

DISSOCIATION OF P₃₀₀ BRAIN POTENTIALS
EVOKED BY RARE VISUAL STIMULI

David Matthews

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews



1995

Full metadata for this item is available in
St Andrews Research Repository
at:
<http://research-repository.st-andrews.ac.uk/>

Please use this identifier to cite or link to this item:
<http://hdl.handle.net/10023/14732>

This item is protected by original copyright

**Dissociation of P300 Brain Potentials Evoked by
Rare Visual Stimuli**

A Thesis Presented by

DAVID MATTHEWS

to

THE UNIVERSITY OF ST. ANDREWS

**In Application for the Degree of
Doctor of Philosophy**

March 1994



ProQuest Number: 10167390

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



ProQuest 10167390

Published by ProQuest LLC (2017). Copyright of the Dissertation is held by the Author.

All rights reserved.

This work is protected against unauthorized copying under Title 17, United States Code
Microform Edition © ProQuest LLC.

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 – 1346

14 B590.

Declaration for the Degree of Ph.D.

I, David Matthews, hereby certify that this thesis, which is approximately 65,000 words in length, has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

Signed

Date 3 March 1994

I was admitted as a research student under Ordinance No. 12 in October 1990 and as a candidate for the degree of Ph.D. in October 1990; the higher study for which this is a record was carried out in the University of St. Andrews between 1990 and 1994.

Signed

Date 3rd March 1994

I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate for the degree of Ph.D. in the University of St. Andrews and the candidate is qualified to submit this thesis in application for that degree.

Signature of Supervisor

Date 3 Mar 94

UNRESTRICTED

In submitting this thesis to the University of St. Andrews I understand that I am giving permission for it to be made available for use in accordance with the regulations of the University Library for the time being in force, subject to any copyright vested in the work not being affected thereby. I also understand that the title and abstract will be published, and that a copy of the work may be made and supplied to any bona fide library or research worker.

Signed

Date 3rd March 1994

Acknowledgements

"For silence and invisibility go hand in hand with powerlessness." Audre Lorde

There are a great many people whom I would like to thank for their help and support during the time this piece of work has taken to complete. Firstly I would like to sincerely thank Mick Rugg for enabling me to carry out this work and providing guidance on its direction throughout the time it took to complete.

A big thank you goes to Juliet for making my first forays into data collection and analysis less precarious than they would otherwise have been, and for endless discussions which helped to make the waters of P300 research somewhat less murky. Together with Juliet I would also like to credit Monika and Annie for creating a comfortable, friendly (gossipy?) yet productive environment in which to work.

Thanks to Fiona, Simon, Helen (Jones), Karl, Colin, Richard and Helen (White), together with David for helping to create a social life in St. Andrews which proved to be so enjoyable. Sincere thanks to Helen Jones for providing so much help and support during the tedious final couple of days of work. Thanks must also go to Sally, Sarah, Jo, Kim and Marion for providing long term friendship and support from afar in the good times as well as the not so good.

Finally a big thank you to Mam and Dad together with Mae, Nana, Niki and Steven for their consistent support throughout the years.

Contents

Contents

Abstract

Table of Figures

List of Abbreviations

Chapter 1 Introduction

Background to the Study of ERPs	1
What are ERPs?	1
Physiological Bases of ERPs	2
Recording the ERP	2
Signal to Noise Improvement	3
Artifacts	3
Recording Conventions	4
ERP Components	5
Quantifying ERP Components	6
Classification of ERP Deflections	7
Exogenous Components	7
Mesogenous Components	7
Endogenous Components	8
Oddball Tasks	9
P300 Complex	11
Nomenclature	12
P300 Latency	13
Component Topography	15
Multiple Sources of P300 Activity	16
Evidence of Dissociability	17
Visual Modality Dissociation	17
Auditory Modality Dissociation	19
Somatosensory Modality Dissociation	19
Lesion Studies	20
Theories of the Functional Significance of the P300	21
Triarchic Model (Johnson 1986; 1988; 1993)	21
Context Updating Model (Donchin 1981)	25
Context Closure Model (Verleger 1988)	26
Attentional Trace Theory (Naatanen 1982; 1990; 1992)	27

Auditory Processing Outside the Attentional Trace	29
Visual MMN	30
Visual Negativities	32
Considerations of the Functional Models	33
Summary of the Models of the P300 Complex	36
Aims of Programme	37
Chapter 2 General Methodolgy and Data Analysis	
General Methodology	39
Data Analysis	41
Chapter 3 Experiment 1: Investigation of the Dissociation of the P300 Complex in Auditory and Visual Modalities	
Introduction	45
Method	46
Results	49
Discussion	58
Chapter 4 Experiment 2: Investigation of the Dissociation of the P300 Complex Employing Knight's (1991) Visual Stimuli	
Introduction	67
Method	68
Results	69
Discussion	75
Chapter 5 Experiment 3: Dissociation of Responses to Rare Stimuli Employing Spatially Deviant Rare Nontarget Stimuli	
Introduction	79
Method	80
Results	82
Discussion	88
Chapter 6 Experiment 4: Investigation of Mean Amplitude and Scalp Amplitude Distribution Evoked by Three Classes of Equiprobable Stimuli	
Introduction	92
Method	94
Results	97

Discussion	106
------------	-----

Chapter 7 Experiment 5: Investigation of Mean Amplitude and Scalp Amplitude Distribution Evoked by Increasing the Physical Contrast Between Frequent and Target Stimuli

Introduction	112
Method	113
Results	115
Discussion	122

Chapter 8 Experiment 6: Investigation of the Effect of Advancing Age upon the Scalp Amplitude Distribution of Visually and Auditorially Evoked P300 Potentials

Introduction	128
Method	130
Results	132
Discussion	155

Chapter 9 General Discussion

Aim of the Research Programme	161
Auditory Dissociation of the P300 Complex	161
Visual Dissociation of the P300 Complex	162
Experimental Manipulations within the Visual Modality	163
The P300 Complex and Elderly Subjects	166
Modality Specificity of the P300 Complex	167
Functional Models of the P300 Complex	169
Context Updating and Context Closure Models	169
Attentional Trace Model	170
Other ERP Components Measured	173
N100 Deflection	173
N200 Deflection	174
Slow Wave Deflections	175
Lateral Parietal Differences between 150 - 350 msec	175
Conclusion	177
Future Developments	178

References

179

Appendix

Figures of Appendix

Abstract

The P300 event related potential (ERP) has consistently been dissociated into separate components on the basis of scalp amplitude distribution within the auditory modality (for instance Squires *et al.* 1975). A parietally maximum P300 deflection being evoked in response to target stimuli in comparison with a more frontally maximum P300 deflection evoked in response to rare nontarget stimuli. Results obtained within experiment 1 and 6 demonstrated such a dissociation employing auditory stimuli within a three stimulus oddball paradigm.

It did not prove possible to obtain such a dissociation of P300 deflections on the basis of scalp amplitude distribution within the visual modality. Across a number of experimental manipulations both target and rare nontarget stimuli evoked P300 deflections with similar amplitude distributions (centro-parietal maximum along the midline). Experiment 5 demonstrated that frequent stimuli similarly evoked a centro-parietal maximum amplitude distribution.

It was demonstrated that both stimulus probability (Experiment 4) and the physical characteristics of the stimuli (Experiment 5) affected the mean amplitude of the evoked P300 deflection. However, the scalp amplitude distribution of the evoked deflections remained constant.

Within Experiment 6 it was demonstrated that within both auditory and visual modalities P300 deflections, evoked in response to both target and rare nontarget stimuli, demonstrated an equipotential amplitude distribution within an elderly group of subjects. In addition across both modalities amplitude evoked in response to rare nontarget stimuli demonstrated an asymmetric distribution across lateral chains of electrodes. Amplitude evoked along the right chain was significantly reduced in comparison to that evoked along the left chain.

It would appear that the same, or a similar combination of, underlying neural generators are responsible for the activity that may be recorded at the scalp as the P300 deflection within the visual modality.

Table of Figures

Figure 3.1a and 3.1b Waveforms, averaged across 11 subjects, for each condition of the visual (Figure 3.1a) and auditory (Figure 3.1b) stimuli in Experiment 1.

Figure 3.2a and 3.2b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by auditory (Figure 3.2a) and visual (Figure 3.2b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode site).

Figure 3.3a and 3.3b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by auditory (Figure 3.3a) and visual (Figure 3.3b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

Figure 3.4a and 3.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by auditory target (Figure 3.4a) and rare nontarget stimuli (Figure 3.4b) in Experiment 1.

Figure 3.5a and 3.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by visual target (Figure 3b.5a) and rare nontarget stimuli (Figure 3.5b) in Experiment 1.

Figure 3.6a and 3.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by auditory (Figure 3.6a) and visual (Figure 3.6b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

Figure 3.7a and 3.7b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory target (Figure 3.7a) and rare nontarget (Figure 3.7b) stimuli in Experiment 1 (collapsed across electrode chain).

Figure 3.8a and 3.8b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by visual target (Figure 3.8a) and rare nontarget (Figure 3.8b) stimuli in Experiment 1 (collapsed across electrode chain).

Figure 3.9a and 3.9b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range of 500 -850 msec elicited by auditory (Figure 3.9a) and visual (Figure 3.9b) frequent, target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

Figure 4.1a and 4.1b Waveforms, averaged across 12 subjects, for each condition of the triangle procedure (Figure 4.1a) and circle procedure (Figure 4.1b) in Experiment 2.

Figure 4.2a and 4.2b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by target (Figure 4.2a) and rare nontarget (Figure 4.2b) stimuli in Experiment 2.

Figure 4.3 Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the N100 deflection elicited by frequent, target and rare nontarget stimuli in Experiment 2 (collapsed over electrode site).

Figure 4.4a and 4.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 4.4a) and rare nontarget (Figure 4.4b) stimuli in Experiment 2 (collapsed across experimental procedure).

Figure 4.5a and 4.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 4.5a) and rare nontarget (Figure 4.5b) stimuli in Experiment 2.

Figure 4.6a, 4.6b and 4.6c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by frequent (Figure 4.6a), target (Figure 4.6b) and rare nontarget (Figure 4.6c) stimuli.

Figure 4.7a and 4.7b Bar diagram illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the triangle (Figure 4.7a) and circle (Figure 4.7b) procedures at lateral parietal sites in Experiment 2.

Figure 5.1a and 5.1b Waveforms, averaged across 16 subjects, for each condition of the "single line" (Figure 5.1a) and "fragmented" (Figure 5.1b) procedure in Experiment 3 (collapsed across experimental procedure).

Figure 5.2a and 5.2b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by target (Figure 5.2a) and rare nontarget (Figure 5.2b) stimuli in Experiment 3.

Figure 5.3a and Figure 5.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by the single line (Figure 5.3a) and fragmented (Figure 5.3b) procedures in Experiment 3.

Figure 5.4a and Figure 5.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by the single line (Figure 5.4a) and fragmented (Figure 5.4b) procedures in Experiment 3 (collapsed across experimental condition).

Figure 5.5a and 5.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 5.5a) and rare nontarget (Figure 5.5b) stimuli within the single line procedure of Experiment 3.

Figure 5.6a and 5.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 5.6a) and rare nontarget (Figure 5.6b) stimuli within the fragmented procedure of Experiment 3.

Figure 5.7a, 5.7b and 5.7c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited by frequent (Figure 5.7a), target (Figure 5.7b) and rare nontarget (Figure 5.7c) stimuli in Experiment 3 (collapsed across experimental procedure).

Figure 5.8a and 5.8b Bar diagrams illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the single line (Figure 5.8a) and fragmented (Figure 5.8b) procedures at lateral parietal electrode sites (collapsed across electrode sites) in Experiment 3.

Figure 6.1a and 6.1b, Waveforms, averaged across 16 subjects, for each condition of the two condition (Figure 6.1a) and three condition (Figure 6.1b) procedures in Experiment 4.

Figure 6.2a and 6.2b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by simple (Figure 6.2a), target

(Figure 6.2b) stimuli within the two condition procedure in Experiment 4.

Figure 6.3 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by the two condition procedure in Experiment 4 (collapsed across experimental condition).

Figure 6.4a and 6.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by simple (Figure 6.4a) and target (Figure 6.4b) stimuli within the two condition procedure in Experiment 4.

Figure 6.5a and 6.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec by simple (Figure 6.5a) and target (6.5b) stimuli within the two condition procedure in Experiment 4.

Figure 6.6a, 6.6b and 6.6c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by simple (Figure 6.6a), target (Figure 6.6b) and complex (Figure 6.6c) stimuli within the three condition procedure in Experiment 4.

Figure 6.7 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by the three condition procedure in Experiment 4 (collapsed across experimental condition).

Figure 6.8a, 6.8b and 6.8c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by simple (Figure 6.8a), target (Figure 6.8b) and complex (Figure 6.8c) stimuli within the three condition procedure in Experiment 4.

Figure 6.9a, 6.9b and 6.9c Graph illustrating the distribution, across electrode site, of rescaled amplitude elicited within the latency range 500 - 850 msec by simple (Figure 6.9a), target (6.9b) and complex (Figure 6.9c) stimuli within the three condition procedure in Experiment 4.

Figure 6.10 Bar diagram illustrating the mean amplitude evoked by simple, target and complex stimuli within the three condition procedure in Experiment 4.

Figure 7.1a and 7.1b Waveforms, averaged across 16 subjects, for each condition of the target heterogeneous (Figure 7.1a) and target homogeneous (Figure 7.1b)

procedure in Experiment 5.

Figure 7.2a, 7.2b and 7.2c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by frequent (Figure 7.2a), target (Figure 7.2b) and rare nontarget (Figure 7.2c) stimuli within the target heterogeneous procedure in Experiment 5.

Figure 7.3a, 7.3b and 7.3c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by frequent (Figure 7.3a), target (Figure 7.3b) and rare nontarget (Figure 7.3c) stimuli within the target homogeneous procedure in Experiment 5.

Figure 7.4a, 7.4b and 7.4c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by frequent (Figure 7.4a), target (Figure 7.4b) and rare nontarget (Figure 7.4c) stimuli within the target heterogeneous procedure in Experiment 5.

Figure 7.5a, Figure 7.5b and 7.5c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by frequent (Figure 7.5a), target (Figure 7.5b) and rare nontarget (Figure 7.5c) stimuli within the target homogeneous procedure in Experiment 5.

Figure 7.6a and 7.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited within the target heterogeneous (Figure 7.6a) and target homogeneous (Figure 7.6b) procedures within Experiment 5 (collapsed across electrode chains).

Figure 7.7a and 7.7b Bar diagram illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the heterogeneous (Figure 7.7a) and homogeneous (Figure 7.7b) procedures at lateral parietal sites in Experiment 5.

Figure 8a.1a and 8a.1b Waveforms, averaged across 16 subjects, for each condition within the young (Figure 8a.1a) and elderly (Figure 8a.1b) subject groups in Experiment 6.

Figure 8a.2a and 8a.2a Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8a.2a) and rare nontarget (Figure 8a.2a) stimuli within the young group of subjects in Experiment 6.

Figure 8a.3a and 8a.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8a.3a) and rare nontarget (Figure 8a.3b) stimuli within the elderly group of subjects in Experiment 6.

Figure 8a.4a, 8a.4b and 8a.4c Bar diagrams illustrating the amplitude distribution evoked by auditory rare nontarget stimuli at frontal (Figure 8a.4a), temporal (Figure 8a.4b) and parietal (Figure 8a.4c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8a.5a, 8a.5b and 8a.5c Bar diagrams illustrating the amplitude distribution evoked by auditory target stimuli at frontal (Figure 8a.5a), temporal (Figure 8a.5b) and parietal (Figure 8a.5c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8a.6 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by auditory stimuli within Experiment 6 (collapsed across subject group and experimental condition).

Figure 8a.7a and 8a.7b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory target stimuli within the young (Figure 8a.7a) and elderly (Figure 8a.7b) groups of subjects within Experiment 6.

Figure 8a.8a and 8a.8b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory rare nontarget stimuli within the young (Figure 8a.8a) and elderly (Figure 8a.8b) groups of subjects within Experiment 6.

Figure 8a.9 Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited by auditory stimuli within Experiment 6 (collapsed across experimental conditions).

Figure 8b.1a and 8b.1b Waveforms, averaged across 16 subjects, for each condition within the young (Figure 8b.1a) and elderly (Figure 8b.1b) subject groups employing visual stimuli in Experiment 6.

Figure 8b.2a and 8b.2b Graph illustrating the distribution, across electrode chain, of

rescaled amplitude of the P300 deflection elicited by target (Figure 8b.2a) and rare nontarget (Figure 8b.2b) stimuli within the young group of subjects in Experiment 6.

Figure 8b.3a and 8b.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8b.3a) and rare nontarget (Figure 8b.3b) stimuli within the elderly group of subjects in Experiment 6.

Figure 8b.4a, 8b.4b and 8b.4c Bar diagrams illustrating the amplitude distribution evoked by visual rare nontarget stimuli at frontal (Figure 8b.4a), temporal (Figure 8b.4b) and parietal (Figure 8b.4c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8b.5a, 8b.5b and 8b.5c Bar diagrams illustrating the amplitude distribution evoked by visual target stimuli at frontal (Figure 8b.5a), temporal (Figure 8b.5b) and parietal (Figure 8b.5c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8b.6 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by visual stimuli within Experiment 6 (collapsed across experimental condition and subject group).

Figure 8a.7 Graph illustrating the distribution of rescaled amplitude of the N200 deflection elicited by target stimuli within the young and elderly groups of subjects within Experiment 6.

Figure 8b.8a and 8b.8b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by visual rare nontarget stimuli within the young (Figure 8b.8a) and elderly (Figure 8b.8b) groups of subjects within Experiment 6.

Figure 8b.9a, 8b.9b and 8b.9c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by visual frequent (Figure 8b.9a), target (Figure 8b.9b) and rare nontarget (Figure 8b.9c) stimuli within the young subject group of Experiment 6.

Figure 8b.10a, 8b.10b and 8b.10c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by visual frequent (Figure 8b.10a), target (Figure 8b.10b) and rare nontarget (Figure 8b.10c)

stimuli within the elderly subject group of Experiment 6.

Figure 8b.11a and 8b.11b Bar diagram illustrating the mean amplitude evoked by visual frequent, target and rare nontarget stimuli within the young (Figure 8b.11a) and elderly (Figure 8b.11b) groups of subjects at lateral parietal sites within Experiment 6.

List of Abbreviations

ANOVA	Analysis of variance
BESA	Brain electrical source analysis
EEG	Electroencephalographic
EOG	Electro-oculogram
ERP	Event related potential
ISI	Interstimulus interval
MMN	Mismatch negativity
MRI	Magnetic resonance imaging
Nd	Negative difference
msec	milliseconds
PCA	Principal component analysis
PN	Processing negativity
RT	Reaction time
VDU	visual display unit

Chapter 1

Introduction

1.1.1 Background to the Study Of Event Related Potentials

R. Caton is acknowledged to have first recorded an "evoked potential" from mammals (Cooper *et al.* 1980). In 1875 he directly recorded a potential from the surface of a rabbit's brain. However, it was almost 80 years before a systematic analysis of event related potentials (ERPs) became possible in man. This delay in the application of the technique was due to two reasons. It was not until 1929 that electronic amplification of the millivolt levels of activity found at the cortical surface of the brain allowed Berger to demonstrate that brain potentials could be recorded in humans through an unopened skull (Cooper *et al.* 1980). The second major advance was made by Dawson (1951) who applied the technique of averaging, or signal summation, this permits the ERP signature to be extracted from the ongoing EEG signal. Averaging enhances any activity that has a consistent temporal relation to a recurrent event, *i.e.* one which is "time-locked" to the eliciting episode. Any activity that is inconsistently related to the event tends to cancel itself. The technique is a means of improving an initially adverse signal to noise ratio and will be discussed in section 1.15.

1.1.2 What are Event Related Potentials?

Electrical potentials arising from the brain and recordable from the scalp may be divided into two types. The first is a continuous series of potential oscillations which are not related in a temporally fixed way to sensory input. This type of activity is recorded from the scalp as the electroencephalogram (EEG). The second type has a fixed temporal relationship to sensory input and is said to be evoked by such stimuli. When potential changes evoked by repeated stimuli are averaged and plotted as a function of time after stimulus presentation, the resulting waveform is termed the event related potential (Goff 1974). ERP activity of the brain reflects neuronal mass activity that generates detectable electric scalp fields in fixed time-relation to information arrival or the initiation of movement (Brandies and Lehmann 1986). The recording of ERPs is a noninvasive technique that allows the investigation of the

neurophysiological basis of cognitive processes. The strength of the technique lies in its ability to monitor electrical brain events with a high degree of temporal resolution. The scalp amplitude field varies over time both in strength and the spatial distribution of the signal. It is, therefore, possible to obtain a spatio-temporal picture on the flow of processing events in the brain before, during and after the critical stimulus or performance. It is possible to infer which regions of the brain are activated and when the activation occurs during stimulus processing and task performance (Näätänen 1992).

1.1.3 Physiological Bases of ERPs

ERPs are generated by changes in the polarisation of cell membranes in the central nervous system. The membrane potentials of neurones are altered during both synaptic activity and action potentials. The flow of current across neuronal membranes generates field potentials in the extracellular fluids that can be picked up at a distance in the form of ERPs (Hillyard and Picton 1987).

The ERP fields generated in the nervous system depend upon the spatial arrangement of the generator elements. So called "closed" electrical fields are the result of patterns of cell membrane polarisation that do not generate potential fields at a distance since they only produce local currents. An "open" field is generated when currents flow beyond the limits of the active cells and their processes. Most cell assemblies in the nervous system generate fields that have both closed and open properties (Hillyard and Picton 1987).

Temporal synchrony also plays a role in determining the field potentials produced by a group of active cells. At any point in a volume conductor there is a summation of the fields generated by the individual cellular elements. If the elements are activated synchronously and if they produce fields of similar sign and orientation, their summation increases the amplitude of the recorded field potential. Significant ERPs are generated only by groups of cells that are synchronously activated in a geometrically organised manner with respect to the eliciting event.

1.1.4 Recording the ERP

A thorough review of the technical aspects of recording EEG and ERPs is provided by Cooper, Osselton and Shaw (1980), Picton (1980) and Lindsley and Wicke (1974). This section is intended simply as a summary of the necessary techniques to successfully record ERPs.

EEG may be regarded as the difference in voltage between two electrodes. There are three methods of deriving electrical signals from an electrode array. These are known as bipolar, unipolar and average references. Essentially, however, all derivations are bipolar in the sense that a detecting device such as an amplifier must be connected between two points and will indicate the potential difference between them. Any electrode can be chosen as a reference point with respect to which the potentials at the other electrodes can be measured.

1.1.5 Signal to Noise Improvement

The ERP is a series of voltage changes that are contained within an epoch of EEG that is time-locked to the presentation of a stimulus or the initiation of a movement. The ERP, the time-locked signal, needs to be extracted from the recorded epoch of EEG, the ongoing noise. Two methods are available for improving the initially adverse signal to noise ratio. Superimposition (Cooper *et al.* 1980) is rarely used nowadays, the most common method of improving the ratio is that of averaging.

Here the signal is repeatedly presented and the EEG signals for the duration of interest immediately following the presented signal are summed and then divided by the number of presentations to obtain the ERP. The amplitude of the EEG during the recording epoch is measured or "sampled" at a series of discrete points. This process is known as digitising and is performed by means of analogue to digital converters. The signal is first amplified so it is large enough to be dealt with by the converters. The sampling rate determines which components of the ERP it is possible to resolve. The theoretical maximum resolution is half the sampling rate. The use of signal averaging is based upon two assumptions. Firstly that the signal (the ERP) remains the same over numerous presentations. Secondly that the noise (the EEG) is uncorrelated with the signal. If these two assumptions are satisfied the signal to noise ratio of an ERP will improve as a function of the square root of the number of trials used to form the average (Picton 1980).

Artifacts

ERP studies are more prone to contamination by artifact than clinical EEG recording since signal to noise improvement techniques means that artifacts synchronised with the stimulus will appear with the ERP waveform after signal enhancement.

Artifacts may arise from the subject in the form of non-cerebral physiological potentials, and those resulting from the electrical activity in the subject's surroundings. Potentials may be induced by the electromagnetic fields surrounding power lines, transformers and motors. Such artifacts may be reduced by grounding the subject and/or shielding the recording area with a high electrical conductivity material (Picton 1980). Electrostatic potentials in a subject caused by such things as friction with clothing can change with movement and cause large artifacts in the scalp recorded activity.

The human eyes provide the major sources of non-cerebral activity. There is a standing potential of several millivolts between the cornea and the retina. Eyeblinks cause a positive potential in the anterior scalp regions by connecting those areas to the positive potential at the cornea (Matsuo *et al.* 1975). It is possible to either disregard all EEG epochs that are affected with eye blinks or to use a correction procedure that removes such artifacts from the ERP signal (for instance see Gratton *et al.* 1983; O'Toole and Iacono 1986).

Movement of the muscles of the face and tongue can cause large electrical fields that will be picked up from the scalp electrodes. It is necessary to reject such contaminated trials from the average.

1.1.6 Recording Conventions

The majority of EEG and ERP laboratories now conform to the international EEG system of electrode placement, referred to as the International System (Jasper 1958). This system is based on the proportional distances between anatomical landmarks of the head in order to compensate for different head sizes. It defines electrode sites as 10% or 20% of distances along the midline frominion to nasion in a longitudinal plane, and along a line in a transverse plane which halves the distance betweeninion and nasion in the plane of the auditory meatuses. A number of laboratories find it necessary to augment this standard array of electrodes by others of intermediate location. When this is done the location can either be designated as an absolute distance from a 10-20 electrode site or between two or more sites.

The system uses letters and numbers. The letters refer to brain lobes, O, P, C, F and T referring to occipital, parietal, central, frontal and temporal lobes respectively. The numbers refer to one or other hemisphere; odd numbers are over the left hemisphere and even numbers over the right.

1.2 ERP Components

An ERP may be thought of as a series of positive and negative deflections. Although a particular deflection within the waveform may provide a convenient anchor point for analysis and discussion it is not necessarily generated by a unitary, or single, underlying neurophysiological process or generator. Näätänen and Picton (1987) regard an ERP "component" to be the contribution to the recorded waveform of a particular underlying neurophysiological generator process. While it is possible to directly measure the peaks and deflections of the waveform, it is only possible to infer from the results of experimental manipulation the particular components contributing to the generation of the deflections. Such a definition of an ERP component is said to be "physiological" in its outlook.

