of distraction. Finding a P3 task that stabilizes the latency measure despite significant amounts of distraction is a reasonable approach to the problem of testing a clinical population with potential memory or cognitive disorders. It is the P3 latency measurement that is of primary interest in the assessment of short-term memory disorders

such as, dementia (Filipovic & Kostic, 1995; Goodin & Aminoff, 1986). Attempting to mimic cognitive dysfunction in young normal adults, however, is a difficult endeavor. It assumes that stabilizing the P3 measures in young normal adults will stabilize those measures in populations with cognitive disorders. Whether that can be done is unknown. Expectancy is not well utilized by many populations including those with cognitive immaturities (Bargones & Werner, 1994; Werner, et al., 1996). It remains to be shown whether the passive sequence paradigm can stabilize latency in a population with cognitive disorders.

### 3. P3 amplitude

One hypothesis of this study was that P3 amplitude would grow more during the passive listening condition as intensity was increased than for active listening. There was no interaction found between stimulus intensity increases and the listening strategy on the P3 response amplitude. The amplitude of the response was changed by the main effects of listening condition and intensity increases only. In part, an interaction was not found because P3 amplitude grew in both listening conditions. However, it does appear from these findings that high intensities cannot fully compensate for the lack of attentional focus during passive listening, at least in a young, non-impaired adult population. It was theorized that the well-documented, alerting effects of stimulus intensity would stabilize the latency and amplitude attributes of the P3 measures, especially in populations that were instructed to listen passively. It was not shown that a passive listener would generate a P3 response at high intensities similar to an active listener. It was shown, however, that high intensity stimuli would generate the response more frequently. This study shows that these are fundamentally different responses in these subjects. The P3 measures during passive listening are less prevalent (except at high intensities), longer in latency and lower in amplitude than when these measures are obtained during active listening. It remains to be shown whether there is an interactive effect of intensity and listening condition on a

population with a cognitive disorder.

## Experiment 2

### A. Do unequal toneburst intensities change the P3 measures?

Experiment 2 was designed to investigate whether tonebursts of unequal intensity (i.e., the oddball tone lower in intensity than the standard) can effect the P3 measures. Since many clinical populations on whom this response has been applied are at high risk for hearing loss (Gold, et al., 1996; Widen, et al., 1987) and since the most common audiometric configuration in an elderly population is high-frequency hearing loss, there will likely be circumstances when hearing loss will affect the perception of the two stimuli used to evoke the P3 response. A common P3 clinical protocol is one in which the oddball tone is higher in frequency than the standard, thus increasing the possibility that the oddball frequency will be in an area of hearing loss. This will usually result in the oddball toneburst being heard at a lower level than the standard for some of the individuals being tested. While it is well-documented that an oddball tone that is higher in intensity than the standard results in a larger amplitude and a shorter latency P3 response (Polich, 1986), the effect on the P3 if the oddball is less intense than the standard is unknown. The purpose of Experiment 2 was to compare P3 responses when the toneburst stimuli are equal or unequal in intensity. In the equal condition, both the oddball and the standard tonebursts were 70 dB SL. In the unequal intensity condition, the oddball was at 50 dB SL while the standard was at 70 dB SL (see Methods).

#### 1. P3 prevalence to unequal intensity tonebursts

A significant difference was found in the prevalence of the response when both listening strategy and relative toneburst intensity were considered. Significantly fewer P3 responses were obtained when the tones were unequal in intensity and the subject was listening passively. In all other conditions, it was highly likely that a P3 would be

obtained. Although it is clearly not an advantageous condition for a subject to have the tonebursts unequally intense and to be listening passively, it is a situation which occurs for many clinical populations. Alzheimer's disease is most likely to occur in elderly individuals (Haass, 1996; St George-Hyslop, et al., 1992) and presbycusis is a hearing disorder that, by definition, occurs in the elderly (Martin, 1997). Further, individuals with memory disorders are even more likely to have hearing problems (Gold, et al., 1996). Therefore, applying the P3 procedure to an elderly individual suspected of developing Alzheimer's disease requires that careful consideration be given to stimulus related issues, especially the intensity of the stimuli. The findings of this study suggest that, if the individual is listening passively, the prevalence of the response is dependent on the relative intensity of the stimuli. Tone pairs that are equal in intensity are more successful at eliciting a P3 response than tone pairs in which the oddball is less intense than the standard.