It is also possible to define ERP components in a more "psychological" manner, for instance in the manner advocated by Donchin *et al.* (1978). Employing this approach the definition of an ERP component depends upon the particular cognitive process performed by a particular neural system that generates the recordable ERP signal on the scalp. An extreme view of such a definition means it is possible for a particular deflection in the waveform that is generated by the activity of multiple underlying neural generators to be regarded as a single component as long as the generators are acting together in an organised manner to carry out a particular cognitive process. In order to further the knowledge of cognitive processing using ERPs it is necessary to examine the variance in the waveform due to the experimental manipulations. If such manipulations cause changes in a region of the waveform which are independent of what happens in the rest of the waveform this region may be considered to be a component of the ERP.

In the majority of instances the "physiological" and "psychological" approaches to component definition are combined. Donchin *et al.* (1978) have proposed that a component ought to be defined in terms of its polarity, its latency, its scalp distribution and its sensitivity to experimental manipulation.

Throughout this thesis the term deflection will be employed to refer to an observable point within the waveform without reference to the possible neural generator(s) producing the activity that is being recorded from the scalp in the form of the deflection. The term component will be employed to refer to the contribution made by a particular brain region that is thought to be contributing to the complete or partial generation of the deflection.

1.2.1 Quantifying ERP Components

As discussed above (section 1.2) the deflections recordable from the scalp may be made up from the activity of either a single or the overlay of a number of neural substrates or generators. A number of techniques have been developed that allow such neural sources to be inferred from the scalp activity fields themselves. The characterisation of the underlying generators, the so called inverse problem, has been studied as a means of examining the anatomy and physiology of sensory, motor and cognitive processes. Nunez and Katznelson (1981) provide a clear exposition of the equivalent dipole concept in the context of electroencephalography.

One of the techniques that has been employed to use such procedures has been BESA (Brain Electrical Source Analysis; Scherg 1990). Here the ERP waveform recordable from the scalp is assumed to represent the summed activity of a number of different sources of neural activity. The procedure attempts to compute how the activity of these different neural sources must change over time in order to produce the observed activity at the scalp. Each source identified by the procedure is believed to represent an ERP component.

Successful implementation of inverse dipole estimation has been restricted to responses adequately modelled by one or at most two active generators (Gulrajani *et al.* 1984). It has not proved possible to apply such analysis to late sensory and cognitive responses such as the P300 (Snyder 1991). This is due to the fact that such procedures do not solve the inverse problem, *i.e.* that a unique solution for the origins of an electric field on the surface of an object cannot be derived solely from knowledge of the field's spatial distribution

Principal components analysis (PCA)(for instance see Squires *et al.* 1977) has also been employed as a means of dissociating the observed deflections from the scalp into a number of separate underlying components, or generators. The aim of this procedure is to reduce a set of ERP waveforms to a small number of factors or components and then to estimate the relative contributions of these factors to each waveform in the data set (Donchin and Heffley 1978). A major problem with the application of PCA to ERP data is that it assumes that each component in the waveform has a constant latency across experimental conditions. Wood and McCarthy (1984) have also demonstrated, employing a simulation study, that PCA misallocated variance between supposedly orthogonal components.

1.2.2 Classification of ERP Deflections

The peaks of the deflections of the ERP waveform are typically labelled by their polarity (positive or negative) and either their approximate latency post stimulus, or their ordinal position within the waveform. The latency of the deflection is usually given in milliseconds (msec). A large number of ERP deflections may be recorded from the human scalp. A system to classify such components has been developed that depends upon the relationship of the component to external stimuli (Donchin *et al.* 1978).

Exogenous Components

Exogenous components are stimulus bound, reflecting the physical parameters of the stimulus regardless of the context in which it was presented. Such components are obligatorily elicited by the occurrence of an appropriate stimulus (Näätänen and Picton 1987). For a thorough review of exogenous components within the auditory modality see Näätänen (1990), in the visual modality see Halliday (1982) and Regan (1988) and in the somatosensory modality see Desmedt (1988).

Mesogenous Components

Mesogenous components occur approximately 50-250 msec post stimulus. Such components are affected by both stimulus parameters and psychological factors. The N100 deflection may be regarded as a mesogenous component. The deflection observable as the N100 is not a unitary phenomenon, Näätänen and Picton (1987) have identified three so-called "true" components which are dependent on the physical and temporal aspects of the stimuli and the level of arousal of the subject. For a complete review of these "true" N100 components see Näätänen and Picton (1987).

Three other components within the latency range of the N100 component have also been identified which depend more on the conditions in which the stimulus occurs rather than its physical characteristics. Näätänen and Picton (1987) do not regard these longer lasting components as part of the N100 complex, however, they do overlap the N100 latency region and so may affect the amplitude of the N100 obtained within an ERP waveform. The other three components that have been identified as overlapping the N100 include the mismatch negativity (MMN) and two components of processing negativity. Both the mismatch negativity and processing negativity will be discussed more

fully in section 1.5.4.1 in connection with the attentional trace theory (Näätänen 1982; 1990; 1992) of the functional significance of the P300 component.

It appears that the "true" N100 components reveal activity reflected by changes from one level of physical energy to another and so are sensitive to the transient aspects of stimuli (Graham 1973; Loveless 1983). Näätänen and Picton (1987) suggest that the first N100 component has three functions, the call of attention to stimulus information, reading out sensory information from the auditory cortex and forming a trace in auditory sensory memory. The significance of the second N100 component is not known. It is suggested that the third component may be involved in producing widespread transient arousal of the organism which facilitates sensory and motor responses to the eliciting stimulus. As is evident from the supposed functions of the N100 components, Näätänen and Picton (1987) limit their application of the functional significance of the N100 components to the auditory modality.

Endogenous Components

Endogenous components reflect active contextually induced cognitive processing of the stimulus on the part of the subject rather than a passive transmission of sensory information (for a review see Hillyard and Kutas 1983). Such components are evoked independently of the parameters of the external stimuli. These components are related to the psychological processes active during the task. The investigation of such components supplements knowledge obtained from traditional cognitive psychology by providing a fine temporal correlate of psychological processes. A number of endogenous components have been identified. The present programme of research was designed to examine the P300 endogenous component of the ERP waveform and will be extensively reviewed in later sections of this chapter. Deflections evoked within the latency range of the N200 will be discussed in greater detail in section 1.5.4.1. A further endogenous component that will be examined is the so-called slow wave.

A number of reports have described slowly varying long duration components whose amplitudes relate directly to task demands (see Ruchkin and Sutton 1983 for a review). Slow wave activity has been found in a variety of tasks. The data from such tasks suggest that there are systematic differences in slow waves such that they appear to be reducible to two broad categories based on their onset latencies, those reflecting either perceptual operations or

conceptual operations. Both the perceptual and conceptual categories of slow waves are present, Ruchkin *et al.* (1988) claim, when task demand is high. It seems that the generator, or generators, of the slow wave component is initiated at the time when additional processing is required. For difficult perceptual operations (for instance the detection and identification of an external stimulus) onset latencies are relatively short (150-450 msec). For cognitive processes that follow perception (conceptual operations) the range of slow wave onset latencies increases to 300 - 800 msec.

The topography of slow wave also varies across tasks. Slow waves associated with perceptual difficulty are generally positive over posterior and central scalp. In some studies the slow wave was also positive, but lower in amplitude over frontal scalp (Johnson and Donchin 1978) while in other studies the frontal aspect of slow wave was found to be negative (Ruchkin *et al.* 1980).

In general it appears that slow wave amplitude increases as a function of task demand and/or behavioural signs of improved processing efficacy (for instance better recall in memory tasks). Topographic differences as a function of task suggest that the slow waves may reflect the nature of the additional processing in the sense that different tasks may involve different neural generators. Ruchkin *et al.* (1988) claim that the general pattern of slow wave experimental results suggests that negative slow waves are associated with scanning and mental imagery, while positive slow waves are associated with memory storage, rule learning and perceptual operations.

A common means of eliciting such endogenous components (N200, P300 and slow waves) is by means of so-called oddball tasks.

1.2.3 Oddball Tasks

As discussed in section 1.15 to improve an initially poor signal to noise ratio it is necessary to present an identical stimulus numerous times in order to collect sufficient trials to form an averaged ERP. Certain endogenous components, for instance the P300, may be elicited by the presentation of rare stimuli presented within a sequence of more frequently occurring background stimuli. This procedure is known as an oddball paradigm (see Fabiani *et al.* 1987 for a discussion of oddball paradigms). This paradigm satisfies the above requirements of presenting an identical stimulus numerous times and allowing the rare stimuli to be placed within a more frequently occurring sequence of standard stimuli.

The "two-stimulus" oddball task consists of a sequence of frequently occurring stimuli within which a relatively rare stimulus is presented. The frequent stimulus has a significantly higher probability of occurrence within the sequence than the rare stimulus. The subject's task is to detect the occurrence of the rare target stimuli and to respond in some way, for instance by making a behavioural response or incrementing a nonverbal count. However, employing rare stimuli as targets confounds the effects of probability and target effects upon the P300 deflection. Both manipulations have been shown to affect P300 amplitude (Johnson and Donchin 1978; see later discussion of the effect of probability and task relevance upon the P300).

A modified version of the two stimulus oddball task may also be employed. Here the lower probability class of stimuli are made up of two categories. The first category consists of rare targets that the subject is required to respond to as previously described. The second category is made up of rare nontargets that do not require a response to be made to them. Such rare nontarget stimuli are of an intrusive nature. Two and three stimulus oddball tasks are both considered by Näätänen (1992) to be "one" channel attentional tasks since the subjects have to attend to all the stimuli in order to detect the deviant stimuli. Such a paradigm with two classes of rare stimuli means it is possible to partially disentangle the target effect from the probability effect by comparing the ERPs to rare target stimuli with those of rare nontarget stimuli (target effect) and the ERPs to rare nontargets to those to frequent nontargets (probability effect).

Passive oddball tasks (Sams *et al.* 1985) require the subject to be engaged in another task, for instance reading, whilst the sequence of stimuli is presented. No response is required on the part of the subject. Such tasks are used to examine brain responses to ignored stimuli and the involuntary discrimination of deviant stimuli among the ignored stimuli.

Dual oddball tasks require the subject to perform a concurrent task whilst detecting targets in a two stimulus oddball task. Such paradigms allow the extent to which the ERP components elicited by the targets are dependent upon the amount of processing resources available to be determined.

Two channel oddball tasks are versions of dichotic selective attention tasks. Subjects are presented with a different sequence of stimuli to each ear. The subject's task is to respond to the rare stimuli presented to only one ear. Such a paradigm allows the investigation of the effects of attention on the processing of the stimuli in each sequence. Two and three stimulus oddball tasks and the

attended channel of the dichotic listening task are all examples of active oddball tasks.

1.3 P300 Complex

The literature on the P300 ERP is extensive, and an exhaustive review is beyond the scope of this more general introduction to the P300 complex. An overview of the more salient features of the phenomenon will be provided, but for a more detailed review see Pritchard (1981; see also Fabiani *et al.* 1987). Section 1.31 will attempt to draw together the variables that affect the amplitude of the P300 deflection with the use of Johnson's (1986; 1988; 1993) proposed triarchic model.

Sutton *et al.* (1965) first reported this late positive wave following a stimulus that appeared to resolve uncertainty. Subjects were required to guess which of two possible stimuli were about to occur. The more improbable the stimulus the greater the amplitude of the evoked potential. This late positive wave had a mean latency of 300 msec.

Many of the variables that have since been associated with P300 are correlational rather than theoretical in nature. Such a distinction was discussed by Pritchard (1981). He pointed out that a correlational explanation consists of statements describing the degree of relationships among observable variables. A theoretical explanation however, "provides principles not immediately given but that lie beyond straight empirical knowledge" (pp. 507). Pritchard (1981) proposed that these categories are not mutually exclusive but instead lie at opposite ends of a continuum. Early P300 experimentation largely consisted of manipulating an observable variable and then assessing the resultant P300 amplitude or latency changes. The fact that the P300 deflection has been found to correlate with so many variables may partially explain why functional explanations of what the P300 represents have taken so long to develop.

Stimulus probability (the *a priori* probability that a certain stimulus will be presented on any given trial) has repeatedly been correlated with the P300 deflection (for example Duncan-Johnson and Donchin 1977). The original P300 experiments by Sutton *et al.* (1965) suggested an inverse relationship between stimulus probability and P300 amplitude. This effect of increasing P300 amplitude with decreasing stimulus frequency is one of the basic findings of P300 research (Verleger 1988). The effect is evident in oddball tasks as well as in tasks such as signal detection (Paul and Sutton 1972), the Sternberg task (Okita *et al.* 1985) and feedback tasks (Campbell *et al.* 1979).

Similarly, the classification of stimuli into either signals (attended and requiring processing) or nonsignals (attended but requiring no overt processing) has repeatedly been correlated with P300. It is typically found that equiprobable stimuli evoke greater P300 amplitude when they serve as signals (targets) than when they serve as nonsignals (nontargets). Squires *et al.* (1975) reported larger P300 deflections to targets than to nontargets, both having equal probability.

Verleger (1988 pp. 346) points out that "when different stimuli are assigned to the categories of targets and nontargets then P300 amplitudes are sensitive to the frequencies of these two categories rather than to the frequencies of any single stimulus." Courchesne *et al.* (1977) reported that P300 amplitude was the same size when a single letter was used as a target stimulus as when numerous different letters were used. They also reported no difference when different letters or one letter were employed as nontargets (see also Friedman *et al.* 1981).

Task relevance has also been correlated with the P300. Both signal and nonsignal stimuli may be considered relevant to the discriminative task given to the subject and both will elicit P300 deflections that vary in amplitude as an inverse function of stimulus probability. The same stimuli elicit no P300 deflection when they are not relevant to the subject's task and are ignored (Duncan-Johnson and Donchin 1977). Whether a given stimulus serves as a task relevant signal or nonsignal is a function of the instructions given to the subject and not something intrinsic to the stimulus itself (Pritchard 1981).

The P300 deflection would appear to reflect only the general informational properties of stimuli. In its most basic form the deflection indicates that a stimulus was task relevant and of low subjective probability (see section 1.51 on subjective probability). A wide variety of psychological factors have been suggested to explain the functional significance of the P300, including resolution of uncertainty, stimulus evaluation, orienting response, equivocation, subjective probability and decision confidence (see Pritchard 1981). Experimental studies indicate that each of these factors influences P300 amplitude when all other factors are held constant (Begleiter *et al.* 1983).

1.3.1 Nomenclature

In the Chapters that follow a positive deflection of the waveform with a mean latency of between 250 and 600 msec will be referred to as a P300 deflection whether elicited by target or rare nontarget stimuli and regardless of

scalp amplitude distribution. The results of the experimental manipulations within the auditory, visual and somatosensory modalities suggest that the P300 is not a unitary phenomenon but may be dissociated into two (at least partially) separate components on the basis of scalp amplitude distribution.

The nomenclature outlined by Squires *et al.* (1975) to differentiate the deflections evoked by target and rare nontarget stimuli on the basis of scalp amplitude distribution will be employed throughout this thesis. A P300 deflection evoked by target stimuli with a maximum amplitude distribution at parietal sites will be referred to as the P3b component. A deflection evoked by rare nontarget stimuli with a more anterior scalp distribution than obtained in response to target stimuli will be referred to as the P3a component. Those deflections that do not demonstrate such a dissociation on the basis of scalp amplitude distribution will be referred to as target P300 and rare nontarget P300 deflections respectively.

Such a classification of P300 responses does not imply that the underlying neural substrates, or generators, producing the P3b and P3a deflections are mutually exclusive. It implies that while it is possible that the P3b generator may contribute to the P3a deflection it is not necessarily correct to assume that a similar proportion of the output of the P3a generator contributes to the P3b deflection. The observed dissociation of target and rare nontarget deflections on the basis of scalp amplitude distribution may be explained by the differential contributions of the proposed underlying generators to the target and rare nontarget stimuli.

1.3.2 P300 Latency

The use of P300 latency as a measure of cognitive processing time derives from data on the amplitude of the P300 deflection. Duncan-Johnson (1981) claims that to use P300 latency to measure the timing of cognitive processing requires the assumption that if the amplitude of the P300 depends on the "surprise" value of the stimulus, then the stimulus itself must be evaluated before P300 is elicited. The latency of the P300 deflection must, therefore, be at least as long as stimulus-evaluation time. This assumption has been incorporated into the "stimulus evaluation theory" which states that identification and evaluation of the subjective probability of a stimulus must be completed before a P300 deflection is observed (Pritchard 1981; Duncan-Johnson and Donchin 1982; Donchin 1979).

The stimulus evaluation theory implies a positive correlation between reaction time (RT) and P300. Experimental design problems have made it difficult to compare P300 latency with RT, for instance the confounding of P300 with brain motor potentials. It is possible to examine the relationship between RT and P300 by assessment of the covariance between the two phenomena (Pritchard 1981). The results of such an examination have been contradictory, a number of studies report a positive correlation (Rohrbaugh *et al.* 1974; Picton *et al.* 1974). Other studies report that the two variables are uncorrelated (Karlin *et al.* 1971). Kutas and Donchin (1977b) claimed this contradiction may have been due to the fact that RT is multiply determined and only some of the variables influencing it also affect the P300. Therefore, if P300 latency represents stimulus evaluation time, then when the variance of RT is largely determined by stimulus evaluation the correlation between P300 latency and RT will be large and positive. However, whenever the variance of RT is determined by response selection processes the P300-RT correlation will be small.

Kutas and Donchin (1977b) demonstrated that when subjects were instructed to maximise their response speed, the correlation between the latency of mean RT and mean P300 was lower than under accuracy maximising instructions. Pritchard (1981) has pointed out that the assumption that P300 latency is proportional to stimulus evaluation time does not mean that the P300 response represents a manifestation of stimulus evaluation. It does mean that stimulus evaluation must be completed before the processing that the P300 deflection represents is initiated.

A number of studies support the stimulus evaluation time hypothesis. Squires *et al.* (1977) found that P300 latency varies as a function of the discriminability of the relevant stimulus in a counting task. Gomer *et al.* (1976), Adam and Collins (1978) and Ford *et al.* (1979) all used the Sternberg paradigm and all replicated the finding that RT increased linearly with increasing short-term memory load. All three studies also reported that P300 latency increased linearly with increasing memory load. The slope of RT as a function of the number of items was steeper than the slope of P300 latency as a function of the number of items, supporting the notion that RT and P300 latency do not necessarily reflect the same processes.

A study by McCarthy and Donchin (1981) has also demonstrated that P300 is relatively independent of response selection processes. Subjects made either a so-called compatible response (for example a button press with the right thumb in response to the stimulus word right) or an incompatible response (for

example a button press with the right thumb in response to the stimulus word left). On half the trials, the stimulus words were embedded in visual noise. Both visual noise and response incompatibility increased the reaction time to the stimuli, however, only visual noise increased P300 latency. P300 latency was, therefore, affected by the variable resulting in degraded perception (and increased stimulus evaluation time) and not by the variable affecting response selection.

A study by Magliero *et al.* (1984) supports the findings of McCarthy and Donchin (1981). They demonstrated that the latency of the P300 deflection is responsive to manipulations that affect stimulus evaluation while the latency of the P300 is altered by only a small amount by manipulations affecting response compatibility.

Magliero *et al.* (1984) emphasises that the phrase "stimulus evaluation" is not intended to imply a purely perceptual encoding process. Duncan-Johnson and Donchin (1982) reported that the phrase is used to label the entire complex of processes that are independent of, and precede, response selection and execution. The conclusions of both McCarthy and Donchin (1981) and Magliero *et al.* (1984) serve more to exclude the response related processes than to identify the stimulus related processes that do affect P300 latency. Magliero *et al.* (1984) propose that it may be more accurate to use the phrase "situation evaluation" to label the processes that determine P300 latency.

P300 latency data would, therefore, appear to support the stimulus evaluation time hypothesis, since P300 varies in latency as task difficulty is manipulated, while at the same time it seems to be largely independent of RT (Pritchard 1981).

1.3.3 Component Topography

ERP deflections may be dissociated into separate ERP components on the basis of scalp distribution. Such a dissociation provides evidence that separate components are produced by, at least partially, separate neural generators. Differences in the spatial locations of the particular generators mean that particular experimental manipulations within a paradigm will elicit a different proportion of output from each generator. A particular ERP component will, therefore, be elicited with its own characteristic scalp distribution.

To determine whether separate neural generators are contributing to deflections recordable from the scalp it is necessary to carry out topographic

analyses. The procedure for carrying out such analysis will be discussed in section 2.64.

The P300 deflection has developed from being a monolithic phenomenon encompassing every positive deflection of the ERP waveform within a latency range of 250 - 600 msec to one that is now largely regarded as being made up of a number of sub-components. Each component may be characterised by an eliciting event (target or rare nontarget) and a characteristic scalp topography.

1.4 Dissociation of P300 Deflections

1.4.1 Multiple Sources of P300 Activity

A thorough discussion of the neural generators of the P300 deflection is provided by Johnson (1993). The P300 deflection has traditionally been regarded as arising from a single neural generator (Johnson 1993). Such an outlook initially resulted in simplistic explanations of the functional significance of the phenomena and has encouraged a lack of attention to the topographical analysis of amplitude deflections. As outlined by Fabiani *et al.* (1987) it is generally assumed that the appearance of differences in topography imply that different generators are responsible for the ERPs. Picton *et al.* (1987) state that "evoked potential components with significantly different scalp distributions must derive from different sources. Either different cells are involved in the generation of the scalp recorded potential or the active cells are differentially responsive" (pp. 518-519).

However it ought to be noted that the converse is not necessarily true, neural generators may be different in two conditions yet the scalp topography obtained may be the same. Several investigators (for instance see Wood *et al.* 1980) have proposed that P300 does not arise from a unitary generator but rather from multiple sources with multiple orientations. This does not mean that P300 represents multiple psychological processes, as several neural generators may need to be simultaneously activated to carry out what would be considered a unitary psychological process. It does, however, suggest that if the same set of multiple sources can be differentially activated in order to accommodate minor changes in the processing required by a particular task then this may lead to slight differences in scalp topography.

Establishing the existence of multiple neural sources of P300 would seem straightforward. If the P300 deflections associated with different experimental variables demonstrate different scalp distributions this would seem to be

evidence that separate neural generators, or separate combinations of underlying generators, are generating the P300 deflections. Such an effect would appear as a significant interaction between the experimental condition variable and the electrode factor in an ANOVA.

1.4.2 Evidence of Dissociability

Several investigators (for instance Courchesne *et al.* 1975; Picton *et al.* 1980) claim that P300 is not a unitary process. Courchesne *et al.* (1975) reported "... the P3 wave is not a unitary phenomenon but should be considered in terms of a family of waves, differing in their brain generators and in their psychological correlates" (pp. 142). In order to determine whether the P300 is a unitary process the dissociability of the scalp amplitude distribution of target and rare nontarget stimuli will be examined.

In order to investigate the effect of task relevant and task irrelevant stimuli upon the P300 complex several methodological steps are required (Courchesne *et al.* 1975). Rare stimuli of both types (task relevant and task irrelevant) need to be presented unpredictably within the same sequence of stimuli. To determine if separate neural generators are contributing to the deflections evoked in response to task relevant and task irrelevant stimuli the distribution of the scalp amplitude of the two responses needs to be compared. Henceforth task relevant and task irrelevant stimuli will be referred to as target and rare nontarget stimuli respectively.

The P300 deflections to target and rare nontarget stimuli have been dissociated on the basis of scalp amplitude distribution in the auditory (Squires *et al.* 1975), visual (Courchesne *et al.* 1975; 1978) and somatosensory (Yamaguchi and Knight 1991a) modalities. The examination of discrete cortical lesions (Knight 1984) has also provided evidence that the deflections may be dissociated.

1.4.2.1 Visual Modality Dissociation

Courchesne *et al.* (1975; see also Courchesne 1977; Courchesne *et al.* 1977; Courchesne *et al.* 1978) reported that deflections evoked in response to target and rare nontarget stimuli may be dissociated on the basis of scalp amplitude distribution. Target stimuli were compared with rare nontarget stimuli. Both stimulus types were randomly interspersed within a sequence of frequently occurring background stimuli.

Four types of visual stimuli were employed. The number "2" as the frequently occurring stimulus; the number "4" as the rare target stimulus of which subjects were instructed to keep a running count. Rare nontarget stimuli were of two classes: the first, the "simples" were easily recognisable (for instance simple geometric shapes such as black and white patterns and geometric figures). The second class of stimuli, the "novels", were unrecognisable colourful abstract designs. Neither the "simples" nor the "novels" required the subjects to make an overt response.

The target stimuli (the counted number "4"s) elicited P300 waves that were largest over the parietal scalp. Rare nontarget, unrecognisable "novel" stimuli elicited P300 waves that were largest over the centro-frontal scalp. This more frontal variety of P300 wave did not appear to be a simple response to the physical complexity of the stimulus since once "novel" stimuli became familiar in content and predictable in time of delivery they evoked only small and posterior P300 waves. Such posterior waves were also elicited by the rare nontarget but structurally simple and easily recognised stimuli, the "simples".

Courchesne *et al.*'s (1975) data provided evidence for at least three types of P300 deflection. A parietal maximum P300 deflection elicited by any target stimulus. A second P300 deflection was elicited by non-target unrecognisable stimuli, this wave had a more anterior scalp distribution being maximally distributed at centro-frontal scalp sites. A third type of P300 wave was elicited to non-target easily recognised stimuli, this deflection had a parietal maximal distribution similar to that evoked by target stimuli.

Knight (1991; personal communication) has also reported a dissociation of target and rare nontarget P300 deflections on the basis of scalp amplitude distribution within the visual modality. He employed single line triangles as either frequent to be ignored or target stimuli. Mutilated (fragmented) triangles were employed as rare nontarget stimuli. A centro-parietal maximum amplitude distribution was observed in response to target stimuli while a fronto-central maximum distribution was observed in response to rare nontarget stimuli.

A number of studies have reported differences in latency and scalp topographies between Go-P300 and NoGo-P300 responses (Karlin *et al.* 1970; Podlesny *et al.* 1984; Pfefferbaum *et al.* 1985). In a Go/NoGo task subjects are required to make a specific motor response to one class of stimuli (Go response) and to with-hold the Go response to the other (NoGo response). The NoGo-P300 had a longer latency than that of the Go-P300 and a more anterior centro-parietal distribution. Two explanations have been proposed to account

for the difference in scalp topography between these two responses. Simson *et al.* (1977) proposed that it is due to superimposition of the contingent negative variation (CNV) on the NoGo-P300. The second explanation proposed that there were two separate P300 components whose topographies were different from each other and hence may be produced by two (at least partially) separate generators (Pfefferbaum and Ford 1988).

1.4.2.2 Auditory Modality Dissociation

Squires *et al.* (1975) compared the scalp amplitude distributions of the P300 deflections evoked in response to target and rare nontarget stimuli. Subjects were presented with a sequence of tones in which there were occasional changes in the intensity of the stimuli. The task for the subjects was to count the number of changes in intensity. Subjects in the second condition were instructed to ignore the stimuli and read a book.

During the target condition the intensity changes elicited a P300 deflection with an amplitude distribution that was maximum at parietal scalp sites, this component was labelled the P3b. In the rare nontarget condition, in which subjects ignored the stimuli, a P300 deflection with an earlier latency and a maximum amplitude distribution at frontal and central sites was obtained, this component was labelled the P3a. Such a dissociation of the P300 complex into separate components on the basis of scalp amplitude distribution has consistently been found within the auditory modality (Knight 1984; Knight *et al.* 1987; Holdstock 1992; Holdstock and Rugg 1993). Knight (1984) employed a discrimination task in which frequent tones were occasionally interrupted by rare attended target tones that required a behavioural response and rare nontarget tones that did not require a response. This paradigm evoked a P300 deflection with a fronto-central distribution to the infrequent unpredictable rare nontarget sounds. The rare target tones evoked a P300 deflection with a parietal scalp amplitude maximum. The P300 deflection evoked in response to rare nontarget stimuli had an earlier latency than the P300 deflection that was evoked in response to the target tones.

1.4.2.3 Somatosensory Modality Dissociation

Responses to somatosensory target and rare nontarget stimuli within the P300 latency range have also been dissociated on the basis of scalp amplitude data (Yamaguchi and Knight 1991a). Mechanical taps to the second finger

were employed as frequent stimuli (76%) and taps to the fifth finger as target stimuli (12%). Two categories of rare nontarget stimuli were employed. Tactile rare nontarget stimuli (6%) were mechanical taps to the third or fourth fingers and shock rare nontarget stimuli (6%) were electric shock stimuli delivered to the median nerve. Correctly detected target stimuli generated a parietally distributed P300 response. Both tactile and shock rare nontarget stimuli generated a P300 response with a centro-parietal scalp distribution. The shock stimuli generated a P300 response with an earlier latency and a greater amplitude than either the frequent or tactile rare nontarget stimuli.

1.4.2.4 Lesion Studies

Studies examining the effect of focal brain lesions have also reported a dissociation of the responses evoked by target and rare nontarget stimuli. Knight (1984) reported those control subjects and subjects with unilateral prefrontal lesions demonstrated comparable P300 deflections to auditory target stimuli. In response to rare nontarget stimuli control subjects demonstrated large fronto-central N200 and P300 deflections. Frontally lesioned subjects, however, failed to demonstrate either an enhancement of the N200 deflection or a fronto-central P300 deflection. The P300 response had a parietal distribution and demonstrated similar amplitude to that evoked in response to target stimuli.

Subjects with lesions of posterior association cortex have also been examined (Knight *et al.* 1987; 1989). Subjects with focal lesions of superior parietal cortex and rostral sections of inferior parietal cortex demonstrated no overall reduction of P300 amplitude in response to either target or rare nontarget stimuli. However, the N200 deflection was abolished in response to target stimuli and markedly reduced to rare nontargets.

An orthogonal pattern of results was found in patients with unilateral lesions to the temporo-parietal junction. Here the N200 deflection in response to both target and rare nontarget stimuli was similar in both distribution and amplitude to that found in control subjects. However, the P300 deflection evoked in response to target stimuli was abolished and the P300 deflection evoked in response to rare nontarget stimuli was markedly reduced. These same lesions resulted in partial preservation of P300 activity at frontal scalp sites that supports the notion that multiple neural generators contribute to the P300 deflections evoked in response to target and rare nontarget stimuli (Knight 1989).

A similar dissociation of P300 deflections evoked in response to somatosensory target and rare nontarget stimuli in subjects with anterior and posterior association cortex lesions has been reported by Yamaguchi and Knight (1991b). Subjects with temporo-parietal lesions demonstrated reduced P300 deflections evoked by target and rare nontarget stimuli. Subjects with parietal lesions demonstrated P300 deflections with normal amplitude and distribution. However, subjects with frontal lesions demonstrated reductions of the P300 evoked by rare nontarget stimuli while the P300 deflection evoked by target stimuli demonstrated minimal change.

Such lesion data support the hypothesis that multiple neural P300 generators exist and that at least partially separate generators are responsible for the elicitation of P300 deflections evoked by target and rare nontarget stimuli.

Lesion studies have a number of methodological problems associated with them that limit the extent to which inferences deduced from such studies may be generalised to a healthy population. The extent of a lesion may extend further than is apparent, for instance it may affect fibre pathways. Damage may be diffuse and therefore affecting a large area with no clear boundary. If no ERP is recorded from the scalp a number of explanations are possible other than the lesion has removed the underlying neural generator of the activity. For instance the lesion may have removed some facilitation that was necessary for the ERP to be generated or it may have distorted the conducting medium. All that may be inferred from such results is that the area of the lesion was necessary for the generation of the particular scalp recorded deflection.

1.5 Theories of the Functional Significance of the P300

Neisser (1976) proposes that human beings interact with their surrounding environment in such a way that information is processed in a bottom-up manner as well as a top-down manner. Such a proposal requires that post-decision information feeds back to the so-called "hypothesis generator" to modify future hypotheses. Such a formulation has been incorporated into a number of models of the functional significance of the P300 deflection.

1.5.1 Triarchic Model (Johnson 1986; 1988; 1993)

As outlined in section 1.3 a number of hypothetical constructs have been suggested to account for the observed variations in the amplitude of the P300

deflection. Johnson (1986; 1988; 1993) attempts to reduce such constructs to three dimensions. These dimensions form the basis of a model of P300 amplitude. The proposed model postulates that the overall amplitude of the P300 deflection recorded at any given electrode site represents the summation of activity from different neural generators each related to processing a different type of information. A drawback of the model is that it deals almost exclusively with the P300 deflection evoked by target stimuli, the so-called P3b component of the P300 complex (see section 1.43). Johnson (1993) states that "this model was designed specifically to describe the P300, or P3b component of the late positive complex and not related components, such as the P3a or novelty P3..." (pp. 90). The proposed model is difficult to generalise beyond the oddball paradigm. However, an overview of the model allows a grasp to be made of the considerations that need to be taken into account when designing experimental manipulations that affect the P300 deflection.

The three dimensions of the proposed model, subjective probability, stimulus meaning and information transmission, are believed to interact to determine the overall amplitude of the P300 deflection. Subjective probability and stimulus meaning are regarded as having independent and additive effects on P300 amplitude. The amplitude contributions of these two dimensions are dependent on the proportion of transmitted stimulus information. The relations among these three dimensions may therefore be denoted as:

$$\text{P300 Amplitude} = f[T \times (1/p + M)]$$

where T represents the proportion of transmitted information, p represents subjective probability, and M represents stimulus meaning.

Subjective Probability

The first dimension that is thought to affect P300 amplitude is that of subjective probability. This is directly related to the amount of uncertainty reduced by a stimulus. Both *a priori* probability and sequential expectancies have been found in a number of tasks to contribute to the overall amplitude of the P300 deflection. Such tasks include counting (Johnson and Donchin 1980); reaction time tasks (Duncan-Johnson and Donchin 1982) and prediction tasks (Friedman *et al.* 1973). When large numbers of different stimuli are presented P300 amplitude is related to the probability of the stimulus categories rather

than to the probabilities of the individual stimuli (Courchesne *et al.* 1977; Johnson *et al.* 1985).

As well as the *a priori* probability of the stimulus in a sequence, the local structure of the stimulus sequence and the temporal probability of the stimuli affect the expectancies of the occurrence of a stimulus. Sequential probability (the occurrence of a particular stimulus within a number of stimuli) and temporal probability (occurrence of a particular stimulus within a period of time) are important sources of information which combine with other things, such as the information given to the subject about the stimuli, to produce the subjective probability of the stimulus. Subjective probability may be regarded as the likelihood of a particular stimulus occurring calculated by the subject throughout the sequence of stimuli, in contrast *a priori* probability is the true likelihood of a particular stimulus occurring.

Expectancies formed by the subject due to the sequential structure of the sequence have been found to affect P300 amplitude. Squires *et al.* (1977) quantified the relation between P300 amplitude and sequential structure, stimuli which were repeated were found to elicit a smaller P300 deflection than those which were not. In a more complicated sequential effect study (Johnson and Donchin 1980) one condition required one of three equiprobable tones in a sequence to be counted, in a second condition one of two tones with probabilities of 0.33 and 0.67 had to be counted. The P300 deflections elicited by the two counted stimuli were identical to that elicited by one uncounted stimulus which was twice as probable. Such results suggested that the amplitude of the P300 was determined by the subjective probability of the target event and was associated with the category to which the stimulus was assigned rather than the physical stimuli.

Stimulus Meaning

The second dimension of the model is that of stimulus meaning. The portion of P300 amplitude sensitive to changes in meaning is a function of three independently manipulable variables: task complexity, stimulus complexity and stimulus value. Various studies have reported that a P300 deflection with increased amplitude may be evoked by stimuli incorporated into paradigms where the primary task is more complicated. Paired associate learning (Horst *et al.* 1980) and feedback time estimation (Johnson and Donchin 1978) have both produced P300 deflections with increased amplitude compared to tasks in which the same stimuli were simply counted by subjects.

Verbaten (1983) demonstrated that intricate visual patterned stimuli elicited greater P300 deflections than simple visual stimuli. Such a study demonstrates that the complexity of the stimulus independent of the task affected the amplitude of the P300 deflection.

Various studies have also demonstrated that the effects of stimulus value affect the amplitude of the P300. Duncan-Johnson and Donchin (1977) have demonstrated that equiprobable stimuli elicit P300 deflections with larger amplitudes when such stimuli are designated as targets as compared when they are designated as non-targets.

These three variables are related to the concept of task demand. Increased complexity requires that a stimulus be processed more extensively in order to extract its full content. Johnson (1986; 1988; 1993) points out that a major difficulty in illustrating the relationship between P300 amplitude and task complexity is the scarcity of data from experiments in which one group of subjects performed more than one task using the same stimulus conditions.

The second variable on the stimulus meaning dimension is stimulus complexity. Some stimuli have more relevant features than others and thus require more processing for identification and categorisation. Verbaten (1983) used patterned visual stimuli at two levels of complexity and found that larger P300s were elicited by the stimulus with the more intricate pattern.

The third variable is that of stimulus value. Since the significance of events can be varied (for example by monetary payoffs) it appears that these variables are independent of either task complexity or stimulus complexity. Larger P300s are elicited by high-value stimuli than low-value stimuli when monetary payoffs are manipulated (Begleiter *et al.* 1983).

Information Transmission

The third dimension of the model is that of information transmission. This is the proportion of stimulus information received by a subject relative to the total amount of information originally contained in the stimulus. Variables on this dimension alter the amplitude contributions of the other two dimensions. Two categories of variables exist on this dimension: those creating equivocation and those affecting the allocation of attention. Equivocation is a term from classical information theory (Shannon *et al.* 1963) which describes the amount of information loss that occurs during the presentation of a stimulus as a result of the subject's *a priori* uncertainty about having correctly perceived an event (Johnson and Donchin 1978). Such a point is illustrated by the finding that a P300 deflection released by the omission of an expected stimulus is of

smaller amplitude than that elicited by a presentation of a stimulus (Ruchkin and Sutton 1978). The second category of variables covers instances in which stimulus information is lost due to inattention.

Johnson (1993) claims "that the additive relations in the model imply that different neural generators are activated by each of the different variables associated with the subjective and stimulus meaning factors" (pp. 91). The selective nature of these neural generators means that each may be regarded as a distinct information processor. Such independence means that each may be activated selectively and in different combinations. The number and configuration of active generators are believed to depend upon the nature of the stimulus information and the subject's task. Differences in the spatial location of generators means that the effects of each on P300 amplitude will have its own characteristic scalp distribution.

Johnson's proposed model (1986; 1988; 1993) may be regarded as a psychological theory of the (target) P300, however, the model fails to make suggestions concerning the functional significance of the P300. The model provides a framework that may be employed to explore and categorise the various experimental variables that affect the amplitude of the (target) P300. It demonstrates that many of the variables interact to affect the amplitude of the P300 deflection.

1.5.2 Context Updating Model (Donchin 1981; Donchin and Coles 1988)

Donchin and Coles (1988) suggest that the P300 deflection is not a direct reflection of a cognitive process but is rather a by-product of the activation of a neural process involved in information processing. Donchin (1981) claims that individuals maintain a representation of the environment. These representations are thought to form a model of the environment, such a model is used to evaluate incoming information and in selecting appropriate responses. Donchin makes the key assumption that there must be mechanisms that maintain the accuracy of the model or schema. When the "context" changes the model must be revised. A model lacking such an updating component would fail to reflect the ongoing context. Such contexts are continually changing, the model is so required to undergo constant revisions. It is necessary to integrate events such as novelty, surprise and the occurrence of improbable events into the model either by revising its mapping of probabilities on the environment or by rejecting the significance of the event and leaving the model unchanged.

Donchin (1981) argues that "the schema may be conceptualised as a large and complex map representing all the available data about the environment. It is the reservoir of information that is necessary for performing whatever tasks require active processing at any time....Representations decay because of misuse or because of shifting strategies and tasks. New information is brought in. Choices are made in the process of using this schema" (pp. 508). It is proposed that the model is revised by generating new representations by incorporating incoming information into the schema or model that is based upon long-term memory.

Donchin and Coles (1988) argue that "the sensitivity of P300 to the probability of events adds plausibility to the suggestion that it is associated with maintaining the schema" (pp. 369). It is suggested that the processes underlying the P300 response are involved with the maintenance of the model of the current context. It is assumed that the larger the amplitude of the P300 the larger the change in the model. He makes no claims concerning the nature of the system that implements the contextual model or about the processes by which the context updating is implemented. The model is, therefore, vague about the specific mechanisms that underlie the generation of the P300. However, he claims that the model is specific with respect to types of functions likely to be manifested by the P300. He further points out that the theoretical analyses of the processes that underlie the generation of the P300 are limited to the extent that they enable advances to be made to his experimental programme.

In summary Donchin and Coles (1988) state that "the context updating model asserts nothing more than the P300 is associated with the maintenance of our model of the environment" (pp. 370).

1.5.3 Context Closure Model (Verleger 1988)

Verleger (1988) proposes that the context closure hypothesis developed from the observation that the structured and repetitive design of experimental paradigms that are employed to elicit P300 deflections are not only necessary for measuring P300 responses accurately but may be necessary in evoking P300 deflections at all. He believes that P300 responses are elicited when subjects are required to deal with a repetitive highly structured environment. Subjects are believed to combine successively presented stimuli into meaningful contexts. A P300 may, therefore, be defined as "evoked when a perceptual epoch is closed" (Verleger 1988 pp. 351). Verleger points out that

the term "perceptual epoch" may be substituted with that of "cognitive epoch", "subtask" or "context".

Verleger claims that subjects maintain an internal template of the context, which includes maintaining an expectancy of the event that will close the context. When the stimulus is the expected one stimulus evaluation leads to response selection as well as to closure of the present context. Desmedt and Debecker (1979) first proposed the closure of a cognitive epoch as a functional explanation of the P300 deflection.

Whereas expectancy was defined as "working memory" in the context updating model (Karis *et al.* 1984) within the context closure model it is defined as "awaiting the closing stimulus " (Verleger 1988 pp. 350). The major difference between the theories is, therefore, that a P300 deflection will occur when expectancies are fulfilled in the context closure model whereas in the update model a deflection will occur when expectancies require revision.

Verleger concentrates upon the parietal maximum P300 deflection evoked in response to target stimuli, the so-called P3b component of the complex. The model proposes that the more anterior scalp P300 deflection, the P3a is elicited when a cognitive task is interrupted instead of being brought to its intended closure. Verleger proposes that the two P300 deflections may be related to one another. The P3b deflection within the context closure model is assumed to indicate the release of excess activation from perceptual control areas. Similarly the P3a deflection may indicate release from a higher level of behavioural control since the behavioural chain is completely interrupted.

1.5.4 Attentional Trace Theory (Nataanen 1982; 1990; 1992)

For a thorough review of Naatanen's theory of the role of attention in auditory information processing as revealed by ERPs see Näätänen (1982; 1990; 1992). He has proposed a model based entirely upon ERP data. The theory accounts for both passive and active forms of attention. It is proposed that the P3b and P3a components are produced by two, at least partially, separate generators. The P3b component is hypothesised to be evoked in situations that require active attention (target detection) on the part of an individual. The P3a component is thought to be evoked in situations that require individuals to passively attend to a sequence of stimuli.

The processing of acoustic stimuli is divided into two different modes: task-independent, basic sensory analysis and task-dependent sensory analysis. Task-

independent sensory analysis is based on rigid hardwired neuronal mechanisms.

During selective attention within the auditory modality the subjects are instructed to attend to auditory stimuli differing from other stimuli in location or tonal frequency or both (Alho *et al.* 1992). ERPs to attended stimuli are negatively displaced in relation to unattended stimuli. This negative difference (Nd) consists of separate early and late portions which Nääätänen (1990; 1992) proposes originate from auditory and frontal cortices respectively. A question arises over whether Nd is caused by an enhancement of exogenous N100 components (Hillyard *et al.* 1973) or by an endogenous processing negativity (PN) component overlapping with the exogenous ERP components unaffected by attention (Nääätänen *et al.* 1978; Nääätänen 1990; 1992). The view that the Nd is caused by an endogenous PN suggests that stimulus selection occurs as a matching process between the sensory input and an attentional trace (Nääätänen 1982; 1990; 1992).

An attentional trace is an actively formed and maintained cortical representation of the feature(s) separating the attended stimuli from other stimuli. The theory assumes that selective attention does not modulate the initial processing of stimulus features but is based on a separate matching process between the sensory input and the attentional trace (Nääätänen 1986).

The trace is formed and maintained using selective listening, with each auditory stimulus compared to the trace. The more similar the processed stimulus is to the attended stimuli with regard to the features represented by the trace the longer the comparison will last and a PN component with a longer duration and a larger amplitude will be elicited (Alho *et al.* 1992). Stimuli matching the trace are selected for further processing. If there is no match a stimulus is rejected and the PN generation is terminated. The Nd may, therefore, be regarded as the difference of a large and long duration PN elicited by relevant stimuli and a smaller and shorter duration PN elicited by irrelevant stimuli (Alho *et al.* 1990). A number of studies (Hansen and Hillyard 1980; 1984; Woods and Clayworth 1987; for reviews see Nääätänen 1982; 1985) have indicated that there are in fact two successive PN components. The earlier PN component, within a latency of approximately of 100-200 msec, has a centro-frontal amplitude maximum whereas the later PN component reaches its amplitude maximum at frontal sites at 300-400 msec latency (Alho *et al.* 1990).

A great deal of behaviour is self-initiated. Certain kinds of stimuli are preferred over others. These facts provide the motivational background of

selective attention. This form of selective attention is based on the attentional trace which may be thought of as a temporary feature recognition system for the rapid selection of relevant stimuli.

A match between the attentional trace and the current stimulus triggers the prepared further processing that is being held in readiness. When a target is found in this processing there is a P3b deflection and the designated response is released.

1.5.4.1 Auditory Processing Outside the Attentional Trace

Physically deviant auditory stimuli in a sequence of repetitive standard stimuli elicit the mismatch negativity (MMN - also referred to as the N2a component) component of the ERP (Näätänen 1990; 1992; Czigler and Csibra 1990). The MMN is best seen in a difference wave obtained by subtracting the standard stimulus ERP from the deviant stimulus ERP. Näätänen (1990; 1992) proposes that the MMN is generated by a brain mechanism responsible for the automatic detection of a change occurring in any repetitive aspect of auditory stimuli. Such detections occur during periods of passive attention. Näätänen (1985) reports that the amplitude of the MMN is directly proportional to the magnitude of the stimulus deviation (up to a plateau at 10% deviation), whereas its onset and duration has been reported to be inversely related to the degree of deviation.

The MMN is often followed by the P3a component (Näätänen 1990; 1992). Näätänen believes the P3a may reflect an attention switch to an environmental change encoded by the cerebral process generating the MMN. If the stimulus deviation is great the P3a may be preceded by a N2b component (Näätänen *et al.* 1982; for a review see Näätänen and Gaillard 1983). These components are, therefore, said to form a N2b-P3a wave complex (Näätänen 1990; Courchesne *et al.* 1975; Squires *et al.* 1977). Snyder and Hillyard (1976) claim the N2b-P3a wave complex "reflects the operation of a mismatch detector which signals any change in an ongoing background stimulus". However, an N2b can occur without a P3a (Knight 1990) and a P3a without a preceding N2b, for instance in response to deviants in ignore conditions (Sams *et al.* 1985).

Although the MMN may be elicited by deviant stimuli in active and passive oddball conditions, it is best observed in the ignore conditions. This is because there is no overlap with the N2b component, which would make a separate measurement of the MMN in active oddball conditions difficult (Alho *et al.* 1990).

The neuronal traces involved in MMN generation might form the neurophysiological basis of the short duration sensory memory in audition known as "echoic memory" (Näätänen 1984; Näätänen *et al.* 1986). This memory is believed to be an attention-independent, large-capacity sensory storage system with a short decay time (Cowan 1984).

The process generating the MMN may represent a command from the preattentive mechanisms to focus attention caused by a physical stimulus change (Näätänen 1985). Woods (1990) has suggested that the N2b-P3a complex might be associated with an attentional switch. Novel sounds were presented infrequently to either ear during selective dichotic listening. These sounds elicited large N2b-P3a waves and prolonged the RT to the subsequent targets in the attended input regardless of whether the novel sounds occurred in the attended or the ignored input.

The MMN may be used to assess the automaticity of auditory sensory processing. The occurrence of the MMN to slightly deviant stimuli even in the absence of attention suggests that the sensory stimulus features are fully processed independently of attention. It would appear that all discrete auditory stimuli receive a rapid and complete processing of their physical features. Such processing is not influenced by the direction of attention (but see Woldorff *et al.* 1991).

The attention-switching mechanisms revealed by the MMN allow environmental control over the focus of attention. Such mechanisms are able to make the organism attend to the present environmental situation by interrupting an attentional state directed at, for instance, task performance. Näätänen (1990; 1992) claims that ERPs may also reveal some of the brain events associated with attention switching itself. The P3a component may be the most sensitive cerebral indicator of an attentional switch (Näätänen *et al.* 1982; Sams *et al.* 1985). Näätänen and Gaillard (1983) claim that the cerebral events underlying the P3a component may also participate in the sequence of processes leading to the release of the autonomic nervous system response known as the orienting response (Luria 1973).

Näätänen (1992) suggests that the MMN and the P3a are related to the physical stimulus deviation but not to stimulus significance, for instance whether the stimulus is a target or not. He also suggested that the N2b might be related to expectancy violation (Näätänen 1986, 1992). N2b seems to be elicited by infrequent events in attended input. It is not related to stimulus significance in the sense of the stimulus being a target. Alho *et al.* (1990) and

Näätänen *et al.* (1982) have demonstrated that N2b may be elicited by both target and nontarget deviants in one-channel situations.

1.5.4.2 Visual MMN

MMN is proposed to reflect the operation of a deviance or novelty detector. Näätänen (1990) points out such a mechanism has obvious survival value and probably developed early in the evolutionary history of the species.

MMN is one of the central points of the attentional trace model, the role of MMN appears to be limited to a measure of sensory deviation from a homogeneous background. Ciesielski (1990) claims that if mismatching effects are considered to be the essence of selective information processing it would not be expected that MMN would be limited to the auditory modality but would be seen in all modalities. However, Näätänen (1990; 1992) confines the attentional trace theory to audition. This is largely due to the fact that different ERP correlates of visual attention and auditory attention are obtained (Czigler 1990).

The model proposed by Näätänen largely depends upon the development of an attentional trace that is regarded as a representation of so-called "echoic" memory. Haber (1983) questions the functional significance of the visual sensory, "iconic" memory, and goes so far as to claim "the notion of an icon as a brief storage of information persisting after stimulus termination cannot possibly be useful in any typical visual information processing task" (Haber 1983). If an underlying attentional trace in the visual system does not exist the question arises as to whether a MMN or P3a response will be elicited by visual stimuli.

Eriksen and Schultz (1978) have stressed the poor temporal resolution in vision, they have suggested that there is no storage of any one moment in time of a discrete slice of information. Haber (1983) has claimed that there may be an echoic store in audition since it would appear necessary to have a device to hold sequential auditory inputs while they are being processed. Haber believes such a device is necessary within the auditory modality since such a sensory system is inherently designed for sequential information pickup. However, he believes that vision is a spatial sense and as such does not require such mechanisms (for a full review of the concept of the visual icon see Haber 1983).

Czigler and Csibra (1990) reported that the ERPs to undetected nontarget deviant visual stimuli were similar to ERPs to frequent irrelevant stimuli. They, therefore, did not obtain the visual analogue of the auditory MMN, that

is an ERP component independent of the detection of the deviant stimulus feature.

As described above in the auditory modality a correlate of selective attention, the PN, has been interpreted as the manifestation of a matching process. A voluntarily maintained memory or attentional trace is compared to the representation of the incoming stimulus. Without "refreshment" (Czigler and Csibra 1992), *i.e.* the repeated presentation of the relevant stimulus, the attentional trace would decay. The theory, therefore, predicts that as the frequency of the attended stimulus decreases the PN will also decrease. Alho *et al.* (1990) obtained only a very small PN when the probability of the attended stimulus was 0.33%. Czigler and Csibra (1990) claim that since the probability of the attended stimulus within their study within the visual modality was 1% a PN would not have been predicted. However, a PN was obtained they, therefore, claim that the mechanism underlying these components may be different from the matching process suggested by the attentional trace theory within the auditory modality.

Czigler (1990) poses the question of whether the attended trace theory of auditory selective attention proposed by Näätänen (1990,1992) ought to be regarded as limited to simply the auditory modality with the result that separate models of selective attention are required for visual attention and for the other modalities. If the model is intended to be modality specific the failure to elicit a visual MMN is not problematic. However, if the theory is to be regarded as a more general theory of selective attention attempts to explain the failure to elicit a visual MMN are required.

1.5.4.3 Visual Negativities

Although the MMN seems to be modality specific, a modality non-specific negative component (N2b Näätänen and Picton 1982; or Nb - Renault and Lesevre 1979) may be recorded in the visual as well as the auditory modality. This component is elicited by infrequent events (Czigler and Csibra 1990). In visual discrimination tasks, the N2 is considered to be a correlate of stimulus categorisation (Ritter *et al.* 1983) and orientation to the stimulus (Renault *et al.* 1982; Näätänen and Picton 1982).

Posterior or occipital negativities may also be recorded in visual discrimination tasks. Czigler and Csibra (1990) reported that when the deviant and frequent stimuli differences were large the earliest difference recorded was a posterior negative wave. This initial negativity was followed by another

occipital negative component when the deviant stimulus was a target. The appearance of occipital negativities has been claimed to be a common finding for visual discrimination tasks (Harter and Guido 1980; Hillyard and Munte 1984; Wijers *et al.* 1989a; 1989b). The duration of this component becomes larger as a function of the similarity between the evoking stimulus and the target (Harter and Previc 1978). Harter and Guido (1980) observed a frontal positivity as well, and similar findings have been reported by Wijers *et al.* 1987a; 1987b).