### 2. P3 latency to unequal intensity tonebursts

This study did not find that latency was effected by whether the tones were equal or unequal in intensity. Since previous studies have found that presenting the stimuli at unequal levels (oddball more intense) did not change the latency (Polich, 1987b), the findings of this study suggest that unequally intense stimuli, whether the oddball is higher or lower in level, preserves the salience of the discrimination, at least to the extent that short-term memory updating is considered. When the oddball is different in two domain, i.e., frequency and intensity, the ease of processing is not adversely effect.

### 3. P3 amplitude to unequal intensity tonebursts

The P3 amplitude was adversely effected by unequally intense tonebursts, but only during active listening. In this situation, the unequally intense tonebursts elicited significantly lower amplitude responses. During passive listening, the P3 amplitudes were lower overall, as expected and observed previously, but not significantly changed by the relative intensity of the tonebursts. This may be due to a "floor effect" of response

amplitude. That is, passive listening results in P3 amplitudes that are already very low. Any further effects including, stimulus effects, beyond this amplitude reduction from passive listening may not be possible. Support for this argument comes from the fact that the prevalence of the response is significantly lowered when the tonebursts are unequal in intensity and the individual is listening passively. The only possible further deterioration in the response may be no response at all.

Any time this test is administered to a clinical population hearing should be carefully defined and the level of the tone pairs adjusted to be equal, especially during passive listening. This compensatory method would maximize the P3 amplitude. The results of this study suggest that unless the discrimination is done equivalently across individuals, amplitude variability will be high. If P3 amplitude is used as a clinically significant measure, care must be taken to insure that the discrimination task is carried out in an equivalent fashion for all subjects.

Two potential findings were predicted for Experiment 2. First, as shown in Figure 4, it was predicted that when the subjects heard the stimuli at unequal levels, the P3 amplitude would be high for both active or passive listening indicating that the unequally intense tonebursts were highly salient. The other prediction, shown in Figure 5, suggested that for tonebursts of unequal intensity, the P3 amplitude would be lower overall during both passive and active listening despite the listening strategy used. In fact, no interaction regarding P3 amplitude was found. Only the main effects of listening condition and relative stimulus intensity were found to be significant. P3 amplitude was always lower when listening passively. Consequently, the relative intensity is not a salient feature, when it is the oddball that is lower in level than the standard. It was found that stimuli of unequal level resulted in longer P3 latencies and a lower overall prevalence. This provides further evidence that when the oddball is at a lower level than the standard, the discrimination task is made more difficult.

B. What are the interactive effects of unequal toneburst intensities on the P3 measures when the listening condition is varied?

One of the purposes of Experiment 2 was to investigate whether the P3 measures were adversely effected by both undiscovered hearing loss and in the inability of some individuals to comprehend and cooperate with an active listening task. An interaction was found between the listening strategy (passive or active) and the relative intensity of the tones on both the response prevalence and P3 latency. No interaction was shown for amplitude. During passive listening when the tones were at unequal levels, this study showed that the response was significantly less likely to occur and, when the response was available, was significantly longer in latency. In a clinical population e.g., individuals with dementia, the lack of a P3 response or the finding of an increase in P3 latency is a clinically significant finding (Goodin, et al., 1983, Muir, 1988 #28). This study shows that the intensity of the tones, especially during passive listening, does matter. If hearing loss is known prior to testing, the stimulus intensity must be adjusted so that the discrimination is carried out equivalently across individuals. Without careful consideration of the stimulus parameter generating the response (i.e., intensity), the P3 measures could be misinterpreted. Further, the P3 response is sometimes poorly correlated with neuropsychological measures of some clinical disorders (e.g., dementia) (Cohen, et al., 1995). Inadvertent differences in stimulus intensity could contribute to variability in the measure and reduce its sensitivity to disorders of short-term memory.

Stimulus level compensations to rectify the problem of differential sensitivity across frequencies can be complex. In normally hearing individuals, the range between threshold for a sound (barely audible) and perceiving a sound as loud can be 70-80 dB. Individuals with cochlear hearing loss, however, may experience recruitment, an abnormal growth of loudness. In recruitment, the range between threshold for a sound and the perception of loudness can be as low as 20-30 dB. In the present study, all of the subjects had normal

hearing. Consequently their dynamic range of hearing was likely similar (though this was not directly tested in this study). During the data collection for Experiment 1, the subjects were sometimes asked if the tonebursts sounded equally loud. All subjects answered affirmatively. However, since the tonebursts are different in frequency, loudness judgement is a more complicated task (Martin, 1997). Nevertheless, using stimulus levels related to hearing threshold such as, sensation level, to equate loudness among subjects with sloping hearing loss may not work. If sensation level is used, the stimulus in the frequency region associated with hearing loss may be perceived as much louder than the stimulus in the area of normal hearing. If the tone pairs are perceived as unequally loud, this study shows that the P3 measures will be effected. Loudness balancing procedures such as, the alternate binaural loudness balance (ABLB) test or the alternate monaural loudness balance (AMLB) test have been used to equate loudness (Rintelmann, 1991). These tests are very time consuming, however, and may be difficult to carry out with a clinical population. The important information to obtain, when possible, is a complete hearing threshold assessment. This information could then be used to select tone pairs for P3 testing that avoid areas of hearing impairment, thus avoiding loudness differences between the tone. It may be that other procedures, including physiologic procedures, could be used to objectively determine loudness so that difficult-to-test individuals with significant hearing loss across all frequencies could be tested. However, additional investigation is required to apply physiologic procedures in this way.

## Chapter VII Conclusions

### Experiment 1

\* Intensity is an important determinant in obtaining the P3 response. The prevalence of the response is greater while the amplitude is larger and latency is shorter at high stimulus intensity levels.

\* The P3 response should be done at high stimulus intensities. This is especially important when listening passively. When a subject is not able to cooperate with an active listening task either because of poor motivation or poor comprehension of the required task, high stimulus intensity levels will improve the likelihood of evoking the response as well as increasing the amplitude and shortening the latency.

\* High stimulus intensity did not cause a passive listener to generate a P3 response that was statistically similar to the response from an active listener. These responses remain very different. Comparisons should not be made between responses from subjects who adopt different listening strategies (active vs passive).

### Experiment 2

\* Stimuli should be presented at equal relative intensities and at high levels. This is especially important if the individual is listening passively. Passive listening and unequal relative intensities (oddball lower intensity than standard) reduced the response prevalence and P3 amplitude.

\* Hearing evaluations should be done prior to P3 testing. The stimuli should be adjusted so that the discrimination is done using tones of equal loudness. Sensation level may be a good method for equating loudness in normally hearing individuals.

\* The P3 amplitude was not detrimentally affected by a lower level oddball tone. This would suggest that the salience of the discrimination task did not change when the toneburst intensities were unequal and the subject was listening passively.

## References

- Baddeley, A. (1990). Human Memory: Theory and Practice. London: Allyn and Bacon.
- Bargones, J. Y., & Werner, L. A. (1994). Adults Listen Selectively; Infants Do Not. Psychological Science, *5*(3), 170-173.
- Berman, S., & Friedman, D. (1995). The development of selective attention as reflected by event-related brain potentials. J. of Experimental Child Psychology, *59*, 1-31.
- Blackwood, D. H. R., St Clair, D. M., Muir, W. J., & Oliver, C. J. (1988). The development of Alzheimer's disease in Down's syndrome assessed by auditory event-related potentials. Journal of Mental Deficiency, *32*, 439-453.
- Broadbent, D. E. (1958). Perception and communication. New York: Pergamon.
- Brown, W. S., Marsh, J. T., & LaRue, A. (1983). Exponential electrophysiological aging: P3 Latency. Electroencephalography and clinical Neurophysiology, *55*, 277-285.
- Bruning, James L. and Kintz, B.L. (1987). Computational Handbook of Statistics. Glenview, Illinois: Scott Foresman and Company.
- Buchanan, L. H. (1990). Early Onset of Presbycusis in Down Syndrome. Scand Audiol, *19*, 103-110.

Cohen, R. A., O'Donnell, B. F., Meadows, M. E., Moonis, M., Stone, W. F., & Drachman, D. A. (1995). ERP indices and neurophysiological performance as predictors of functional outcome in dementia. Journal of Geriatric Psychiatry and Neurology, 8, 217-225.

Courchesne, E. (1978). Neurophysiological correlates of cognitive development: Changes in long-latency event-related potentials from childhood to adulthood. Electroencephalography and clinical Neurophysiology, 45, 468-482.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within human information-processing system. Psychological Bulletin, 104(2), 163-191.

Coyle, S., Gordon, E., Howson, A., & Meares, R. (1991). The effects of age on auditory event-related potentials. Experimental Aging Research, 17(2), 103-111.

Das, J., Divis, B., Alexander, J., Parrila, R. K., & Naglieri, J. A. (1995). Cognitive Decline Due to Aging Among Persons with Down Syndrome. Research in Developmental Disabilities, 16(6), 461-468.