Harter *et al.* (Harter and Previc 1978; Harter and Guido 1980; Harter and Aine 1984) have related the occipital negative waves to the processing negativity components of auditory selective attention experiments (Näätänen and Michie 1979).

Within the auditory modality stimulus deviance may be automatically registered without detection as indicated by MMN obtained when stimuli are not attended (Näätänen *et al.* 1978). Czigler and Csibra (1990) suggested that in the case of the visual modality when deviance is salient enough to be preattentively registered detection automatically occurs. When deviance is not salient enough it is not preattentively registered and detection occurs only via an attentive search. Some visual identification studies (for example Bergen and Julesz 1983; Sagi and Julesz 1985) resulted in a similar distinction of processes.

1.6 Considerations of the Functional Models

The triarchic (Johnson 1986; 1988; 1993), context update (Donchin 1981) and the context closure (Verleger 1988) models all regard task relevance and subjective probability as important factors that affect P300 amplitude. The triarchic model suggests that these two factors operate independently. Both the context updating and context closure models suggest that the two factors are interactive.

Interaction between the two would be possible if both factors influenced a common intervening variable as suggested by the "closure" model (Verleger 1988) or "update" model (Donchin and Coles 1988). Pritchard (1989) has attempted to determine whether the two factors act independently or interact together. He employed a standard oddball paradigm in which subjects counted one of two tones presented in random order. The frequency of occurrence of target tones was varied across blocks (20%, 50%, 80%) to determine whether the effect of task relevance on P300 (defined as targets versus nontargets)

would remain constant across probabilities. The effect of task relevance did not differ between the 20% and 50% blocks, but was reduced in the 80% block. This result suggests an interaction between the two factors.

Verleger and Berg (1991) similarly examined whether probability and task relevance are independent factors. High and low tones were presented in random order with equal probability. In the control condition (standard oddball) every high tone had to be counted. In the so-called "waltz" condition high tones were only counted if they were preceded by two other high tones.

The additive hypothesis proposed by Johnson would predict that P300 deflections would not be larger in the waltz than in the standard oddball because task relevance was the same. The interactive hypothesis (Verleger and Berg 1991) would predict that P300 deflections would be larger in the waltz than the in oddball, because targets were less frequent in the waltz condition, *i.e.*, the probability of task relevant events was an important factor. The results supported the interaction hypothesis. However, Johnson (1993) claims that Verleger and Berg (1991) have confused the concept of additivity as exemplified in the Additive Factors Method and the concept of additivity as employed by Johnson (see Johnson 1993 for a thorough review).

Johnson (1986) argued that the relevance - probability distinction might be related to the controlled-automatic distinction of attention. Hasher and Zacks (1984) have proposed that information on the probability of events is processed automatically. However, a number of researchers have demonstrated instances in which probability of events has not been processed automatically (Birnbaum *et al.* 1987; Jonides *et al.* 1987). MacLeod and Dunbar (1988) have suggested that there is a continuous transition from automatic to controlled processing. This suggestion would not be compatible with the strict independence of task relevance and probability dimensions. However, such independence is a necessary feature of Johnson's triarchic model.

Verleger and Berg (1991) argued it was of note that the target P300 deflections were evoked by nontargets following two high tones in the waltz condition. These P300 deflections demonstrated a more anterior scalp distribution. As reported previously (see section 1.421) more anterior scalp distributions have been found in Go/Nogo tasks for the Nogo stimuli (Hillyard *et al.* 1976; Simson *et al.* 1977). Verleger and Berg (1991) suggested that these anterior Nogo P300 deflections are equivalent to the anterior P3a component reported by Courchesne *et al.* (1975; 1978) and Squires *et al.* (1975) and Knight (1984). These anterior P300 deflections were evoked by unannounced stimuli interspersed in oddball tasks. The common feature is that

the ongoing task was aborted rather than brought to its intended closure. In the Go/Nogo tasks, subjects are prepared to process the target stimuli but have to cancel this activity when the target is not presented. In the Courchesne *et al.* type paradigm, subjects temporarily stop performing the oddball task in order to classify the unknown stimuli.

In general the two P300 deflections may be related (Verleger and Berg 1991), the posterior P3b component indicating the closure of subtasks when brought to their intended ending (Desmedt and Debecker 1979; Verleger 1988). The anterior P3a component indicating "the closure of subtasks to a more thorough extent or on a higher level of behaviour control, because the behaviour chain is cancelled altogether" (Verleger and Berg 1991 pp. 475).

Verleger (1988) points out a crucial disparity between the context updating and context closure models. He argues that P300 deflections will occur when subjects have managed to integrate a number of items into a meaningful context (by the process of "closing"). Since the process of closing is unable to occur to the first stimulus (novel) of a row of stimuli a P300 should not be elicited. However, according to context updating model such a novel stimulus should elicit a P300 since the P300 is believed to reflect the process of updating. New stimuli will require updating of the cognitive map of the environment held by the subject.

An oddball paradigm enables examination of which of these two formulations is correct. Context closure leads to the assumption that there will be no P300 in response to the first (unfamiliar) stimuli, as the same stimulus is repeatedly presented and the subject integrates the stimuli into a meaningful context, a larger P300 deflection should occur later in the series. The reverse is expected of the context update hypothesis, a novel stimulus necessitates updating thus leading to a large P300 at the first trial. Repetition will reduce the novelty effect of the stimulus hence no P300s or smaller ones should be seen.

Ritter *et al.* (1968) reported a Cz P300 that was largest in the first averaged ERP and a smaller P300 in the second ERP. Similarly Megela and Teyler (1979) also reported decreases in auditory P300. Roth (1973) Becker and Shapiro (1980), and Lutxenberger *et al.* (1983) all found a decreasing Cz P300 over subsequent ERPs.

Similar though less extensive studies have been carried out in the visual modality. Verleger claimed that in response to visual novel stimuli (Courchesne *et al.* 1978) an anterior rather than parietal P300 deflection was demonstrated. Megela and Teyler (1979) presented rows of visual stimuli and

found the largest P300 at the posterior electrode. Verbaten *et al.* (1986a; 1986b) and Woestenburg *et al.* (1983) also reported that the largest P300 in response to the first (novel) stimulus was at Pz.

In support of the context closure model Courchesne *et al.* (1975) reported that the parietal P300 decreased in amplitude as a function of stimulus repetition. However, the Courchesne and Knight studies may be interpreted on the basis of the context updating model. Fronto-central (P3a) activity reflecting updating in the sense of new concepts and parietal activity in the sense of updating within the limits of existing concepts.

Both the context closure and context updating theories are able to account for the experimental data pertaining to the target P300 deflection. They are able to do so due to the generality and vagueness of their explanations. Such generality makes it difficult to test specific predictions made by them, it is hence difficult to "prove" or "disprove" either model.

1.6.1 Summary of the Models of the P300 Complex

Four models concerning the functional significance of the P300 deflection have been briefly reviewed. A direct comparison of the models is difficult since each evaluates the evidence pertaining to the P300 from a different theoretical standpoint.

The early version of Johnson's (1986; 1988) triarchic model attempted to reduce the observed variations in the amplitude of the P300 deflection to three dimensions. His later version (Johnson 1993) extends this attempt such that the overall amplitude of the P300 represents the summation of activity from different neural generators each of which is related to the processing of a different type of information. The triarchic model deals with the antecedent conditions of the elicitation of the P300, it fails to critically examine the activity of the underlying neural substrate that the P300 deflection may represent. The model also fails to explicitly examine the separate components of the P300 complex since it deals largely with task relevant (target) stimuli.

The context updating (Donchin 1981) and the context closure (Verleger 1988) models examine the functional significance of the P300 deflection. The fundamental differences between these two models are discussed above. Both models deal almost exclusively with the P300 response to target stimuli within an oddball paradigm. As with the triarchic model neither the update nor closure models examine the underlying neural substrate that is responsible for the generation of the P300 scalp deflection. The three models also treat the

P300 as a modality non-specific phenomenon. The main criticism with theories attempting to explain the functional significance of the P300 deflection is that such theories need to be fairly general in order to account for the large number of published findings pertaining to the P300 complex.

The attentional trace model proposed by Näätänen (1990; 1992) develops ERP data into a model of auditory selective attention. It has proved difficult to extend this theory to other modalities given the failure to evoke a MMN in modalities other than audition. This model deals with the P3a and P3b components of the P300 complex.

1.7 Aims of Programme

An extensive literature exists on the experimental variables that affect both the latency and amplitude of P300 deflections evoked by target stimuli in both auditory and visual modalities. A growing literature also exists on the variables necessary to dissociate the P300 deflections evoked by auditory target and rare nontarget stimuli on the basis of amplitude distribution. Less progress has been made to determine the feasibility of dissociating the P300 deflections evoked by visual target and rare nontarget stimuli on the basis of amplitude distribution.

It is not possible at the moment to determine whether the P300 deflections evoked by different tasks or stimuli (target or rare nontarget) are manifestations of a single neural generator system or a system with dissociable separate neural generators. An important aspect of this question concerns the modality specificity of the P300 component(s).

Johnson (1989) reported that the amplitude distributions of P300 responses to target stimuli were reliably different between the auditory and visual modalities. Visual P300 responses were larger than auditory ones over central and frontal scalp. Barrett *et al.* (1987) have also reported that the target P300 responses in the auditory and somatosensory modalities were different. The somatosensory P300 response was largest at central sites while the auditory P300 response was largest at parietal sites. However, Picton *et al.* (1984) reported that the scalp distribution of the P300 response to target stimuli in auditory, visual and somatosensory modalities were similar. Similarly Squires *et al.* (1977) reported that the amplitude distribution of the P300 deflection in auditory and visual modalities was similar.

The development of a visual as well as an auditory paradigm that dissociates the P300 responses to target and rare nontarget stimuli on the basis of amplitude distribution would allow the question concerning the modality specificity of the neural generator(s) of the P300 to be addressed.

The development of a visual paradigm would also allow questions arising over the models of the functional significance of the P300 to be examined. In particular such a paradigm would enable an examination of the attentional trace theory. As pointed out by Ciesielski (1990) if mismatching is crucial to selective information processing an MMN ought to be seen in each sensory modality. A paradigm that evokes an MMN and a P3a component within the visual modality would allow examination of the form an underlying attentional trace would take (see the preceding controversy over "iconic" memory).

Such a visual paradigm would also allow the modality specificity of the triarchic, context updating and the context closure models to be examined. The majority of evidence employed to validate such models has relied upon studies carried out within the auditory modality.

In summary the aim of this programme was to develop a visual paradigm that dissociated the P300 responses to target and rare nontarget stimuli on the basis of scalp amplitude distribution. Such a paradigm would allow the examination of the question of the modality specificity of the P300 complex.

Chapter 2

General Methodology and Data Analysis

2.0 General Methodology

2.1 Paradigm

A modified version of Knight's three stimulus oddball task was employed (Knight *et al.* 1989; see Fabiani 1987 for a review of oddball paradigms). 300 stimuli were presented in each experimental run of auditory and visual stimuli. The stimuli had an interstimulus interval (ISI) of 2 seconds. 70% of the stimuli were frequent nontargets. 15% were designated as targets that required a prompt motor response, a button press using the right index finger. The remaining 15% were rare nontarget stimuli. Subjects were instructed not to respond to either frequent or rare nontarget stimuli. Stimuli were presented in a random order.

2.2 Stimuli

Auditory

The auditory stimuli employed will be described in section 3.4.1.

Visual

Visual stimuli were presented upon a visual display unit (VDU) approximately 90 cm in front of the subjects. All three stimulus types had a presentation duration of 300 msec. In the case of experiment 1 the stimuli were adapted from Courchesne *et al.* (1975) and will be described in section 3.5.1. All other experiments employed visual stimuli adapted from Knight (1991; personal communication) and will be described in section 4.2.

2.3 Subjects

With the exception of the elderly subjects that participated in experiment 6 (see section 8.2) all the subjects were university students. All were financially reimbursed for participating. None of the subjects in experiment 1, 2 or 6 had

previously participated in an ERP experiment. 3 in experiment 3, 3 in experiment 4 and 5 in experiment 5 had previously participated in ERP studies.

2.4 Procedure

The subjects were tested seated upright in a dimly lit sound attenuated room. During the recording session they were requested to keep their eyes open and fixate upon a small dot on a VDU approximately 90cm in front of them and to refrain from blinking and moving as much as possible.

Before each auditory and visual experimental run an initial block of 15 stimuli, (4 target and 11 frequent nontarget), were presented to each subject to familiarise them with the stimuli and the required response to the targets. Subjects were instructed to respond whenever they detected a target. Following the practice trials the experimental run was presented. Subjects were informed that their task was the same as in the practice trials.

The 300 stimuli were presented in blocks of 100 with a one minute break provided between blocks. Between experimental runs a 5 minute break was provided. The presentation of experimental runs was alternated between subjects.

2.5 ERP Recording

Electroencephalographic (EEG) activity was recorded from nine scalp locations Fz, Cz, Pz and positions 75% of the distance from the midline to F7, T3, P3, F8, T4 and P4 (designations refer to the International 10/20 system; Jasper, 1958). These positions will be referred to as LF, LT, LP, RF, RT and RP respectively.

EEG was recorded from silver silver/chloride electrodes for experiment 1. For all other experiments EEG was recorded from tin electrodes mounted in a proprietary electrode cap. Silver silver/chloride and tin electrodes were never combined. Linked electrodes placed on the right and left mastoid processes were used as a reference.

A bipolar electro-oculogram (EOG) was recorded from an electrode placed above the right eye and another beside the left eye. EEG and EOG were amplified with a bandwidth of 0.03-30Hz (3dB points) and sampled on-line at 4 msec/point. Sampling began 100 msec before stimulus onset, and continued until 924 msec post-stimulus. ERPs were formed from error-free trials which

were free of EOG artifact, activity above 20 microvolts was rejected (minimum of 15 trials per ERP).

2.6 Data Analysis

Johnson (1993) claims that a key assumption underlying tests of scalp distribution differences is that the component measurements are free from component overlap that could create differences where in reality none exist. Spatial overlap may be overcome by using a comprehensive electrode montage to reduce overlap to a minimum.

The main method of dealing with temporal overlap is to perform the same series of analyses on each component that may overlap with the component of interest. Throughout this thesis the P300 deflection evoked in response to both target and rare nontarget stimuli were examined. Similar analyses were carried out upon the N200 responses to target and rare nontarget stimuli. The response to all three experimental conditions for the portion of the waveform known as the slow wave (designated as the activity within the latency range 500-850 msec) were also analysed. Similarly all three experimental conditions within the N100 latency range were also analysed.

If the measurements of a component's amplitude are contaminated to a substantial degree by the activity of an overlapping component, then both components will respond in a similar fashion to the experimental variables.

2.6.1 Grand Averages

Grand average waveforms were produced by averaging together the individual waveforms from each subject within an experimental procedure for each experimental condition.

2.6.2 Latency Data

The latency of the peak of the designated peak deflections (N100, N200, P300) from the three midline electrode sites (Fz, Cz, Pz) was determined for each experimental procedure. Frequent nontarget, target and rare nontarget peak latencies were determined for deflections in the N100 latency range. In the case of the N200 and P300 deflections target and rare nontarget peak latencies were determined. Subject X Condition X Site ANOVA were performed on the peak latency data.

2.6.3 Amplitude Data

To reduce the influence of unresolved noise in the ERP waveform statistical analyses were carried out on the mean amplitude of the area of the waveform ± 12 msec around the peak of interest rather than on the peak amplitudes themselves.

This was determined in each subject by determining the latency of each peak at the electrode sites where the deflection was observed to be largest in the grand average waveform. To further reduce noise the designated peaks were measured at three sites across the scalp, the mean value of these three measurements being employed as the mean peak latency. In the case of the P300 deflection both target and rare nontarget peaks were determined at the parietal midline and lateral sites (Pz, LP, RP). The mean of these values being employed as the mean peak latency. The peaks of the N100 deflections were also determined at the parietal midline and lateral sites. The N200 peaks in response to both target and rare nontarget stimuli were determined at frontal midline and lateral sites.

A ± 12 msec window was then determined around the peak latency which determined the mean amplitude of this area of the waveform for each electrode site.

ANOVAs were carried out to examine the differences in mean amplitude of the designated peaks of the waveform and the 500 - 850 msec region in the different experimental conditions. ANOVAs were typically in the form of Subject X Condition X Chain X Site. Here Subject and Condition refer to the number of subjects and experimental conditions employed within the experiment respectively.

In order to compare differences in amplitude between midline and lateral electrode sites as well as between hemispheres the nine electrodes of the recording montage were divided into three chains of three electrodes, *i.e.* over the right and left hemispheres and along the midline. Chain in the ANOVA, therefore, refers to the three chains of electrodes and Site to the three electrode sites within each chain (frontal, central/temporal and parietal).

2.6.4 Rescaled Data

The effect of experimental conditions on the scalp distribution of an ERP component is of interest. If the ERPs associated with different experimental variables demonstrate different scalp distributions this would seem to be evidence that separate neural generators are contributing to the ERPs. Such an

effect would appear as a significant interaction between the experimental condition variable and the electrode factor in the ANOVA.

However, such an interpretation is simplistic since it may be due to differences in amplitude across conditions rather than to genuine differences in scalp amplitude distribution (McCarthy and Wood 1985). It is, therefore, necessary to perform an ANOVA on normalised, or rescaled, data. Normalisation of amplitude removes any between condition differences in such a way that the average mean amplitude within each experimental condition is the same. Once data has been rescaled only topographic differences remain. If the intracranial source configuration is the same in different experimental conditions then the scalp amplitude distributions will be the same. However, if the pattern of scalp activity is the result of the output of multiple generators then the experimental variable should still interact with the electrode site in an ANOVA. A difference in scalp topography is evidence that more than one intracranial generator contributed to the activity in the different conditions. Analysis of differences in scalp distribution were, therefore, conducted on data that had been rescaled to remove overall differences in amplitude as recommended by McCarthy and Wood (1985).

The method employed throughout this piece of work was to normalise the data for the two conditions by finding the maximum and minimum values in each condition, subtracting the minimum from each data point, and dividing by the difference between maximum and minimum.

In summary a change in the amplitude of a deflection indicates a change in the strength of a particular generator or a combination of generators. A change in the scalp distribution between conditions indicates a change in the neural generator configuration.

The significance of main effects and interactions involving repeated measures were assessed using a Geisser-Greenhouse adjustment to the degrees of freedom where appropriate to control type I errors associated with inhomogeneity of covariance (Keselman and Rogan 1980). Finally significant main effects and interactions were examined in detail through the Newman-Keuls testing procedure using the 5% level of significance throughout.

Post hoc analysis was initially determined on the highest order interaction within the ANOVA summary table. However, where applicable main effects, in particular condition and procedure main effects, were also analysed.

2.7 Single Trial Analysis

Single trial analysis allows the analysis of single epochs of EEG elicited by a particular class of stimuli. Such analysis allows questions concerning the habituation of scalp distribution of responses to particular classes of stimuli to be examined over a given number of trials. Averaging collapses the individual epochs together to form an averaged response thus losing any possible significant differences between individual epochs.

In order to measure deflections in the single trial data the raw EEG waveforms were initially digitally filtered by using a symmetrically weighted single-step low pass digital filter (Ruchkin and Glaser 1978). The extent of filtering was determined by the experimenter, a cut off of 12.2 Hz was employed. Heavier filtering of the waveforms is required in comparison to the filtering used in previous data analysis since in single trial analysis fewer trials contribute to the waveform in each condition and therefore the background activity producing noise in the ERP waveform would have been averaged out less in the single trial analysis. The heavier filtering of the averaged waveforms removed high frequencies making the ERP more prominent in comparison to the noise.

Analysis was carried out upon the first 10 epochs of EEG free from eye blink artifact for both target and rare nontarget stimuli. ANOVAs were carried out to examine the differences in amplitude across sites over trials. Such ANOVAs took the form of Subject X Trial X Site.

Chapter 3

Experiment 1: Investigation of the Dissociation of The P300 Complex in Auditory and Visual Modalities.

3.1 Introduction

As outlined in Chapter 1, since the work of Sutton *et al* (1965) a positive deflection with a mean latency of between 250-600 msec, the P300, has consistently been demonstrated within the literature. Sutton *et al.* (1965) described a positive going deflection with a latency of approximately 300 msec in response to auditory (click) and visual (flash) stimuli whose occurrence after a cue stimulus was uncertain. It was reported that the amplitude of the P300 deflection was larger in response to stimuli which had a low probability of occurrence compared with high probability stimuli.

The aim of this Experiment was to determine the possibility of dissociating the P300 responses evoked by visual and auditory target and rare nontarget stimuli on the basis of amplitude distribution. Previous reports in both the auditory (Squires *et al.* 1975; Knight 1984; Holdstock 1992; Holdstock and Rugg 1993) and visual (Courchesne *et al.* 1975; Knight 1991; personal communication) modalities have reported a target P300 response with a parietal maximum amplitude distribution. A rare nontarget P300 response has been reported with a more anterior centro-frontal or centro-parietal maximum amplitude distribution.

A visual and an auditory paradigm that dissociated the responses to target and rare nontarget stimuli would enable the question of the modality specificity of the neural generation of the P300 complex to be examined. A visual paradigm would also enable the modality specificity of the functional theories of the P300 complex to be examined.

Reports concerning the modality specificity of the P300 scalp distribution are inconclusive. Johnson (1989a) reported that the distribution of P300 responses to target stimuli was reliably different between the auditory and visual modalities. Barrett *et al.* (1987) have also reported that the target P300 responses in the auditory and somatosensory modalities are different. However, Picton *et al.* (1984) reported that the scalp distribution of the P300 response to target stimuli in auditory, visual and somatosensory modalities were similar. Similarly Squires *et al.* (1977) reported that the amplitude

distribution of the P300 deflection in auditory and visual modalities was similar.

Stimuli employed within the auditory procedure were based upon that employed by Knight (1984) and Holdstock and Rugg (1993; personal communication). The prediction from this procedure was that the dissociation of the P300 responses evoked by target and rare nontarget stimuli previously reported would be replicated. Holdstock and Rugg (1993) reported a target P300 response with a parietal site amplitude maximum. Rare nontarget stimuli evoked a P300 response with an earlier latency and a more anterior centro-parietal distribution.

Stimuli employed within the visual procedure were based upon that employed by Courchesne *et al.* (1975). Courchesne *et al.* reported that target stimuli evoked a P300 response with a parietal maximum distribution. The rare nontarget P300 response demonstrated a centro-frontal distribution. The prediction from this procedure was that the dissociation of P300 responses evoked by target and rare nontarget stimuli would be replicated.

3.2 Method

Subjects

The subjects were eleven university students (mean age 22 years, range 18-27, nine female). None had previously participated in an ERP experiment.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram (EOG) activity were recorded from the scalp montage described in section 2.5 using Ag/AgCl electrodes.

3.3 Data Analysis

Latency Data

See section 2.62 for a description of the peak latencies measured. Latency values for each component were determined for both auditory and visual procedures separately. The ANOVAs took the form of Subject X Condition X Site.

Amplitude Data

See section 2.63 for a description of the ANOVAs performed on amplitude data. The ANOVAs took the form of Subject X Condition X Chain X Site.

Within the auditory modality the peaks of the negative components (N100 and N200) were determined across the anterior scalp site since the deflections were observed to be largest there. The P300 deflection was determined at posterior scalp sites. Within the visual modality peaks were determined as described in Chapter 2.

For the visual procedure a further ANOVA was performed on the mean amplitude within a latency range of 150-350 msec across the three experimental conditions at lateral parietal sites. This analysis was carried out in order to examine the reduced rare nontarget response in comparison to the target response at lateral parietal sites observed in the visual stimuli grand average waveform (see section 3.5.2).

Scalp Distribution

To examine the scalp distribution of experimental conditions and the difference between the scalp distribution of conditions between modalities between modality analyses were carried out. Such analyses took the form of Subject X Modality X Condition X Chain X Site.

To determine the distribution of the P300 responses to target and rare nontarget stimuli along all three chains of electrodes subsidiary ANOVAs were performed on the rescaled data from the auditory and visual modalities separately. Such ANOVAs took the form of Subject X Condition X Chain X Site.

Single Trial Analysis

To examine whether the amplitude of responses evoked by target and rare nontarget stimuli altered during the initial presentation of stimuli single trial analysis as described in section 2.7 was carried out. Such analyses were performed upon data from both auditory and visual modalities.

Within both the visual and auditory modalities single trial analysis was performed upon data from 9 subjects since one subject demonstrated large eye blink artifact upon a significant proportion of the first 10 presentations of the stimuli. The second subject's raw EEG data was unable to be retrieved from the back-up media.

Within this chapter the auditory and visual procedures, together with the results pertaining to the latency and mean amplitude evoked by such stimuli, will be described separately. A comparison of the scalp distribution of the rescaled amplitude evoked in response to auditory and visual stimuli will also be carried out. A separate discussion of the results pertaining to the auditory and visual procedures will be provided.

3.4 Auditory Modality

3.4.1 Method

Stimuli

Stimuli were adapted from Knight *et al.* (1989). Subjects received binaural auditory stimuli through stereo headphones. The frequent and target tones were either 1000 Hz or 750 Hz sinusoidal tones (150 msec duration; 10 msec rise and fall time; 85 dB SL) counterbalanced across subjects. No subject had difficulty differentiating between target and non-target stimuli.

The 15% rare non-target stimuli consisted of 30 different computer sampled snatches of sound. These sounds were short segments of environmental noises, for instance car horns, duck quacks and footsteps, digitised from a sound effects tape onto a computer using the Pro Sound Designer Gold package for the Amiga. This sound editing was carried out by J.Holdstock (1992, unpublished Ph.D thesis). They had an abrupt rise and fall time, a duration of 100 msec and were the same perceived intensity as the tones.

Procedure

Subjects carried out a practice block of 15 trials (4 target and 11 frequent) before carrying out the experimental procedure to familiarise them with the stimuli and the required response to the target stimuli. Before the experimental procedure was presented subjects were informed that their task was the same as during the practice block. They were also told they would occasionally hear "strange noises" but were to refrain from responding to them.

3.4.2 Results

Behavioural Performance

Mean reaction time to target stimuli was 555 msec with a standard deviation across subjects of 117 msec. The mean rate for correctly detected targets was 98.7% and the mean false positive rate was 3.9%.

ERP Data

A grand average waveform was produced (see Figure 3.1b). The waveform made up of the frequent stimuli was formed from an average of 178 trials (range 165-208). The target waveform from 35 trials (range 32-43) and the rare nontarget from 35 trials (range 16-44).

Auditory stimuli evoked a negative deflection within the first 100 msec of the waveform (see Figure 3.1b). This deflection, the N100, was evoked by all three experimental conditions and was evident across all electrode sites. At frontal sites rare nontarget stimuli evoked less amplitude in comparison to frequent and target stimuli. Following the resolution of the N100 rare stimuli evoked a second negative deflection with a mean latency of approximately 200 msec. The N200 was maximum at frontal and central sites. Target and rare nontarget stimuli evoked a positive deflection with a latency of approximately 300 msec. The P300 demonstrated maximum amplitude at parietal sites. Following the resolution of the P300 target and rare nontarget stimuli demonstrated a period of sustained negativity at frontal sites and positivity at parietal sites. This effect was not evident in the frequent stimuli condition.

Table 3.8.1 and 3.8.2 of the Appendix show the mean amplitude and the mean rescaled amplitude elicited by auditory experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 -850 msec for each site, of each electrode chain.

P300 Deflection

ANOVA of latencies produced a main effect of condition (see Table 3.1 of the Appendix). Rare nontarget stimuli evoked a significantly shorter latency than target stimuli collapsed across the midline sites (303.7 ms v 330.1 ms see Table 3.2 of the Appendix).

Figure 3.1a

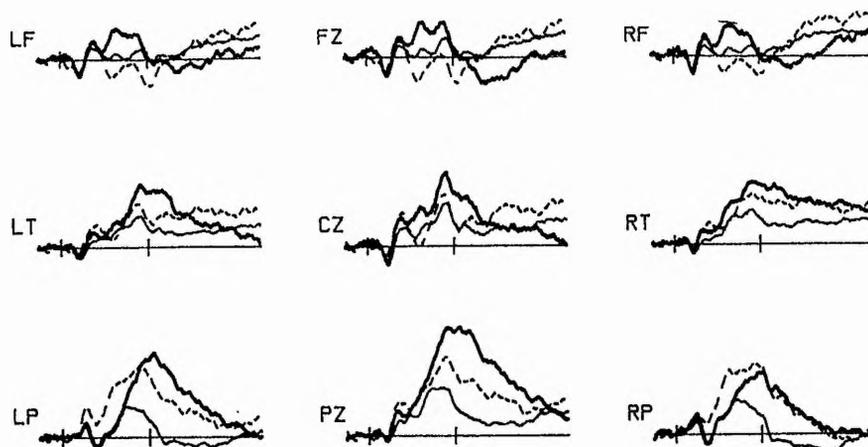


Figure 3.1b

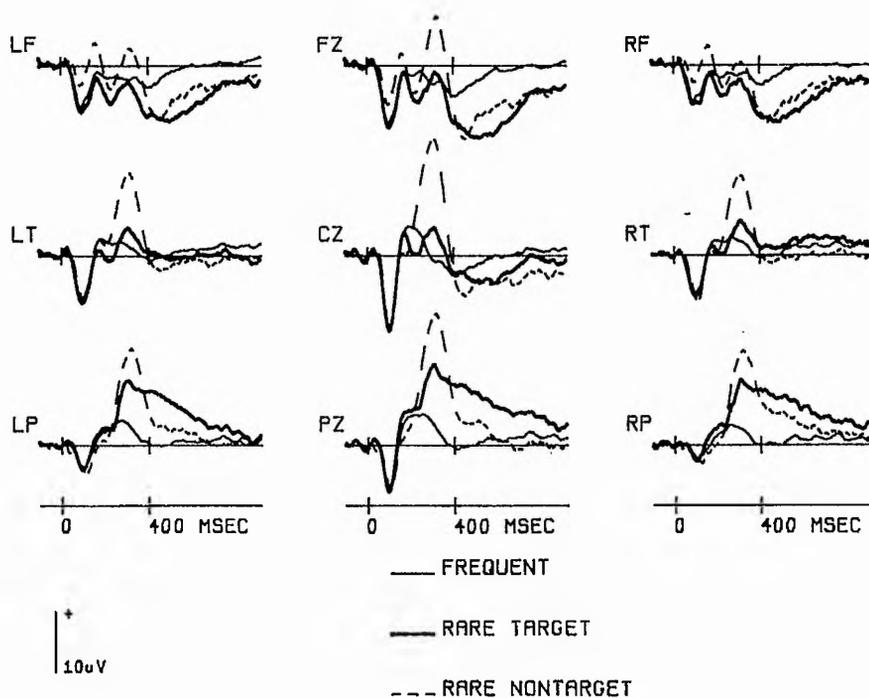


Figure 3.1a and 3.1b Waveforms, averaged across 11 subjects, for each condition of the visual (Figure 3.1a) and auditory (Figure 3.1b) stimuli in Experiment 1

ANOVA of mean amplitude evoked by target and rare nontarget stimuli revealed a significant main effect of condition (see Table 3.3). *Post hoc* analysis demonstrated that the rare nontarget response, collapsed across electrode sites, was reliably larger than the target response (3.8 microvolts vs 11.5 microvolts).

Post hoc analysis of the significant three way interaction involving the factors of condition, chain and site demonstrated that the rare nontarget response was largest at centro/temporo-parietal sites along the three electrode chains. The target response was largest at posterior sites. Along the midline chain the parietal (Pz) electrode demonstrated greater amplitude than either the central (Cz) or frontal (Fz) electrodes. Along the lateral chains the parietal electrodes demonstrated greater amplitude than the frontal electrodes.

Single Trial Analysis

Target Stimuli No main effect of trial was found to be significant (see Table 3.4). A main effect of site was obtained. *Post hoc* analysis demonstrated that the amplitude evoked by target stimuli across sites, collapsed across trials, was not significantly different between Fz and Cz sites, however, the amplitude evoked at the Pz site was significantly greater than that evoked at either Fz or Cz. An interaction involving the factors of site and trial did not prove to be significant.

Rare Nontarget Stimuli No main effect of trial was found to be significant (see Table 3.4). A main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked by rare nontarget stimuli across sites, collapsed over trials, was not significantly different between Cz and Pz but was greater at each of these two sites in comparison to that obtained at Fz. A two way interaction involving the factors of site and trial did not prove to be significant.

N100 Deflection

ANOVA of the peak latencies of the deflections evoked in response to the three classes of experimental stimuli failed to produce a significant main effect or interaction (see Table 3.1 of the Appendix).

ANOVA of the mean amplitude produced a significant two way interaction involving the factors of condition and site (see Table 3.5 of the Appendix).

Table 3.3 ANOVA summary table for analysis of P300 amplitude elicited by auditory target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	28.60	0.000*	102.56
Chain CH	1.5,14.6	8.56	0.006*	28.12
Site ST	1.3,13	36.45	0.000*	100.49
Interactions				
CC X CH	1.9,19.1	18.46	0.000*	7.65
CC X ST	1.4,13.6	5.72	0.024*	16.55
CH X ST	2.4,24.2	2.45	0.099	4.55
CC X CH X ST	1.9,19.4	3.92	0.038*	1.86

Table 3.4 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of auditory target and rare nontarget stimuli.

Target Stimuli	df	F	p	mse
Main Effects				
Trial TR	3.5,31.5	2.011	0.125	247.77
Site ST	1.2,10.7	13.804	0.003*	119.56
Interactions				
TR X ST	3.8,34.6	1.889	0.137	75.431
Rare Nontarget Stimuli				
Main Effects				
Trial TR	3.5,31.7	1.494	0.232	267.58
Site ST	1.4,12.9	9.494	0.005*	333.75
Interactions				
TR X ST	5.7,51	0.682	0.656	45.31

* denotes a p value statistically significant at the 0.05 %

Post hoc analysis, collapsed across electrode chains, demonstrated that both frequent and target stimuli evoked the greatest amplitude at centro/temporo-frontal electrode sites. Rare nontarget stimuli evoked significantly greater amplitude at central/temporal sites than at either frontal or parietal sites.

N200 Deflection

ANOVA of the peak latencies of the deflections evoked in response to target and rare nontarget stimuli produced a main effect of condition (see Table 3.1 of the Appendix). *Post hoc* analysis demonstrated a shorter latency of the rare nontarget than the target response collapsed across electrode sites (207msec vs 236msec - see Table 3.2 of the Appendix).

ANOVA of the mean amplitude failed to reveal a significant main effect of condition (see Table 3.6 of the Appendix). *Post hoc* analysis of the two way interaction involving the factors of condition and site revealed that the responses to stimuli, collapsed over electrode chain, evoked greatest amplitude at frontal sites.

Post hoc analysis of the two way interaction involving the factors of condition and chain demonstrated that, collapsed across electrode sites, rare nontarget stimuli evoked greater amplitude along the lateral chains than along the midline chain. Target stimuli evoked equipotential amplitude across all three chains.

500 - 850 Latency Range

ANOVA of the mean amplitude values in the latency range 500-850 msec produced a significant main effect of condition (see Table 3.7 of the Appendix). *Post hoc* analysis revealed that the frequent stimuli evoked a more positive response in comparison to that of the rare nontargets.

Post hoc analysis of the three way interaction involving the factors of condition, chain and site revealed that target stimuli evoked maximum mean amplitude at the parietal (Pz) electrode site along the midline chain. A temporo-parietal maximal mean amplitude deflection was obtained along the lateral chains. Rare nontarget stimuli revealed a centro-parietal maximal mean amplitude deflection along the midline chain. A more posterior deflection along the right chain was obtained, the parietal electrode (RP) evoking significantly greater amplitude than the frontal electrode (RF). Along the left chain mean amplitude was evoked equally at each electrode site. Frequent

stimuli revealed equipotential deflections across the scalp along all three chains.

3.5 Visual Modality

3.5.1 Method

Stimuli

Stimuli were adapted from Courchesne *et al.* (1975). Subjects were required to watch a sequence of 300 stimuli with an interstimulus interval of two seconds, presented upon a VDU approximately 90cm away.

Frequent and target stimuli consisted of either a "+" or "x" sign presented on a coloured orange square (see Figure 1 and 2 of the Appendix). Rare nontarget stimuli were a heterogeneous set of 45 abstract unrecognisable colourful square designs (see Figure 3 in Appendix). Visual stimuli subtended a visual angle of 2.2 degrees. Rare nontarget stimuli subtended the same visual angle as the frequent and target stimuli. All three stimulus types had a presentation duration of 300 msec. Target stimuli required a prompt motor response to be made, a button press using the right index finger. Target and frequent stimuli were alternated across subjects.

Procedure

As described in section 2.4 a practice block of 15 stimuli was presented. Following the block of practice trials the experimental run was presented. Subjects were informed that their task was the same as during the practice trials. They were also told that they would see "unrecognisable patches of colour" as well as the "x" and "+" signs but were to refrain from responding to them.

3.5.2 Results

Behavioural Performance

Mean reaction time to target stimuli was 509 msec with a standard deviation across subjects of 124 msec. The mean rate for correctly detected targets was 99.5% and the mean false positive rate was 1.1%.

ERP Data

A grand average waveform was produced (see Figure 3.1a). The waveform evoked by frequent stimuli was made up of an average of 170 trials (range 95-205). The target waveform from 36 trials (range 28-45) and the rare nontarget from 36 trials (range 19-45).

The N100 deflection was observed to be largest across frontal sites (see Figure 3.1a). The N200 evoked by target and rare nontarget stimuli was also largest at frontal sites. The positive deflection of the waveform evident at approximately 300 msec for both target and rare nontarget stimuli, the P300, appeared to be largest at parietal sites. Following this positive deflection a period of sustained positivity was observed at parietal sites which became progressively less positive over anterior scalp. A period of increased positivity in response to rare nontarget stimuli was observed at parietal sites following the resolution of the N200 and peak of the P300 deflection.

Table 3.15.1 and 3.15.2 of the Appendix show the mean amplitude and the mean rescaled amplitude elicited by visual experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain.

P300 Deflection

ANOVA of the peak latencies of the target and rare nontarget responses failed to produce a significant main effect (see Table 3.1 and 3.2 of the Appendix - rare nontarget response 338msec vs target response 367msec collapsed across the midline sites).

ANOVA of the mean amplitude failed to produce a main effect of condition (see Table 3.9). *Post hoc* analysis of the significant three way interaction involving the factors of condition, chain and site revealed that the target response evoked the largest P300 deflection at the parietal (Pz) electrode along the midline chain. Along the lateral chains amplitude was largest across temporo-parietal sites. Rare nontarget stimuli evoked the largest P300 deflection at centro/temporo-parietal sites along all three chains.

Table 3.9 ANOVA summary table for analysis of P300 amplitude elicited by visual target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	4.798	0.061	123.826
Chain CH	1.6,16.3	6.886	0.009*	19.384
Site ST	1.2,11.6	51.094	0.000*	49.378
Interactions				
CC X CH	1.5,15.4	4.555	0.036*	21.551
CC X ST	1.4,13.7	0.754	0.439	18.792
CH X ST	2.6,25.7	7.997	0.001*	4.611
CC X CH X ST	2.7,26.6	4.784	0.011*	4.216

Table 3.10 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of visual target and rare nontarget stimuli.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	2.9,23.1	0.930	0.437	358.669
Site ST	1.2,9.4	6.156	0.010*	164.030
Interactions				
TR X ST	3.8,30.3	1.698	0.179	42.154
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	4,32.1	0.815	0.524	283.491
Site ST	1.5,12.1	61.368	0.000*	86.873
Interactions				
TR X ST	3.8,30.8	1.750	0.167	45.167

* denotes a p value statistically significant at the 0.05 %

Single Trial Analysis

Target Stimuli No main effect of trial was found to be significant (see Table 3.10). A main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked by target stimuli across sites, collapsed across trials, was significantly greater at both Cz and Pz in comparison to the amplitude obtained at Fz. However, no significant difference was obtained between the amplitude obtained at the Pz and Cz sites. A significant two way interaction involving the factors of trial and site was not obtained.

Rare Nontarget Stimuli No main effect of trial was found to be significant (see Table 3.10). A main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked by rare nontarget stimuli across sites, collapsed across trials, was greater at Pz in comparison to both Fz and Cz sites, similarly amplitude at Cz was significant greater than that at Fz. The two way interaction involving the factors of trial and site did not prove to be significant.

N100 Deflection

ANOVA of the latency of responses evoked by the three classes of stimuli failed to produce a significant main effect or interaction (see Table 3.1 of the Appendix).

ANOVA of the mean amplitude of the three deflections failed to reveal a significant main effect of experimental condition (see Table 3.11 of the Appendix). *Post hoc* analysis of the two way interaction involving the factors of chain and site demonstrated that N100 amplitude, collapsed over experimental condition, was largest at fronto-central sites along the lateral chains. Amplitude was distributed equipotentially along the sites of the midline chain.

N200 Deflection

ANOVA of the N200 peak latencies of the target and rare nontarget responses failed to produce a significant main effect or interaction (see Table 3.1 of the Appendix).

ANOVA of the mean amplitude evoked by target and rare nontarget stimuli failed to produce a significant main effect of condition (see Table 3.12 of the

Appendix). *Post hoc* analysis of the chain main effect revealed that the left chain evoked significantly greater amplitude than the right.

Analysis of the two way interaction involving the factors of condition and site demonstrated that, collapsed across electrode chain, target stimuli evoked a greater deflection of amplitude across the frontal sites. Analysis of the amplitude evoked by rare nontarget stimuli demonstrated that equipotential amplitude was evoked across the three sites, collapsed across electrode chains.

500 - 850 Latency Range

ANOVA of the mean amplitude produced a three way interaction involving the factors of condition, chain and site (see Table 3.13 of the Appendix). *Post hoc* analysis revealed that target stimuli evoked the largest amplitude at centro/temporo-parietal sites along the three chains of electrodes. Frequent and rare nontarget responses were of equal amplitude at each of the sites along the electrode chains.

150 - 350 msec Latency Range at Lateral Parietal Sites

ANOVA of mean amplitude in the 150-350 msec latency range produced a main effect of condition (see Table 3.14 of the Appendix). *Post hoc* analysis demonstrated that rare nontarget stimuli evoked greater (more positive) amplitude than either the frequent or target stimuli.

3.6 Comparison of Rescaled Amplitude Between Modalities

The scalp distributions of the three deflections (N100, N200, P300) and the mean amplitude evoked within the latency range 500 - 850 msec were contrasted by ANOVA of their rescaled mean amplitudes.

Behavioural Data

A t-test of the mean reaction times to target stimuli between modalities revealed a significant effect ($t(10) = 2.49, p = 0.035$). Examination of the mean reaction times revealed that the response to visual target stimuli was significantly earlier than that to auditory target stimuli (509msec v 555msec). The mean rate for correctly detected stimuli was at ceiling level within both

Figure 3.2a

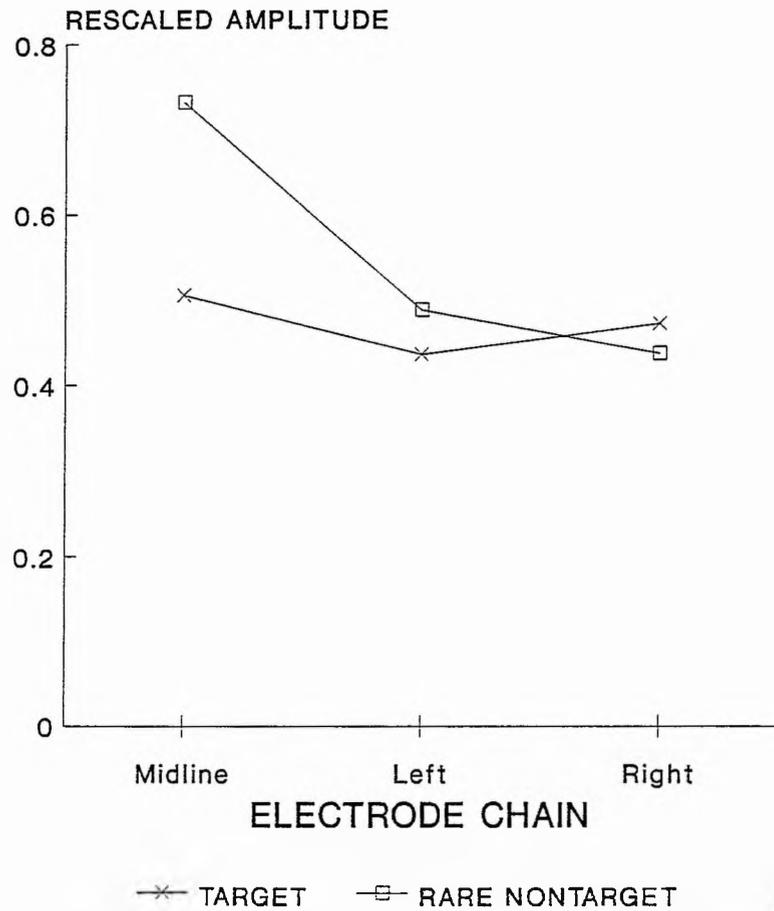


Figure 3.2b

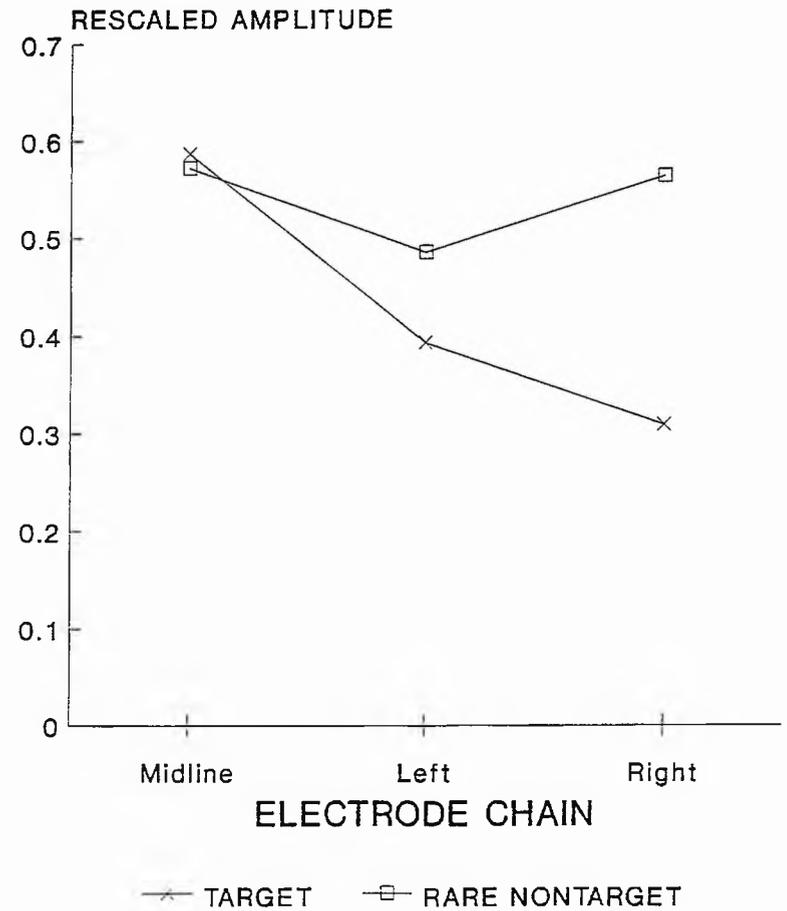


Figure 3.2a and 3.2b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by auditory (Figure 3.2a) and visual (Figure 3.2b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode site).

Figure 3.3a

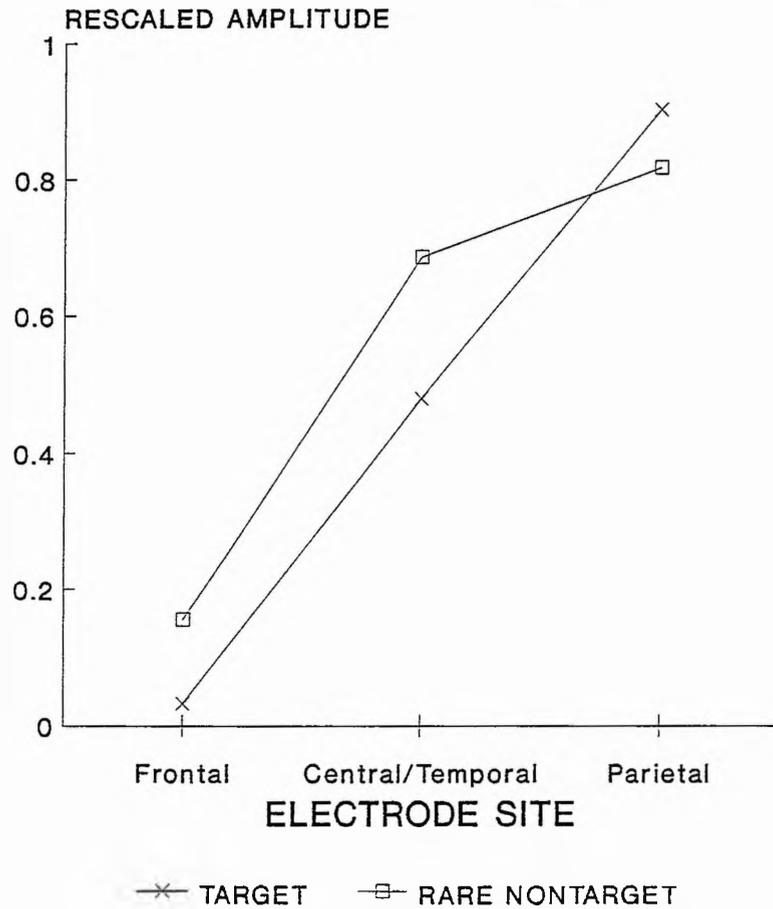


Figure 3.3b

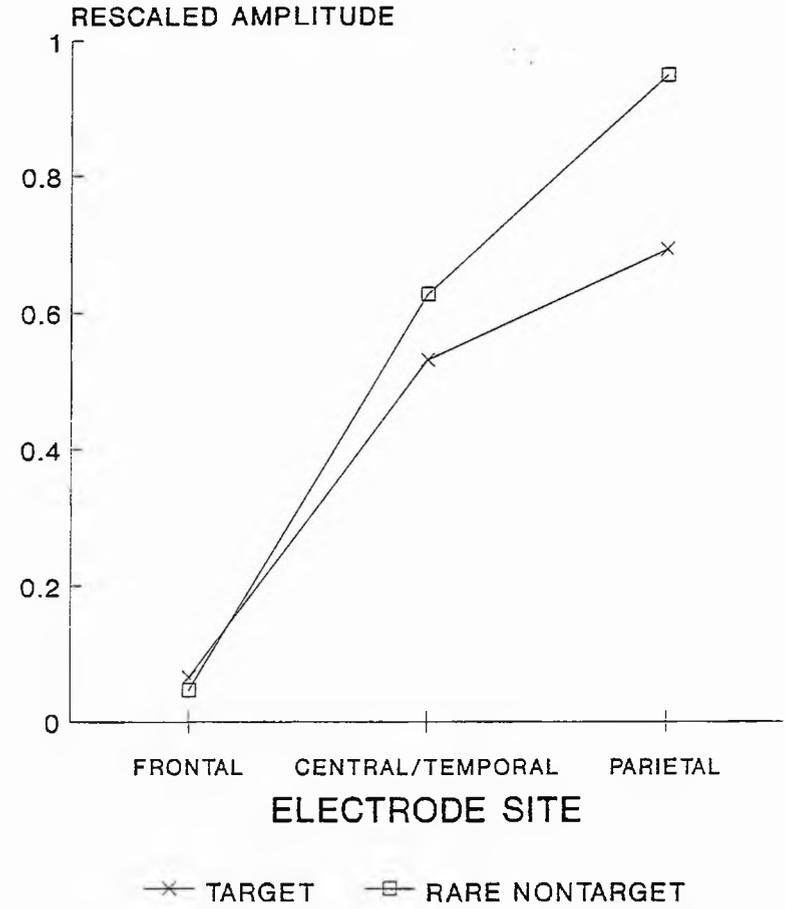


Figure 3.3a and 3.3b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by auditory (Figure 3.3a) and visual (Figure 3.3b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

modalities. Similarly the mean false positive rate was at floor within both modalities, therefore, further analysis was not carried out upon these results.

P300 Deflection

A significant three way interaction involving the factors of modality, condition and chain was obtained (see Table 3.16). *Post hoc* analysis demonstrated that the auditory target response was distributed equipotentially along the electrode chains (see Figure 3.2a). The auditory rare nontarget response was distributed maximally along the midline chain. Visual target stimuli evoked maximum amplitude distributed along the midline chain. The visual rare nontarget response was distributed equally across the three chains (see Figure 3.2b).

Post hoc analysis of the three way interaction involving the factors of modality, condition and site revealed that auditory target stimuli evoked maximal amplitude at parietal sites. Auditory rare nontarget stimuli evoked maximum distribution at centro/temporo-parietal sites (see Figure 3.3b). Visual target stimuli demonstrated a centro/temporo-parietal maximum. Visual rare nontarget stimuli demonstrated a parietal site maximum distribution (see Figure 3.3a).

Post hoc analysis of the three way interaction involving the factors of condition, chain and site demonstrated that in response to both target and rare nontarget stimuli a centro-parietal maximal amplitude distribution was obtained.