Das, J. P., Kirby, J., & Jarman, R. F. (1975). Simultaneous and Successive Synthesis: An Alternative Model for Cognitive Abilities. Psychological Bulletin, 82(1), 87-103.

Devenny, D., Silverman, W., Hill, A., Sersen, E., & Wisniewski, K. (1996). Normal aging in adults with Down's syndrome: a longitudinal study. Journal of Intellectual Disability Research, 40(3), 208-221.

Filipovic, S. R., & Kostic, V. S. (1995). Utility of auditory P300 in detection of presenile dementia. Journal of Neurological Sciences, *131*, 150-155.

Gold, M., Lightfoot, L. A., & Hnath-Chisolm, T. (1996). Hearing loss in a memory disorders clinic A specially vulnerable population. Arch Neurol, *53*, 922-928.

Goodin, D. S., & Aminoff, M. J. (1986). Electrophysiological differences between subtypes of dementia. Brain, *109*, 1103-1113.

Goodin, D. S., Starr, A., Chippendale, T., & Squires, K. C. (1983). Sequential changes in the P3 component of the auditory evoked potential in confusional states and dementing illnesses. Neurology, *33*, 1215-18.

Greenberg, D., Wilson, W. R., Moore, J. M., & Thompson, G. (1978). Visual Reinforcement Audiometry (VRA) with Young Down's Syndrome Children. J. of Speech and Hearing Disorders, *43*, 448-458.

Haass, C. (1996). Presenile because of presenilin: the presenilin genes and early onset Alzheimer's disease. Current Opinion in Neurology, *9*, 254-259.

Halgren, E., Squires, N. K., Wilson, C. L., Rohrbaugh, J. W., Babb, T. L., & Crandall, P. H. (1980). Endogenous Potentials Generated in the Human Hippocampal Formation and Amygdala by Infrequent Events. Science, *210*(14), 803-805.

Hall, J. W. I. (1992). Handbook of Auditory Evoked Responses. Boston: Allyn and Bacon.

- Kay-Raining Bird, E., & Chapman, R. S. (1994). Sequential Recall in Individuals with Down Syndrome. J. of Speech and Hearing Research, 37, 1369-1380.
- Keiser, H., Montague, J., Wold, D., Maune, S., & Pattison, D. (1981). Hearing Loss of Down Syndrome Adults. Amer. J. of Ment. Defic., 85(5), 467-472.
- Marcell, M. M., & Armstrong, V. (1982). Auditory and Visual Sequential Memory of Down Syndrome and Nonretarded children. Amer. J. of Ment. Defic., 87(1), 86-95.
- Marcell, M. M., & Cohen, S. (1992). Hearing Abilities of Down Syndrome and Other Mentally Handicapped Adolescents. Research in Developmental Disabilities, 13, 533-551.
- Martin, B. A., Sigal, A., Kurtzberg, D., & Stapells, D. R. (1997). The effects of decreased audibility produced by high-pass noise masking on cortical event-related potentials to speech sounds /ba/ and /da/. Journal of the Acoustical Society of America, 101(3), 1585-1599.
- Martin, F. N. (1997). Introduction to Audiology (6th edition ed.). Boston: Allyn and Bacon.
- Muir, W. J., Squire, I., Blackwood, D. H. R., Speight, M. D., St Clair, D. M., Oliver, C., & Dickens, P. (1988). Auditory P300 responses in the assessment of Alzheimer's disease in Down's syndrome: a 2-year follow-up study. Journal of Mental Deficiency Research, 32, 455-463.

Musiek, F. E., Baran, J. A., & Pinheiro, M. (1992). P300 results in patients with lesions of the auditory areas of the Cerebrum. J. Am. Acad. Audiol., 3, 5-15.

Naatanen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. Behavioral and Brain Sciences, 13, 201-288.

Northern, Jerry L. and Downs, Marion P. (1991). Hearing in Children (4th edition ed.). Baltimore: Williams and Wilkins.

Papanicolaou, A. C., Loring, D. W., Raz, N., & Eisenberg, H. M. (1985). Relationship between Stimulus Intensity and the P300. Psychophysiology, 22(3), 326-329.

Pearce, J. W., Crowell, D. H., Tokioka, A., & Pacheco, G. P. (1989). Childhood developmental changes in the auditory P3. Journal of Child Neurology, 4, 100-106.