To examine the distribution of the responses to target and rare nontarget responses across electrode chains subsidiary ANOVAs were performed on the rescaled amplitude data from the auditory and visual modalities separately.

Auditory P300 Scalp Distribution A three way interaction involving the factors of condition, chain and site was obtained (see Table 3.17). Rare nontarget stimuli demonstrated a centro/temporo-parietal distribution along the three chains (see Figure 3.4a). The deflection evoked in response to target stimuli demonstrated a parietal site maximum amplitude distribution along all three chains (see Figure 3.4b).

Visual P300 Scalp Distribution A significant three way interaction involving the factors of condition, chain and site was obtained (see Table 3.17). *Post hoc* analysis demonstrated that rare nontarget stimuli demonstrated a

Table 3.16 ANOVA summary table for the analysis of P300 rescaled amplitude elicited by target and rare nontarget stimuli within the visual and auditory modalities.

Rescaled Amplitude	df	F	p	mse
Main Effects				
Modality MD	1,20	0.046	0.832	1.479
Condition CC	1,20	2.324	0.144	0.391
Chain CH	1.6,31.5	12.905	0.000*	0.077
Site ST	1.2,24.7	85.683	0.000*	0.234
Interactions				
MD X CC	1,20	0.054	0.818	0.391
MD X CH	1.6,31.5	0.050	0.917	0.077
MD X ST	1.2,24.7	0.059	0.858	0.234
CC X CH	1.6,32.3	0.263	0.722	0.054
CC X ST	1.4,27	1.376	0.263	0.061
CH X ST	2.9,57.6	8.873	0.000*	0.015
MD X CC X CH	1.6,32.3	10.796	0.001*	0.054
MD X CC X ST	1.4,27	9.767	0.002*	0.061
MD X CH X ST	2.9,57.6	1.846	0.152	0.015
CC X CH X ST	2.8,55.1	6.647	0.001*	0.010
MD X CC X CH X ST	2.8,55.1	1.299	0.285	0.010

Table 3.17 ANOVA summary table for analysis of P300 rescaled amplitude elicited within the auditory modality and within the visual modality.

Auditory Rescaled Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	1.32	0.277	0.246
Chain CH	1.5,14.6	7.34	0.010*	0.076
Site ST	1.3,12.9	36.36	0.000*	0.274
Interactions				
CC X CH	1.9,19.2	13.77	0.000*	0.021
CC X ST	1.3,13.2	7.68	0.011*	0.048
CH X ST	2.4,24.3	2.61	0.085	0.012
CC X CH X ST	1.9,18.9	4.24	0.032*	0.005
Visual Rescaled Amplitude				
Main Effects				
Condition CC	1,10	1.12	0.315	0.537
Chain CH	1.6,15.9	5.63	0.019*	0.078
Site ST	1.2,11.6	52.08	0.000*	0.193
Interactions				
CC X CH	1.5,15.2	3.49	0.067	0.086
CC X ST	1.4,13.7	4.19	0.050*	0.074
CH X ST	2.5,25.3	7.40	0.002*	0.017
CC X CH X ST	2.6,26.2	3.88	0.024*	0.015

* denotes a p value statistically significant at the 0.05 % level or greater.

Figure 3.4a

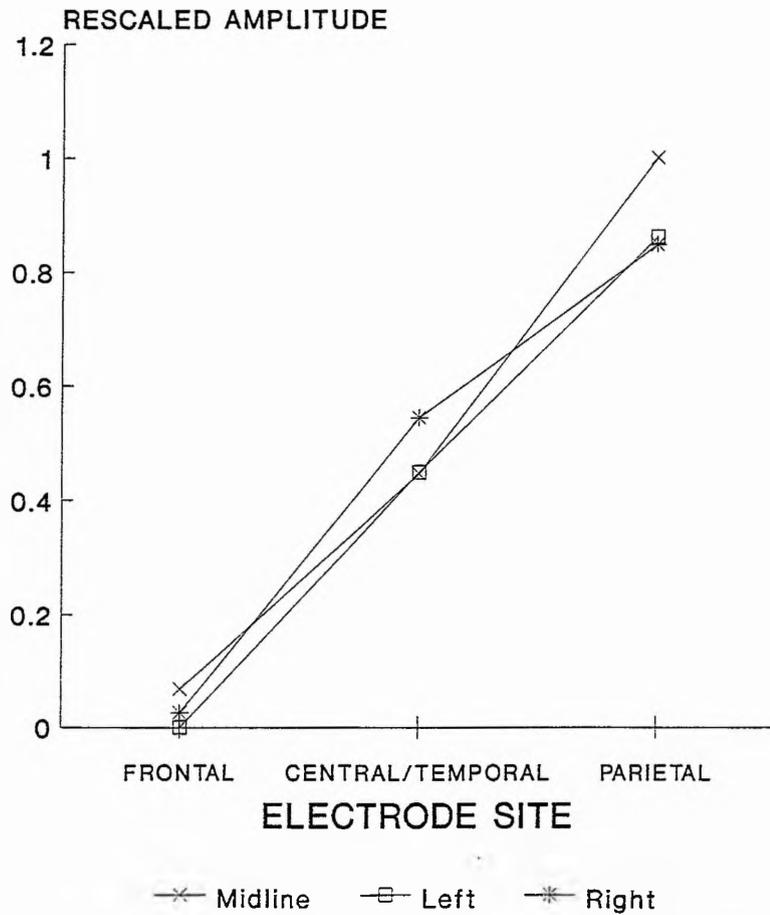


Figure 3.4b

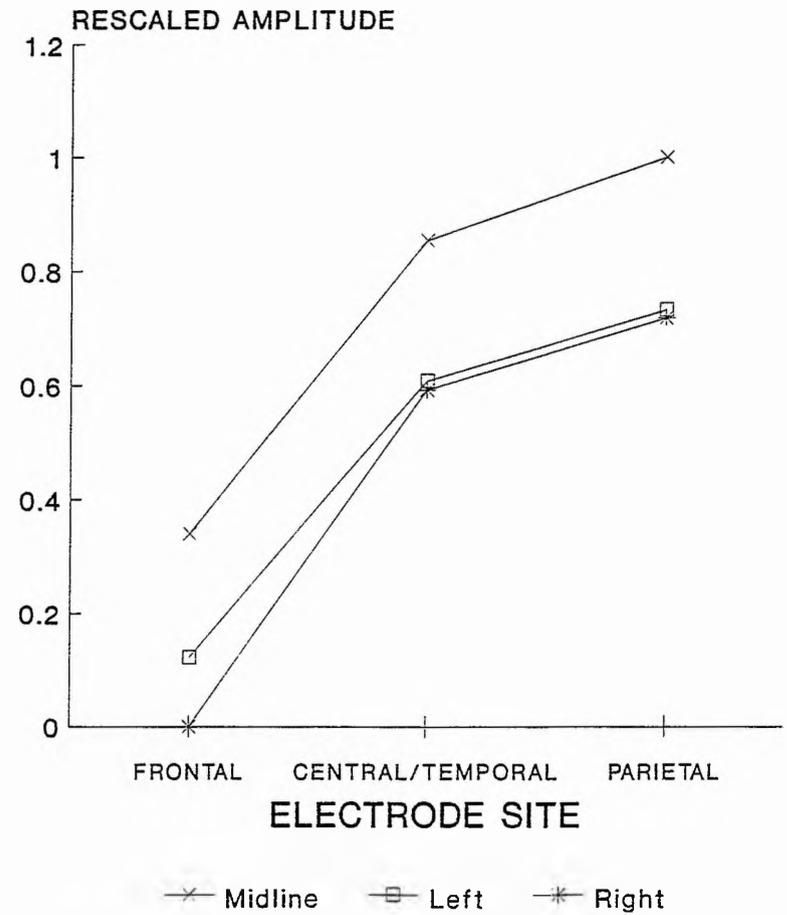


Figure 3.4a and 3.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by auditory target (Figure 3.4a) and rare nontarget stimuli (Figure 3.4b) in Experiment 1.

centro/temporo-parietal distribution along the three chains (see Figure 3.5b). Similarly target stimuli demonstrated a centro/temporo-parietal distribution along all three electrode chains (see Figure 3.5a).

N100 Deflection

A significant three way interaction involving the factors of modality, condition and site was obtained (see Table 3.18 of the Appendix). *Post hoc* analysis demonstrated that the auditory frequent stimuli response was equipotential across the scalp. The target stimuli response demonstrated a fronto-central/temporal maximum distribution, while rare nontarget stimuli evoked a central/temporal scalp maximum distribution (see Figure 3.6a). Visual frequent, target and rare nontarget stimuli responses demonstrated a fronto-central/temporal scalp distribution (see Figure 3.6b).

N200 Deflection

A significant four way interaction involving the factors of modality, condition, chain and site was obtained (see Table 3.19 of the Appendix). *Post hoc* analysis demonstrated that the auditory target stimuli response demonstrated a frontal site maximum distribution along the midline chain. Along the lateral chains greater amplitude was distributed at the frontal than at the parietal sites (see Figure 3.7a). The rare nontarget stimuli response demonstrated that amplitude was distributed at anterior sites along all three chains (greater amplitude was evoked at frontal sites than at either the central/temporal or parietal sites - see Figure 3.7b).

The visual target stimuli response was distributed equipotentially across the scalp along all three chains (see Figure 3.8a). The visual rare nontarget stimuli response demonstrated that amplitude was distributed at anterior sites along all three chains (the amplitude evoked at frontal sites was greater than that evoked at parietal sites - see Figure 3.8b).

500 - 850msec Latency Range

A significant three way interaction involving the factors of modality, condition and site was obtained (see Table 3.20 of the Appendix). *Post hoc* analysis revealed that amplitude evoked in response to the three classes of auditory stimuli demonstrated a centro/temporo-parietal amplitude distribution

Figure 3.5a

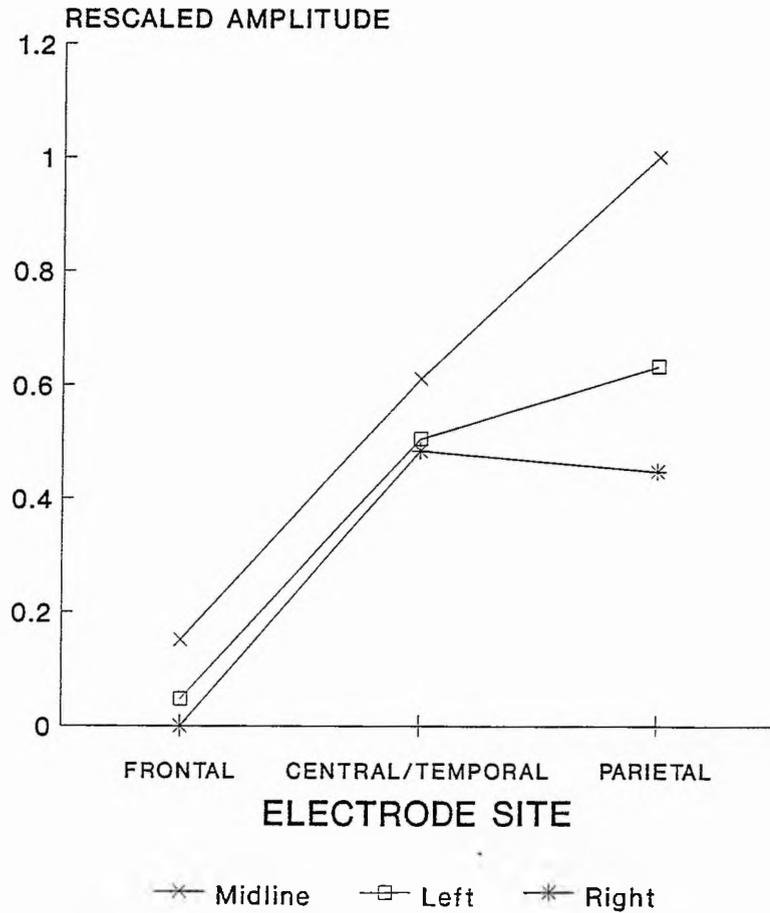


Figure 3.5b

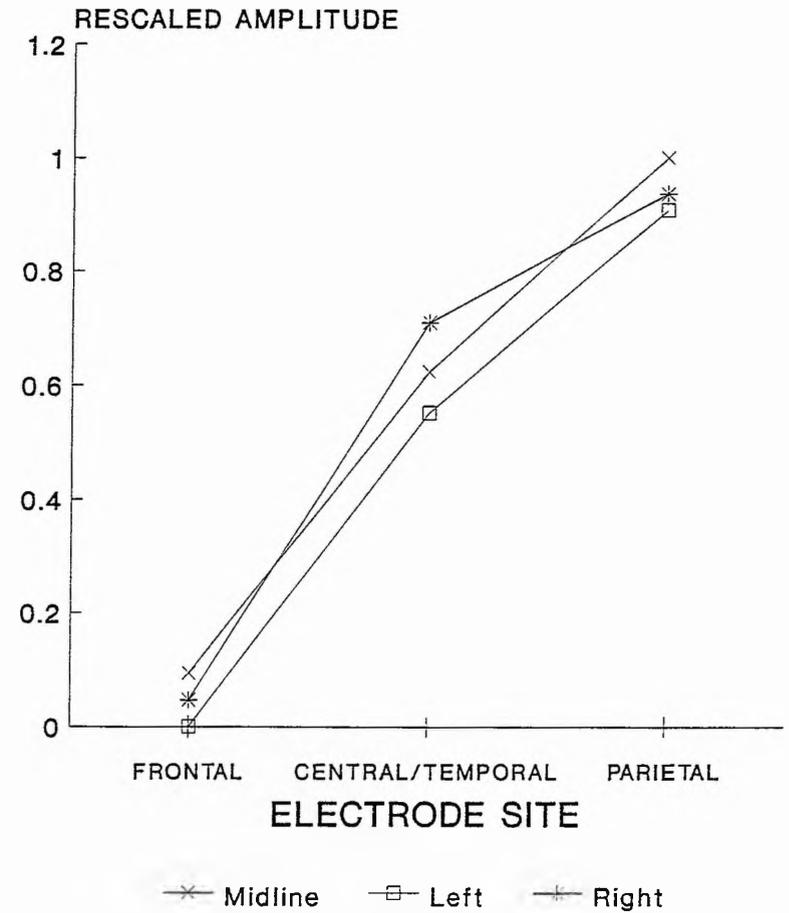


Figure 3.5a and 3.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by visual target (Figure 3b.5a) and rare nontarget stimuli (Figure 3.5b) in Experiment 1.

Figure 3.4a

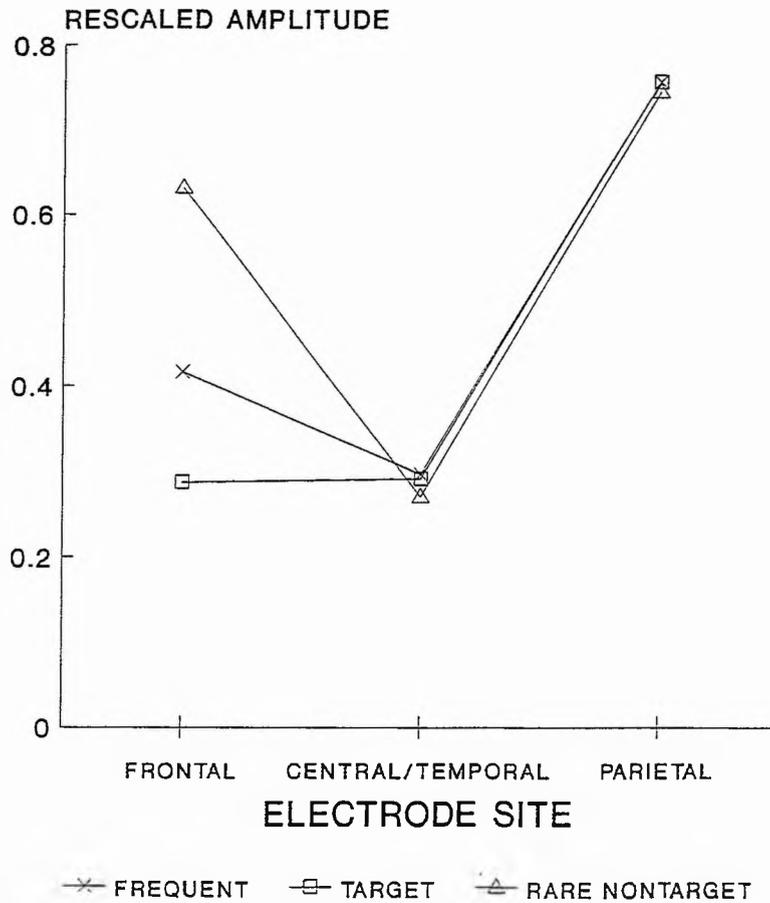


Figure 3.6b

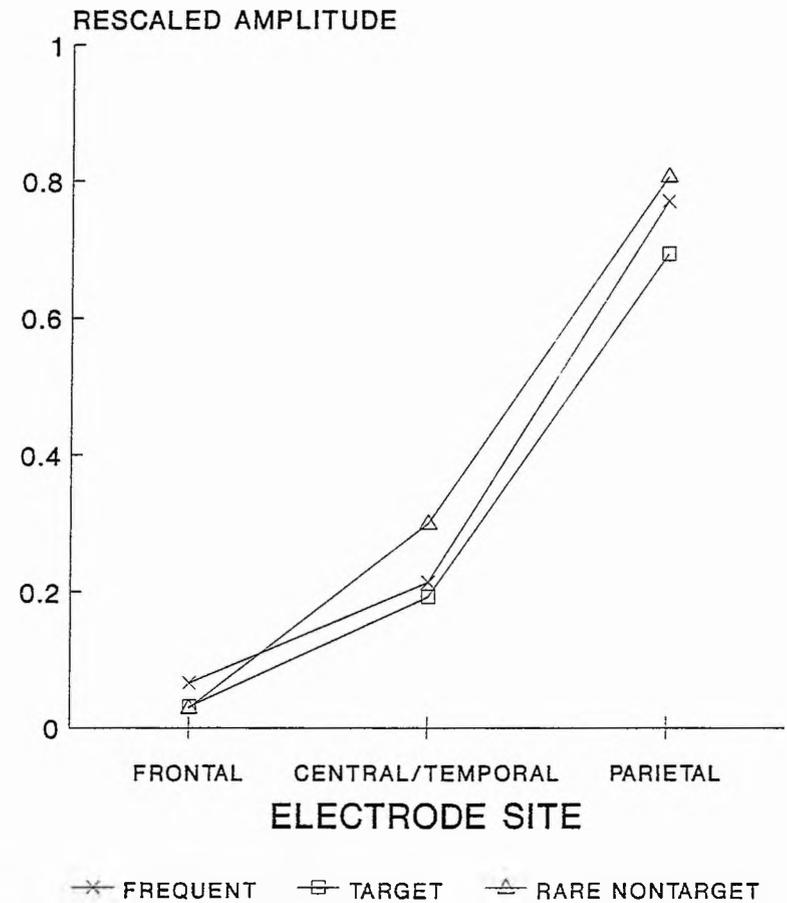
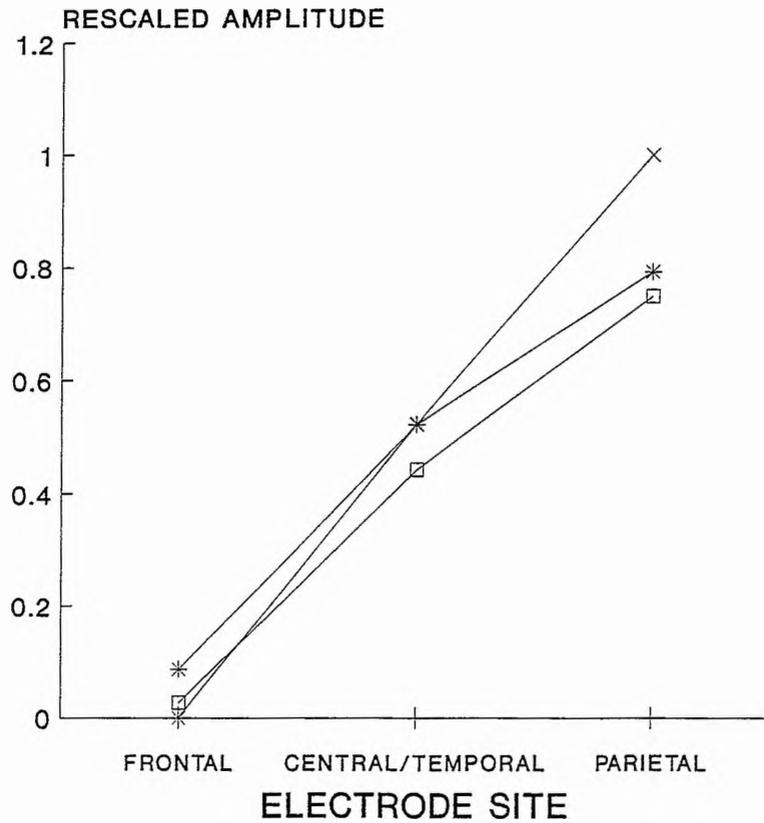


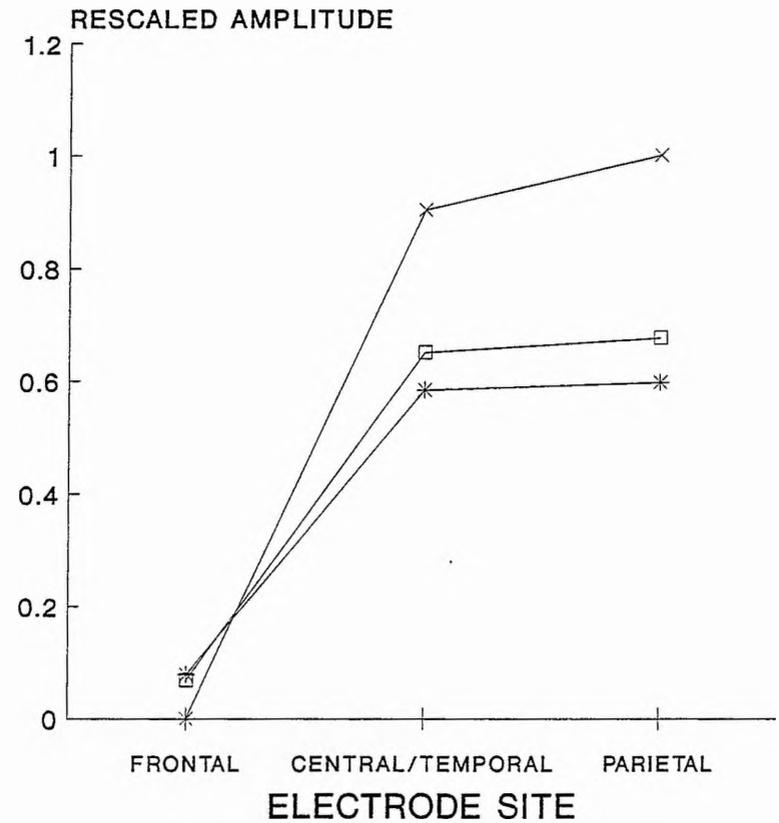
Figure 3.6a and 3.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by auditory (Figure 3.6a) and visual (Figure 3.6b) target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

Figure 3.7a



—x— Midline —□— Left —*— Right

Figure 3.7b



—x— Midline —□— Left —*— Right

Figure 3.7a and 3.7b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory target (Figure 3.7a) and rare nontarget (Figure 3.7b) stimuli in Experiment 1

Figure 3.8a

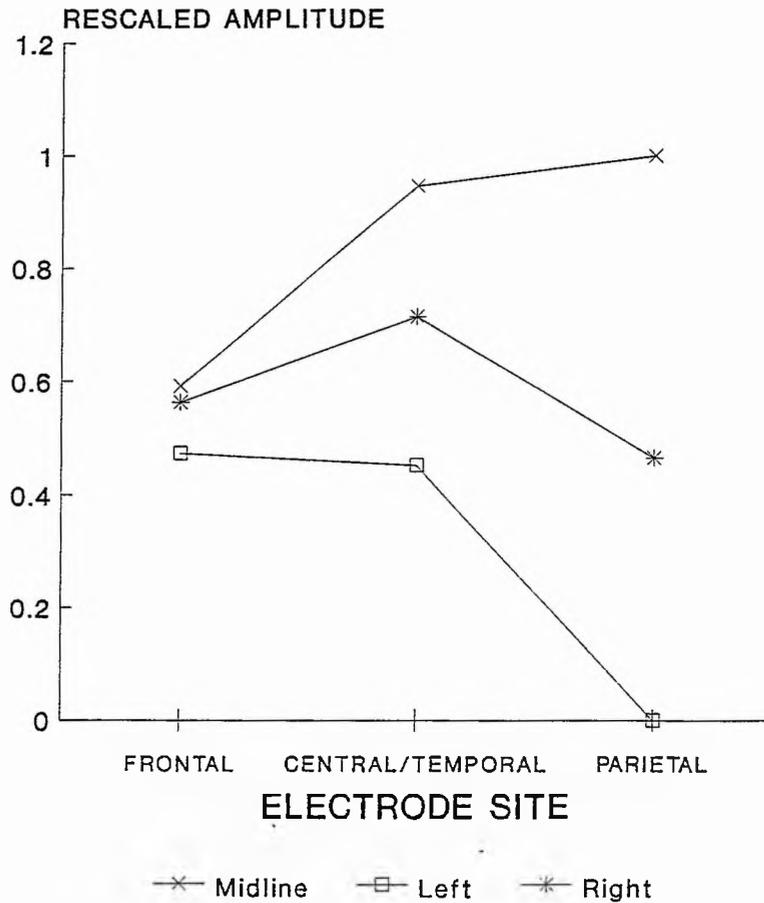


Figure 3.8b

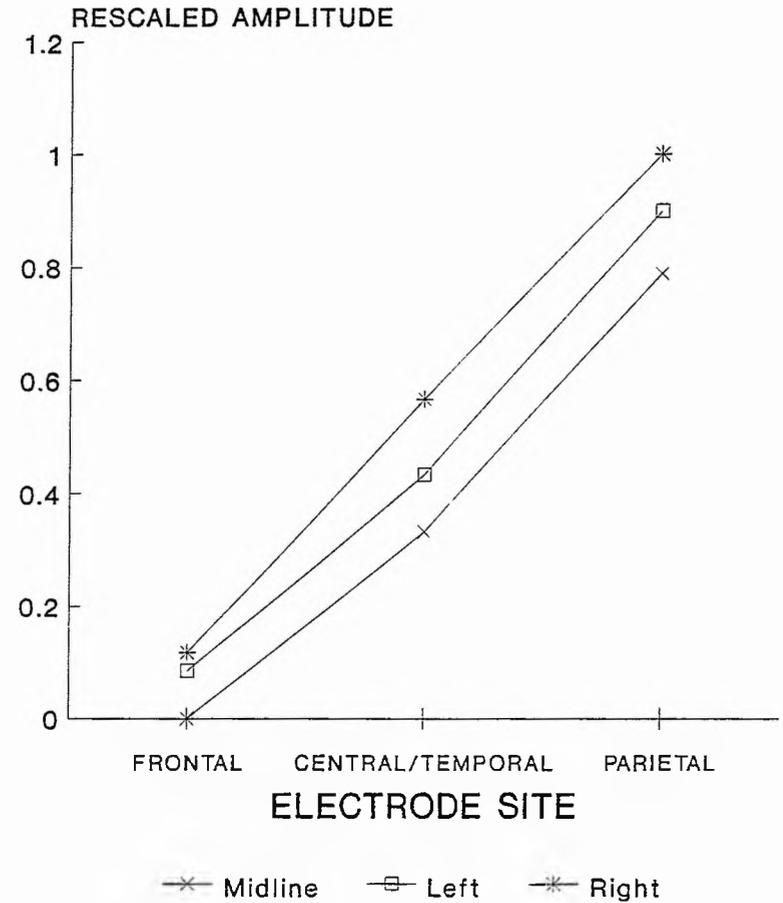


Figure 3.8a and 3.8b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by visual target (Figure 3.8a) and rare nontarget (Figure 3.8b) stimuli in Experiment 1

(rescaled amplitude collapsed across chains - see Figure 3.9a). The visual frequent stimuli response demonstrated a frontal-central/temporal distribution. The visual target and rare nontarget stimuli responses demonstrated an equipotential distribution across the scalp (rescaled amplitude collapsed across chain - see Figure 3.9b).