Pfefferbaum, A., Ford, J. M., Roth, W. T., Hopkins, W. F. I., & Kopell, B. S. (1979). Event-related potential changes in healthy aged females. Electroencephalography and clinical Neurophysiology, 46, 81-86.

Picton, T. W., Stuss, D. T., Champagne, S. C., & Nelson, R. F. (1984). The effects of age on human event-related potentials. Psychophysiology, 2(3), 312-325.

Polich, J. (1986). Attention, probability, and task demands as determinants of P300 latency from auditory stimuli. Electroencephalography and clinical Neurophysiology, 63, 251-259.

Polich, J. (1987a). Comparison of P300 from a passive tone sequence paradigm and an active discrimination task. Psychophysiology, 24(1), 41-46.

Polich, J. (1987b). Task Difficulty, Probability, and Inter-stimulus Interval as Determinants of P300 from Auditory Stimuli. Electroencephalography and clinical Neurophysiology, 68, 311-320.

Polich, J. (1989a). Frequency, Intensity, and Duration as Determinants of P300 from Auditory Stimuli. J of Clin Neurophysiology, 6(3), 277-286.

Polich, J. (1989b). P300 from a passive paradigm. Electroencephalography and clinical Neurophysiology, 74, 312-320.

Polich, J. (1991). P300 in the evaluation of aging and dementia. Event-related Brain Research, EEG supplement 42, 304-322.

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

Scarf, B. (1989). Spectral specificity in auditory detection: The effect of listening on hearing. J. Acoust. Soc Jpn., 10(6), 3093-17.

St George-Hyslop, P., Haines, J. R., E. Mortilla, M., & Roses, A. M., D. Crapper (1992). Genetic evidence for a novel familial Alzheimer's disease locus on Chromosome 14. Nature Genetics, 2, 330-334.

Thase, M. E., Tigner, R., Smeltzer, D. J., & Liss, L. (1984). Age-related Neuropsychological deficits in Down's syndrome. Biological Psychiatry, 19(4), 571-585.

Tomporowski, P. D., Hayden, A. M., & Applegate, B. (1990). Effects of Background Event Rate on Sustained Attention of Mentally Retarded and Nonretarded. Amer. J. on Mental Retardation, 94(5), 499-508.

Van Broeckhoven, C., Backhovens, H., Cruts, M., De Winter, G., Bruyland, M., Cras, P., & Martin, J.-J. (1992). Mapping of a gene predisposing to early-onset Alzheimer's disease to chromosome 14q24.3. Nature Genetics, 2, 335-339.

Verlager, R., Kompf, D., & Neukater, W. (1992). Event-related EEG potentials in mild dementia of the Alzheimer type. Electroencephalography and clinical Neurophysiology, 84, 332-343.

Verlager, R., Neukater, W., Kompf, D., & Vieregge, P. (1991). On the reasons for the delay of P3 latency in healthy elderly subjects. Electroencephalography and clinical Neurophysiology, 79

Vesco, K. K., Bone, R. C., Ryan, J. C., & Polich, J. (1993). P300 in young and elderly subjects: auditory frequency and intensity effect. Electroencephalography and clinical Neurophysiology, *88*, 302-308.

Vierregge, P., Verlager, R., Schulze-Rava, H., & Kompf, D. (1992). Late cognitive event-related potentials in adult Down's syndrome. Biol. Psychiatry, *32*, 1118-1134.

Werner, L. A., Mancl, L. R., & Folsom, R. C. (1996). Preliminary Observations on the Development of Auditory Sensitivity in Infants with Down Syndrome. Ear and Hearing, *17*(6), 455-468.

Whiting, K. A., Martin, B. A., & Stapells, D. R. (1998). The effects of broadband noise masking on cortical event-related potentials to speech sounds /ba/ and /da/. Ear and Hearing, *19*(3), 218-231.

Widen, J. E., Folsom, R. C., Thompson, G., & Wilson, W. R. (1987). Auditory brainstem responses in young adults with Down syndrome. American Journal of Mental Deficiency, *91*(5), 472-478.

Woldorff, M. G., Hackley, S. A., & Hillyard, S. A. (1991). The effects of channel-selective attention on the mismatch negativity wave elicited by deviant tones. Psychophysiology, *28*(1), 30-42.

Wood, C. C., Allison, T., Goff, W. R., Williamson, P. D., & Spencer, D. D. (1980). On the neural origin of P300 in man. Progress in Brain Research, *54*, 51-56.

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