3.7 Discussion

The aim of this Experiment was to dissociate the P300 responses to target and rare nontarget stimuli within the auditory and visual modalities on the basis of scalp amplitude distribution. For the purposes of clarity the results from each modality will be discussed separately.

3.7.1 Auditory Modality

Both classes of rare stimuli employed within the auditory oddball task elicited a positive deflection in the ERP waveform in the P300 latency range (250-450 msec). Stimuli with a random presentation and a low subjective probability of occurrence have previously been reported to elicit such a P300 deflection. As reported by Fabiani *et al.* (1987) P300 amplitude increases as the probability of the eliciting event decreases (probability effect). Events that require a response elicit larger amplitude P300 deflections than other events (target effect). As previously described (see section 1.2.3), employing a three stimulus oddball paradigm partially disentangles the target effect from the probability effect. Within such a paradigm it is possible to compare the ERPs to rare targets with those of rare nontargets. The probability effect is assumed to be constant across both classes of stimuli since both classes of rare stimuli had probabilities of occurrence of 15% in comparison to a probability of occurrence of 70% for the frequent stimuli.

The P300 response elicited by the rare nontarget stimuli was distributed maximally across centro/temporo-parietal sites along all three chains. Rescaled amplitude evoked in response to target stimuli elicited a P300 deflection with a maximum amplitude distribution at parietal sites. Such a dissociation of P300 deflections supports previous reports of a dissociation of the responses to target and rare nontarget stimuli on the basis of scalp amplitude distribution by Knight (1984; 1990), Knight *et al.* (1989) and Holdstock and Rugg (1993).

The P300 deflection evoked in response to rare nontarget stimuli was considered to be the P3a component of the P300 complex reported by previous researchers (Squires *et al.* 1975). The P300 deflection evoked in response to

Figure 3.9a

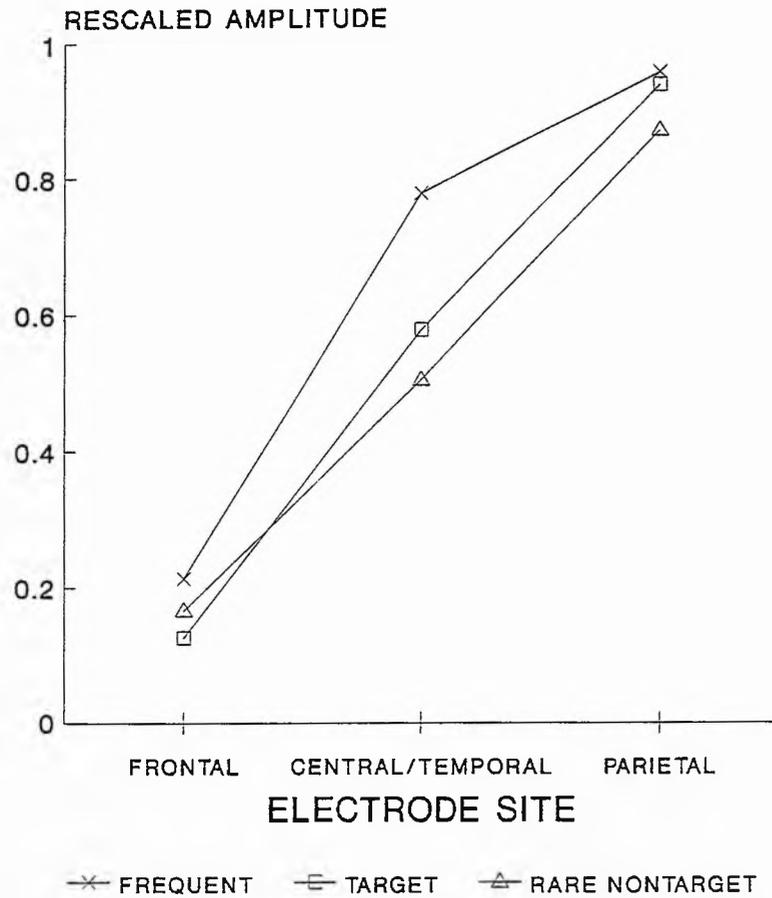


Figure 3.9b

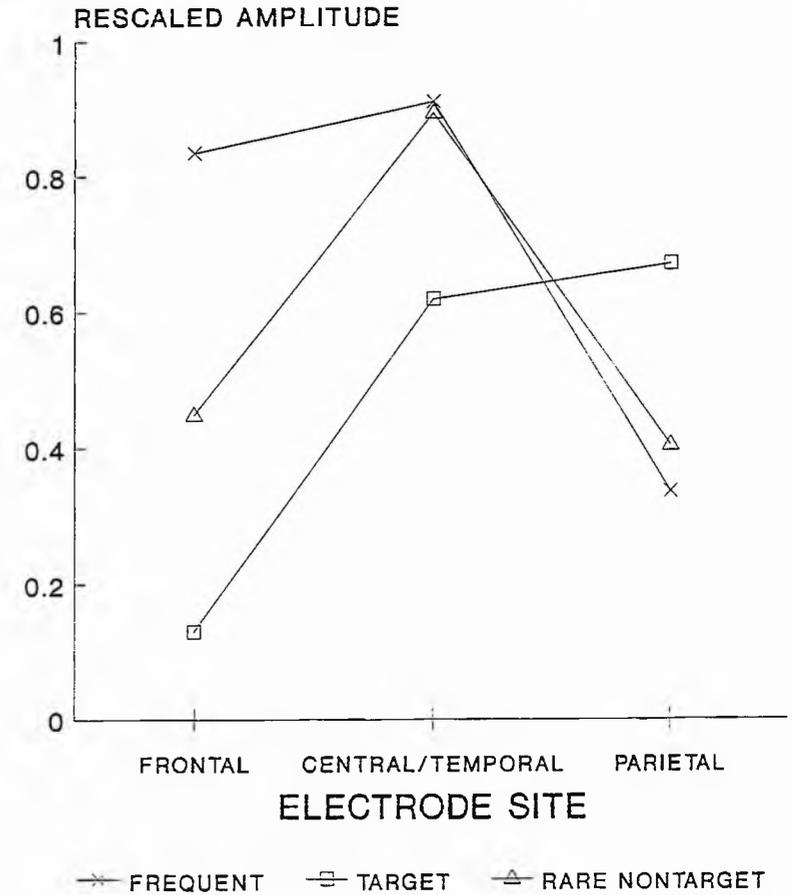


Figure 3.9a and 3.9b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range of 500 -850 msec elicited by auditory (Figure 3.9a) and visual (Figure 3.9b) frequent, target and rare nontarget stimuli in Experiment 1 (collapsed over electrode chain).

target stimuli was considered to be the P3b component. Previous studies have reported that the deflection evoked in response to rare nontarget stimuli, the P3a component, has a fronto-central/temporal distribution rather than the centro/temporo-parietal distribution reported here (Knight 1984; 1990; Knight *et al.* 1989;). However, Holdstock and Rugg (1993) have also reported a centro/temporo-parietal scalp distribution for the P3a component. Yamaguchi and Knight (1991a) have similarly reported a vertex electrode site maximum in response to rare nontarget stimuli in the somatosensory modality.

The difference in the distribution of the amplitude evoked by the two classes of rare stimuli supports the notion that the responses to target and rare nontarget stimuli may be modulated by different underlying neural processes or generators. There is, however, a second explanation for the difference in scalp distribution of the P3a and P3b components. This is that the same generators may be activated by target and rare nontarget stimuli but to different extents. The interpretation of such distributional data is problematic. It is possible that the same neural process, or combination of processes, is generating both responses but the amplitude distribution across the scalp is differentially affected by other components of the waveform. For instance, the amplitude of the response to rare nontarget stimuli may be decreased at parietal scalp by the overlap of a negative component of the waveform. The scalp distribution of the rare nontarget response would, therefore, appear to be more anterior than the posterior distribution observed in response to target stimuli. Similarly the response to target stimuli may demonstrate a posterior maximal amplitude distribution since this response may be affected by the overlap with a period of increased late positivity that does not affect the rare nontarget response to the same extent. The N200 deflections demonstrated an anterior scalp maximum distribution for both classes of rare stimuli. Similarly rescaled amplitude in the 500-850 msec latency range demonstrated the same scalp distribution for both classes of rare stimuli. The amplitude distribution difference observed in response to rare stimuli within the P300 latency range would, therefore, appear to be unaffected by deflections that border this deflection and hence are specific to that particular deflection. The contribution of, at least partially, different neural processes or generators would appear to be responsible for the P300 responses evoked to rare stimuli.

Single trial analysis demonstrated that analysis of amplitude across the three midline sites over the first 10 presentations of both target and rare nontarget stimuli did not change as a function of trial presentation. Target stimuli demonstrated greater amplitude at Pz in comparison to both Fz and Cz sites.

Rare nontarget stimuli demonstrated greater amplitude at Cz and Pz sites in comparison to the Fz site. Such findings are consistent with the results obtained from ANOVA carried out upon averaged target and rare nontarget responses. Knight (1984) however, reported a 27% decrease in amplitude from the first to the fifth rare nontarget stimulus presentation. No results examining the target response over a number of single trials were presented.

Stimuli with a low subjective probability of occurrence that are designated as "target" stimuli are thought to evoke a parietally maximum P300 deflection due to the output of a particular generator. The second class of rare stimuli, those that require no active behavioural processing, elicit a P300 deflection with a more anterior scalp distribution. This more anterior amplitude distribution may be the result of a second generator with a more frontal distribution. Such a formulation is supported by lesion studies that report a reduction of amplitude evoked in response to rare nontarget stimuli following frontal lobe damage (Knight 1984, see section 1.4.2.4). The neural generator that evokes the P300 deflection to target stimuli may contribute to the response to rare nontarget stimuli. Such a contribution may explain the different amplitude distribution reported here and previously by Holdstock and Rugg (1993) in comparison to other investigators who report a more anterior distribution in response to rare nontarget stimuli. The underlying generator responsible for detecting target stimuli may be contributing more amplitude across posterior scalp in response to rare nontarget stimuli than was the case in previous studies.

The response to rare nontarget stimuli was elicited significantly earlier than that of the response to target stimuli. Given the intrusive nature of the auditory rare nontarget stimuli less evaluation of the stimulus to determine if a behavioural response is required may account for the earlier elicitation of the P3a component of the ERP waveform. Such a formulation is supported by the fact that rare nontarget stimuli elicited a shorter latency for the N200 component than that demonstrated by the target stimuli.

The earlier deflection of the waveform in response to rare nontarget stimuli was not evident for all deflections of the waveform. The N100 deflection demonstrated no difference in the latency of responses evoked in response to frequent, target and rare nontarget stimuli.

Mean amplitude evoked within the N100 latency range did not prove to be significantly different between the three classes of stimuli. However, Näätänen and Picton (1987) have proposed that the N100 generating neurons become refractory upon repeated presentations of the same stimulus, at least for the

first N100 component. The amplitude of this component would it is postulated be determined by the physical properties of the stimulus and the timing and physical properties of the previous stimuli. Such factors would determine the refractoriness of the N100 neurons. If two identical stimuli are presented sequentially a smaller N100 deflection would be evoked in response to the second stimulus in comparison to the deflection evoked in response to the first stimulus. It is postulated that the second stimulus would be modulated by neurons which are refractory.

As described in section 1.5.4, the formation of an attentional trace is a crucial aspect of the attentional trace theory of auditory attention proposed by Näätänen (1982; 1990; 1992). Incorporated within this theory is the assumption that infrequent stimuli will evoke large deflections within the N100 latency range such stimuli will act upon neurons which are less refractory. As described the present results fail to support such a formulation. Rare nontarget stimuli across the frontal sites evoked significantly less mean amplitude than either frequent or target stimuli. A possible explanation of why there was no significant difference in the N100 amplitude evoked by the three classes of stimuli is that frequent and target deflections were modulated by other components. The generator neurons of these components may not become refractory upon repeated presentations of the stimulus, such components may overlap the N100 component thereby altering the observed amplitude .

N100 amplitude, collapsed across the chains of electrodes, demonstrated that the response to frequent stimuli was distributed equipotentially across the scalp. The response to target stimuli demonstrated a fronto-central/temporal distribution. Rare nontarget stimuli demonstrated a maximal scalp distribution at central/temporal sites. Such a difference between amplitude distribution suggests that the deflections elicited by the three classes of stimuli are evoked by different generators or rather a different combination of underlying neural generators. The difference in distribution of the N100 response elicited by frequent and target tones suggests that task characteristics may affect the distribution of such responses since the tones employed as target and frequent stimuli were alternated across subjects. The result obtained in response to rare nontarget stimuli may represent either task or stimulus characteristics. It is possible that the more posterior activity of the N100 response to rare nontarget stimuli may have been the result of an overlap with a frontal positivity.

Both target and rare nontarget stimuli elicited anterior scalp amplitude distributions within the N200 latency range. Rugg *et al.* (1988) claimed that it was possible to dissociate target and rare nontarget stimuli on the basis of scalp

amplitude distribution. He claimed that target stimuli elicited a frontally distributed "N2b" component while rare nontarget stimuli elicited a more posterior centro-frontal "N2a" (MMN) component within the auditory modality. However, within the present experiment it was not possible to determine the relative contribution of N2b and N2a/MMN components to the overall N200 deflection since within such an active oddball paradigm it is likely that both components are elicited and hence the deflection recorded is likely to be a composite of the two components. On the grounds of caution it is, therefore, not advisable to attempt to dissociate the response to target and rare nontarget N200 responses on the basis of scalp amplitude distribution.

The mean amplitude elicited within a latency window of 500-850 msec demonstrated that target stimuli elicited a more positive deflection at parietal sites in comparison to both rare nontarget and frequent stimuli. Rare nontarget stimuli elicited greatest mean amplitude at centro-parietal sites along the midline chain. Frequent stimuli evoked equal mean amplitude at each site. Such results are consistent with reports of slow wave activity overlapping and following P300 activity (Ruchkin *et al.* 1988). Squires *et al.* (1975) were the first to demonstrate that slow wave activity could be dissociated from other components of the P300 complex. It was demonstrated that low probability attended auditory stimuli elicited a response which was positive at Pz, of zero amplitude at Cz and negative at Fz.

The three classes of auditory stimuli all demonstrated a centro/temporo-parietal amplitude distribution (rescaled amplitude collapsed across chains). Such a result demonstrated that while the same underlying combination of generators process the three classes of auditory stimuli the output of the combination of generators is different in response to the stimuli. As described target stimuli evoked greater output from posterior generators in comparison to more frontally located generators. Rare nontarget stimuli elicited a response with a more anterior combination of generators while frequent stimuli elicited a yet greater anterior response.

3.7.2 Visual Modality

Both categories of rare stimuli elicited a positive deflection in the P300 latency range (250-450 msec). As in the auditory modality, this observation supports previous reports that the P300 response is elicited by stimuli with low subjective probability.

The results of the visual paradigm did not support previous accounts of a dissociation of responses of target and rare nontarget stimuli on the basis of scalp amplitude distribution (Courchesne *et al.* 1975; 1978). The colourful abstract designs employed as rare nontarget stimuli were presented randomly within a sequence of frequent nontarget and rare target stimuli. Such stimuli elicited a centro/temporo-parietal maximum amplitude distribution along all three chains. Similarly, target stimuli elicited a response that demonstrated a centro/temporo-parietal distribution along all three chains.

Courchesne *et al.* (1975) reports that P300 waves elicited by task-relevant (target) stimuli were largest over the parietal scalp. Task-irrelevant, unrecognisable, (rare nontarget) novel stimuli elicited P300 waves that were largest over centro-frontal scalp. He argued that the anterior distribution to the novel stimuli was not simply a response to the physical complexity of the stimulus, but was instead dependent upon the stimulus being unrecognisable and unpredictable in its time of delivery. Further work by Courchesne *et al.* (1978) demonstrated that not every type of novel deviant stimulus elicited an anterior scalp P300 wave. Deviant stimuli that were easily recognisable (the "simples") elicited P300 waves with the same scalp distribution as the P300 waves to target stimuli, *i.e.* a scalp distribution with a posterior maximum.

Such a difference between the scalp amplitude distribution obtained in response to target and rare nontarget within the present experiment and that reported by Courchesne *et al.* (1975; 1978) is difficult to account for. Courchesne *et al.* (1975;1978) obtained a dissociation of responses on the basis of amplitude distribution. They also reported a more anterior distribution in response to novel (rare nontarget) stimuli.

Single trial analysis demonstrated that analysis of amplitude across the three midline sites over the first 10 presentations of both target and rare nontarget stimuli did not change as a function of trial presentation. Target stimuli demonstrated a greater amplitude at both Cz and Pz sites in comparison to the Fz site. Rare nontarget stimuli demonstrated greater amplitude at the Pz site in comparison to the Fz and Cz sites. Such results are consistent with the results obtained from the ANOVAs performed upon the averaged target and rare nontarget responses. Similarly Courchesne *et al.* (1978) reported no significant amplitude changes for target responses across the first 16 presentations of the target stimuli at Fz, Cz or Pz. However, in response to rare nontarget stimuli P300 amplitude at Fz decreased by 42% across the first 16 presentations, while at Pz amplitude increased by 42% between presentations 5 to 8 as compared to 1 to 4. Courchesne *et al.* (1978) therefore obtained decreasing activity

frontally but increasing activity over parietal scalp. No such alteration of amplitude at either Fz or Pz sites was obtained in the present Experiment employing similar stimulus parameters.

Courchesne *et al.* (1978) reported that a major factor affecting P300 amplitude to the nontarget stimuli appeared to be the degree to which the stimulus contrasted with the background sequence of stimuli. The greater the contrast between the stimulus and the background sequence the greater the amplitude of the P300 wave. ANOVA of the mean amplitude of the deflections elicited by the rare stimuli failed to produce a significant main effect. However, the trend of the mean amplitude evoked in response to target and rare nontarget stimuli collapsed across electrode sites suggests that greater amplitude was elicited in response to target than to rare nontarget stimuli (10.1 microvolts v 6.6 microvolts). Such a trend in the mean amplitude of the data indicates that subjects may not have perceived the contrast between frequent stimuli and the rare nontarget stimuli to be any greater than the contrast between the frequent and the target stimuli.

The latency of the target and rare nontarget responses failed to demonstrate a significant difference. Within the auditory modality it has been suggested that the earlier rare nontarget response in comparison to the target response is the result of the inherently intrusive nature of the auditory novel sounds. Such intrusive sounds require less evaluation in order to determine if a behavioural response is required. A greater amount of evaluation is required to determine if a target tone is sufficiently deviant from a frequent tone to require a behavioural response. The lack of a significant difference between visual rare nontarget and target responses may indicate that the rare nontarget stimuli are not sufficiently intrusive to be categorised as deviant rare nontargets significantly earlier than the targets. Similarly the latency of the N200 target and rare nontarget responses was not significantly different.

No significant difference in the amplitude of the N100 deflection was obtained between the three conditions. Such a result is surprising since as described in relation to the auditory results the N100 generating neurones are believed to become refractory with repeated presentations of the same stimulus. Such refractory neurones would be expected to produce a greater mean amplitude for the averaged responses elicited in response to rare nontarget stimuli since each presented stimulus is unique. However, Näätänen and Picton (1987) based their hypothesis that N100 generating neurons become refractory with repeated presentations upon auditory experimental data. Näätänen (1992) has claimed that only visual-spatial attention appears to be

associated with enhanced components within the latency range of the N100 ERP. He claimed that when relevant and irrelevant stimuli occurred within the same spatial locus attentional selection was predominantly associated with slow negativities (see below).

No difference in scalp distribution was found between the three experimental conditions. Responses to all three classes of stimuli demonstrated a fronto-central/temporal distribution.

Within the latency range of the N200 deflection target stimuli evoked a response that was distributed equipotentially across the scalp. Rare nontarget stimuli demonstrated a more anterior scalp distribution, such a distribution may correspond to an N2a (MMN) component. Such a component may correspond to a subject's responsiveness to low probability "deviant" stimuli when the subject is not attending to the stimulus sequence. However, due to the nature of the oddball paradigm it is unlikely that rare nontarget stimuli elicited a pure N2a component since such a task requires active attention on the part of the subject. The N200 deflection obtained in response to both target and rare nontarget stimuli is likely to be formed from a composite of N2b and N2a components (see section 7.5 for a fuller discussion of this point).

Rare nontarget stimuli demonstrated greater mean amplitude in the 150 - 350msec latency range in comparison to both frequent and target stimuli at lateral parietal sites. Such an observation supports the claim made by Wijers *et al.* (1989a; 1989b) that ERPs evoked by attended stimuli show a prolonged negative shift compared to ERPs to unattended stimuli. Such a negative shift is obtained if the two classes (to be attended - target; not to be attended - rare nontarget) can be discriminated on the basis of simple physical attributed (selection cues). Within the present Experiment it was possible to distinguish target from rare nontarget stimuli on the basis of stimulus contour characteristics. Such characteristics may be thought of as a selection cue, the attended stimulus (the target stimulus) would therefore be expected to demonstrate a negative shift of the ERP in comparison to that seen in response to the unattended stimulus, the rare nontarget stimulus. Näätänen (1992) has postulated that such "selection negativities" are perhaps equivalent to the auditory processing negativity (PN) (see section 9.7 "Lateral Parietal Differences between 150 - 350 msec" for a fuller discussion of this point).

It is worthy of note that Courchesne *et al.* (1975) believed that there was little to connect the so called frontal P300 wave they obtained in response to "novel" stimuli and the so called P3a reported by Squires *et al.* (1975). They pointed out that "novel" visual P300 deflections were elicited when subjects

actively attended to stimuli, whereas P3a deflections appeared only when auditory stimuli were ignored. Secondly "novel" visual P300s demonstrated rapid decrements with repeated exposure to initially effective stimuli; such repeated stimuli then elicited posterior P300 deflections. Squires *et al.* (1975), however, reported no such habituation or changes in scalp distribution over a long session. Finally Courchesne *et al.* (1975) reported that visual "novel" P300 deflections were substantially later in latency and larger in amplitude in comparison to the P3a deflections reported by Squires *et al.* (1975).

Courchesne *et al.* (1975) believed that there was little connection between the visual "novel" P300 deflection and the auditory novel P3a response. However, they did accept that deviant intrusive stimuli within both modalities elicited a P300 deflection that demonstrated a more anterior distribution in comparison to that evoked in response to target stimuli.

Summary

The results of this Experiment support the reports by Johnson (1989) and Barrett *et al.* (1987) that the amplitude distribution of the P300 response is modality specific.

Auditory stimuli elicited P300 responses to target and rare nontarget stimuli that were dissociable on the basis of amplitude distribution. Such results have been reported by Squires *et al.* (1975), Knight (1984) and Holdstock and Rugg (1993).

Visual stimuli elicited P300 responses to both target and rare nontarget stimuli. However, the responses were not dissociable on the basis of amplitude distribution as reported previously (Courchesne *et al.* 1975; 1978). The P300 responses to both target and rare nontarget stimuli demonstrated a centro-parietal amplitude distribution.

Chapter 4

Experiment 2: Investigation of the Dissociation of the P300 Complex Employing Knight's (1991) Visual Stimuli.

4.1 Introduction

As described in Chapter 3, a dissociation of auditory target and rare nontarget P300 responses was achieved on the basis of amplitude distribution. A similar dissociation of visual target and rare nontarget P300 responses employing stimuli used by Courchesne *et al.* (1975) was not obtained.

Knight (1991; personal communication) reported a dissociation of visual target and rare nontarget P300 responses on the basis of scalp amplitude distribution. Single line triangles were employed as either frequent or target stimuli (inverted triangle designated as targets). Complex visual shapes were employed as rare nontargets. Knight reported a centro-parietal deflection evoked by target stimuli and a fronto-central deflection evoked by rare nontarget stimuli. Within this experiment stimuli were adapted from Knight (1991; personal communication). Such stimuli differed from those employed in Chapter 3 in that rare nontarget differed from target and frequent stimuli only on the dimension of stimulus complexity (the contour of rare nontarget stimuli being fragmented in comparison to those of the target and frequent stimuli). The visual rare nontarget stimuli employed in Chapter 3 differed from the target and frequent stimuli on the basis of colour as well as stimulus complexity.

The aim of this experiment was to determine if a dissociation of visual target and rare nontarget P300 responses would be obtained in a modified version of Knight's visual (1991; personal communication) paradigm. It was predicted on the basis of Knight's (1991; personal communication) reports that target stimuli would elicit a P300 response with a posterior maximum scalp amplitude distribution. Rare nontarget stimuli were predicted to elicit a response with an earlier latency and a more anterior maximum scalp amplitude distribution in comparison to that obtained in response to target stimuli.

4.2 Method

Subjects

The subjects were 12 university students (mean age 22 years, range 18-26, nine female). None had previously participated in ERP experiments.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram activity were recorded from the scalp montage described in section 2.5 using a proprietary electrode cap.

Stimuli

Stimuli were adapted from Knight (1991; personal communication). Two types of stimuli were employed to determine if the contour characteristics of the stimuli would alter the signature of the waveform.

In the first procedure frequent and target stimuli consisted of either inverted or upright single white line triangles (see Figure 4 and 5 of the Appendix) subtending a visual angle of 2 degrees. Rare nontarget stimuli were a heterogeneous set of 45 mutilated single white line triangles with broken or distorted outlines (see Figure 6 of the Appendix). This procedure will be referred to as the triangle procedure.

In the second procedure frequent and target stimuli consisted of either a single line white circle or an ellipse subtending a visual angle of 2 degrees. Rare nontarget stimuli consisted of a set of 45 mutilated single white line circles or ellipses with broken or distorted outlines. This procedure will be referred to as the circle procedure. Within both procedures frequent and target stimuli were alternated across subjects.

Procedure

Each subject performed both a "triangle" and a "circle" procedure. Presentation of procedures was alternated between subjects. Each procedure consisted of 300 experimental stimuli presented in blocks of 100 with a one minute rest period between blocks. Between experimental procedures a rest period of five minutes was provided.

As described in section 2.4 a practice block of 15 stimuli were presented to the subjects with the instructions to respond to the target stimuli. Following the block of practice trials the experimental run was presented. Subjects were informed that their task was the same as during the practice trials. They were

told that they would also see "fragmented single white line shapes" but were to refrain from responding to them.

4.3 Data Analysis

Latency Data

See section 2.6.2 for a description of the peak latencies measured. Latency values were determined for both procedures. ANOVAs were performed on the data for each component separately, employing experimental procedure as a factor. The ANOVAs took the form of Subject X Procedure X Condition X Site.

Amplitude Data

See section 2.6.3 for a description of the ANOVAs performed upon the amplitude data, experimental procedure was employed as a factor. The ANOVAs took the form of Subject X Procedure X Condition X Chain X Site. A further analysis was performed on the mean amplitude within a latency range of 150-350 msec across the three experimental conditions at lateral parietal sites. This ANOVA took the form of Subject X Procedure X Condition X Site.

Scalp Distribution

As described in section 2.6.4, in order to examine the scalp distribution of the responses evoked by the experimental conditions of each component ANOVAs were carried out upon rescaled amplitude data, employing experimental procedure as a factor. The ANOVAs took the form of Subject X Procedure X Condition X Chain X Site.

4.4 Results

Behavioural Performance

Mean reaction time to target stimuli within the triangle procedure was 438 msec with a standard deviation across subjects of 79 msec. The mean rate for correctly detected targets was 99.2% and the mean false positive rate was 1.6%.

Figure 4.1a

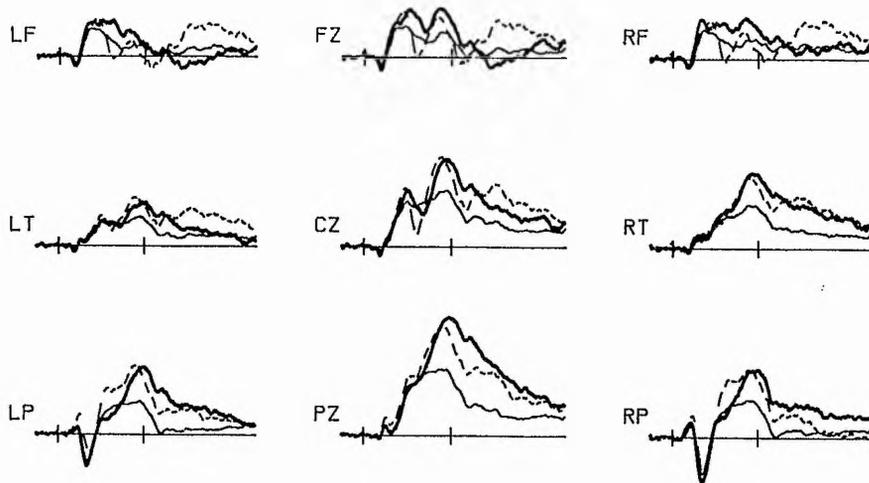


Figure 4.1b

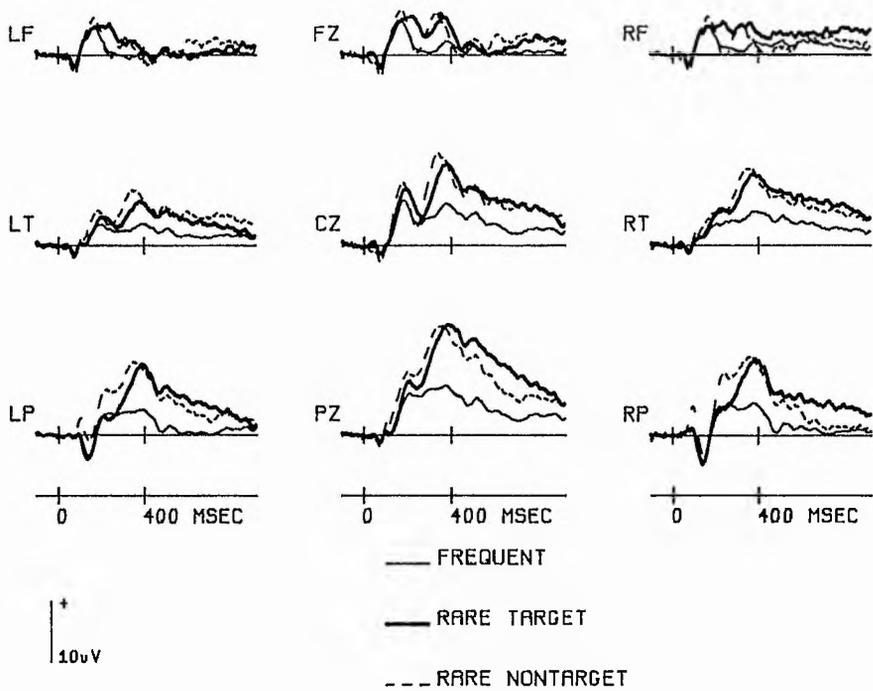


Figure 4.1a and 4.1b Waveforms, averaged across 12 subjects, for each condition of the triangle procedure (Figure 4.1a) and circle procedure (Figure 4.1b) in Experiment 2

Mean reaction time to circle stimuli within the triangle procedure was 465 msec with a standard deviation across subjects of 78 msec. The mean rate for correctly detected targets was 98.8% and the mean false positive rate was 1.2%.

A t-test of the reaction times elicited by target stimuli between the two procedures was not significant ($t(11) = -0.57$, $p = 0.58$).

ERP Data

Grand average waveforms (see Figure 4.1a and 4.1b) were produced for both triangle and circle procedures.

Table 4.0 Mean (range) number of trials making up each waveform for frequent, target and rare nontarget stimuli within each procedure.

	Triangle Procedure	Circle Procedure
Frequent	173 (138-205)	175 (123-200)
Target	38 (28-45)	39 (25-44)
Rare Nontarget	38 (27-45)	37 (26-45)

As may be seen in Figures 4.1a and 4.1b the grand average waveforms formed from the two experimental procedures are similar. Both procedures evoked an N100 deflection which was largest at lateral parietal sites. Following the resolution of the N100 deflection an N200 deflection was observed at anterior scalp sites which demonstrated greater negativity in response to target and rare nontarget stimuli in comparison to frequent stimuli.

A P300 deflection evoked by target and rare nontarget stimuli was observed. This deflection was maximum at posterior scalp sites. The P300 deflection was followed by a period of sustained positivity at parietal sites, this activity was not evident at frontal sites. Following the resolution of the N100 deflection and the peak of the P300 deflection rare nontarget stimuli demonstrated a period of sustained positivity in comparison to both frequent and target stimuli at lateral parietal electrode sites.

Table 4.8.1 and 4.8.2 of the Appendix demonstrate the mean amplitude and the mean rescaled amplitude within the circle procedure elicited by experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain. Similarly Table 4.8a and 4.8b of the Appendix demonstrate the mean amplitude and mean rescaled amplitude elicited within the triangle procedure.

P300

ANOVA of the P300 target and rare nontarget peak latencies along the midline chain produced significant main effects of condition and site (see Table 4.1 of the Appendix). Examination of the latency means, collapsed across sites, demonstrated that rare nontarget stimuli evoked a significantly earlier response than that of the target stimuli (341 msec v 359 msec). A significant interaction between these effects was also produced. At both Cz and Pz sites rare nontarget stimuli evoked significantly earlier deflections of the waveform than did target stimuli (see Table 4.2 of the Appendix).

ANOVA of the mean amplitude evoked by target and rare nontarget stimuli failed to reveal a significant main effect of either experimental procedure (triangle or circle) or condition (target or rare nontarget - see Table 4.3).

Post hoc analysis of the three way interaction involving the factors of condition, chain and site revealed that both target and rare nontarget stimuli evoked greatest amplitude at centro/temporo-parietal sites along the three electrode chains.

Scalp Distribution

ANOVA of rescaled mean amplitude revealed significant main effects for chain (see Table 4.3). *Post hoc* analysis demonstrated that the midline chain evoked greater amplitude distribution than either of the lateral chains. However, greater amplitude was distributed along the right chain in comparison to the left.

A significant three way interaction involving the factors of condition, chain and site was obtained. As illustrated in Figure 4.2b *post hoc* analysis revealed that rare nontarget stimuli evoked a maximum amplitude distribution across centro/temporo-parietal sites along the three electrode chains. Target stimuli evoked a maximum centro/temporo-parietal amplitude distribution along the midline and right electrode chains. Along the left chain the parietal (LP)

Figure 4.2a

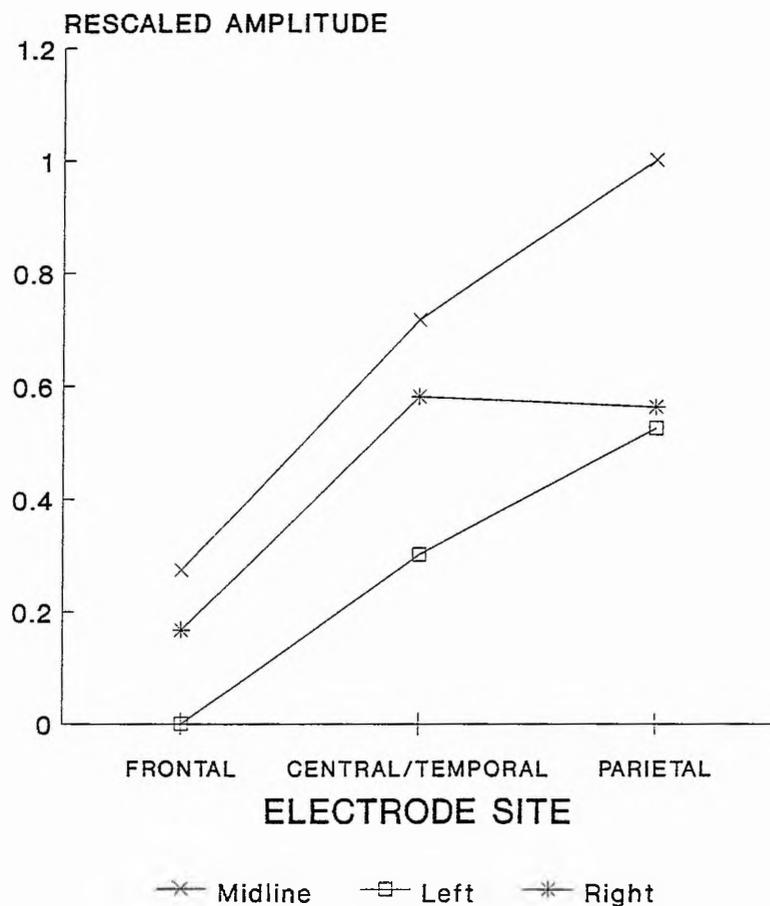


Figure 4.2b

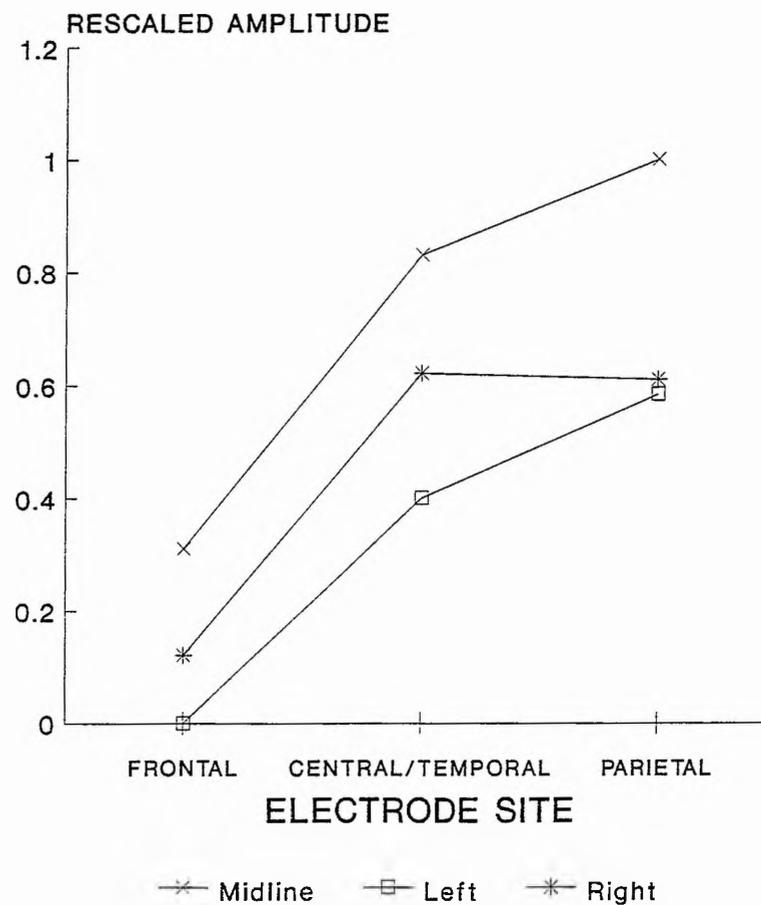


Figure 4.2a and 4.2b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by target (Figure 4.2a) and rare nontarget (Figure 4.2b) stimuli in Experiment 2.

Table 4.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,11	0.001	0.982	163.48
Condition CC	1,11	0.053	0.821	88.88
Chain CH	1.3,14.2	37.311	0.000*	41.03
Site ST	1.6,18	44.00	0.000*	78.15
Interactions				
PR X CC	1,11	3.692	0.081	19.21
PR X CH	1.8,20.1	0.665	0.523	8.10
PR X ST	1.5,16.4	0.108	0.898	13.34
CC X CH	1.9,20.6	0.817	0.446	6.88
CC X ST	1.3,14.7	1.056	0.366	11.00
CH X ST	2.2,24.0	4.454	0.020*	20.46
PR X CC X CH	1.6,17.3	0.203	0.765	2.20
PR X CC X ST	1.3,14.4	0.048	0.887	7.24
PR X CH X ST	2.3,25.5	2.108	0.137	1.35
CC X CH X ST	2.7,30.0	6.090	0.003*	0.98
PR X CC X CH X ST	2.8,30.8	0.505	0.669	0.59
Rescaled Amplitude				
Main Effects				
Procedure PR	1,11	0.149	0.706	0.61
Condition CC	1,11	0.502	0.491	0.34
Chain CH	1.3,14.2	37.108	0.000*	0.15
Site ST	1.6,18.1	44.412	0.000*	0.28
Interactions				
PR X CC	1,11	0.004	0.984	0.07
PR X CH	1.8,19.9	0.386	0.663	0.03
PR X ST	1.5,16.5	0.299	0.743	0.05
CC X CH	1.9,20.9	0.669	0.514	0.03
CC X ST	1.4,15.2	1.708	0.216	0.04
CH X ST	2.2,24.0	4.367	0.022*	0.07
PR X CC X CH	1.6,17.3	0.078	0.884	0.01
PR X CC X ST	1.3,14.4	0.091	0.832	0.02
PR X CH X ST	2.4,26.5	1.711	0.196	0.01
CC X CH X ST	2.8,30.4	4.674	0.010*	0.01
PR X CC X CH X ST	2.8,31.2	0.301	0.814	0.01

* denotes a p value statistically significant at the 0.05% level or greater.

electrode demonstrated significantly greater amplitude distribution than the frontal (LF) site (see Figure 4.2a).

N100

ANOVA of the latencies of the deflections along the midline chain produced a significant interaction involving the factors of condition and site (see Table 4.1 of the Appendix). For each of the experimental conditions there was a tendency for latency to increase as the electrode site became more posterior. This tendency was only statistically significant for target stimuli, both the Cz and Pz electrode sites demonstrated shorter latencies than the Fz site (see Table 4.2 of the Appendix).

ANOVA of the mean amplitude of the N100 deflections produced a significant main effect of condition (see Table 4.4 of the Appendix). *Post hoc* analysis demonstrated that both frequent and target stimuli evoked a greater negative deflection than rare nontarget stimuli.

A significant three way interaction involving the factors of condition, chain and site was also obtained. *Post hoc* analysis demonstrated that along the midline the three classes of stimuli evoked amplitude that was not significantly different at any site. Along the lateral chains frequent stimuli evoked significantly greater amplitude at the parietal site than the frontal. Both target and rare nontarget stimuli evoked greater amplitude at the parietal site than at either the frontal or temporal sites along the right chain. Target stimuli also evoked greater amplitude at the parietal site than the frontal site along the left chain.

Scalp Distribution

ANOVA of rescaled amplitude revealed a significant interaction between the factors of condition and chain (see Table 4.4 of the Appendix). As illustrated in Figure 4.3 *post hoc* analysis revealed that in response to all three conditions amplitude was distributed maximally along the lateral chains in comparison to the midline.

N200

ANOVA of the N200 target and rare nontarget peak latencies along the midline chain produced main effects of condition and site (see Table 4.1 of the Appendix). *Post hoc* analysis revealed that, collapsed across site, rare nontargets evoked a shorter latency than targets (243 msec v 265 msec).

Figure 4.3

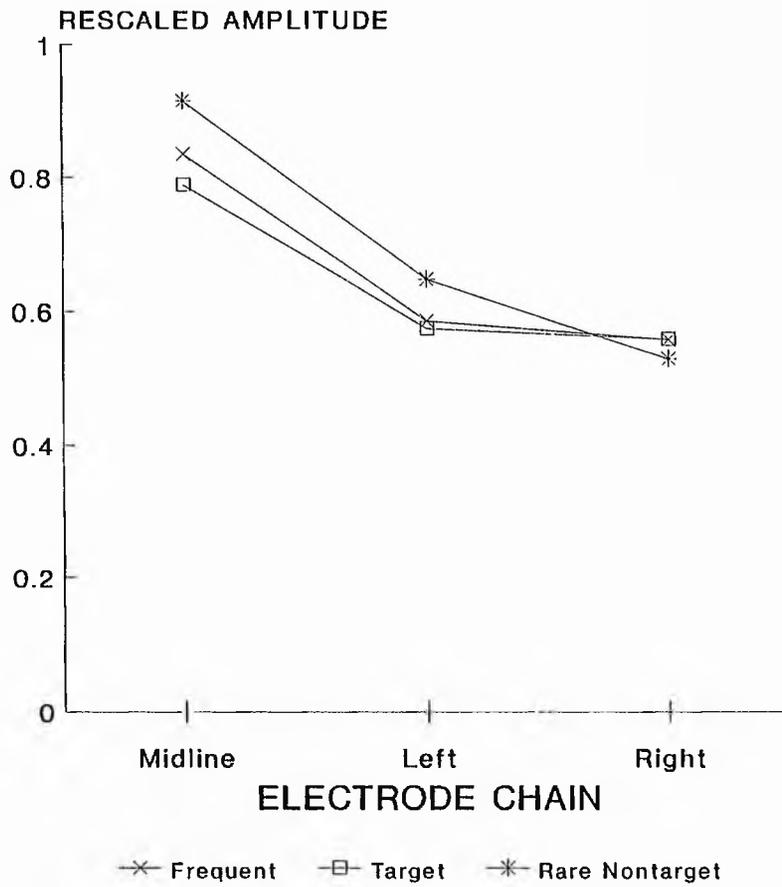


Figure 4.3 Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the N100 deflection elicited by frequent, target and rare nontarget stimuli in Experiment 2 (collapsed over electrode site).

Latency values collapsed over the two conditions revealed that N200 deflections were elicited significantly earlier at Cz and Pz than at Fz (see Table 4.2 of the Appendix).

ANOVA of the mean amplitude evoked by target and rare nontarget stimuli failed to produce a main effect of condition (see Table 4.5 of the Appendix).

Post hoc analysis of the significant three way interaction involving the factors of condition, chain and site demonstrated that rare nontarget stimuli elicited the greatest negative deflection at anterior scalp sites. Along the midline chain a fronto-central maximum deflection was obtained. Along the right chain the frontal site demonstrated greater amplitude in comparison to either the temporal or parietal sites. Along the left chain the frontal site demonstrated greater amplitude than the parietal site.

Target stimuli demonstrated an equipotential N200 amplitude deflection across the electrode sites along all three chains of electrodes.

Scalp Distribution

ANOVA of rescaled amplitude revealed a significant main effect of chain (see Table 4.5 of the Appendix). *Post hoc* analysis demonstrated that amplitude was distributed maximally along the left chain.

As may be seen in Figure 4.4a and 4.4b *post hoc* analysis of the three way interaction involving the factors of procedure, chain and site demonstrated that both the triangle and circle paradigms demonstrated maximum amplitude distribution at fronto-central sites along the midline chain. Within the triangle procedure rescaled amplitude along the lateral chains was distributed equipotentially across the scalp sites. Rescaled amplitude evoked in response to the circle stimuli demonstrated that along the right chain stimuli demonstrated an anterior distribution (greater rescaled amplitude being distributed at the RF site in comparison to that at the RP site). Along the left chain amplitude was distributed equipotentially across the scalp.

Post hoc analysis of the three way interaction involving the factors of condition, chain and site demonstrated that in response to target stimuli greater amplitude was distributed at the frontal site than at the parietal site along the midline chain. Along the lateral chains target stimuli amplitude was distributed equipotentially (see Figure 4.5a). Rare nontarget stimuli demonstrated a fronto-central amplitude distribution along the midline chain. Along the right chain greater amplitude was distributed at the frontal site than at the parietal site. Along the left chain amplitude was distributed equipotentially (see Figure 4.5b).

Figure 4.4a

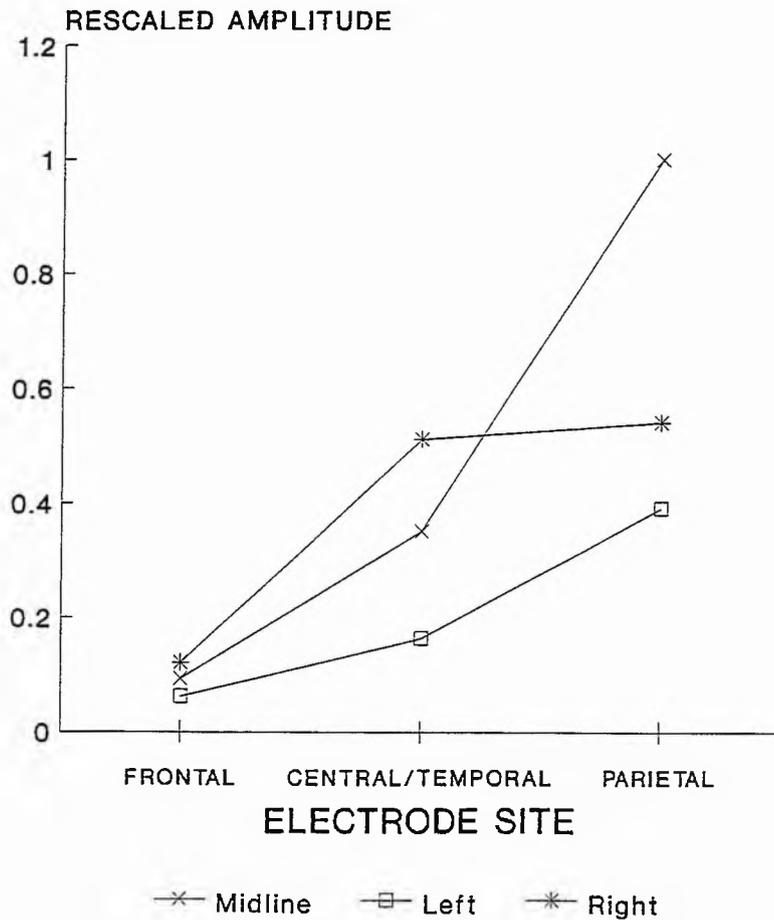


Figure 4.4b

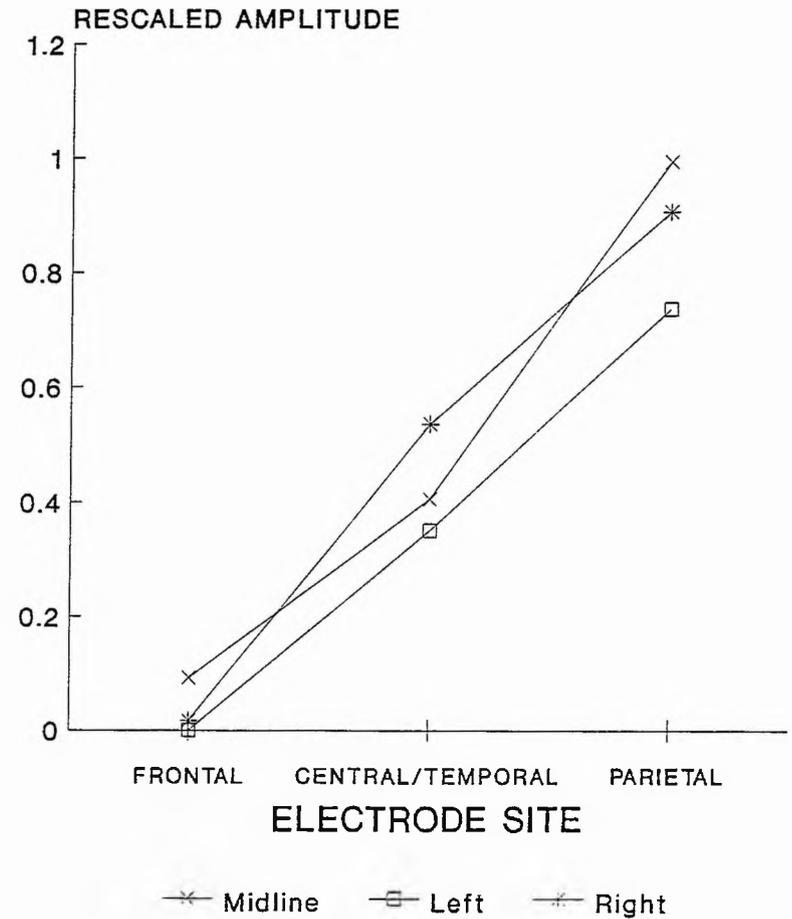


Figure 4.4a and 4.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by the triangle (Figure 4.4a) and circle (Figure 4.4b) procedures in Experiment 2 (collapsed across experimental condition).

Figure 4.5a

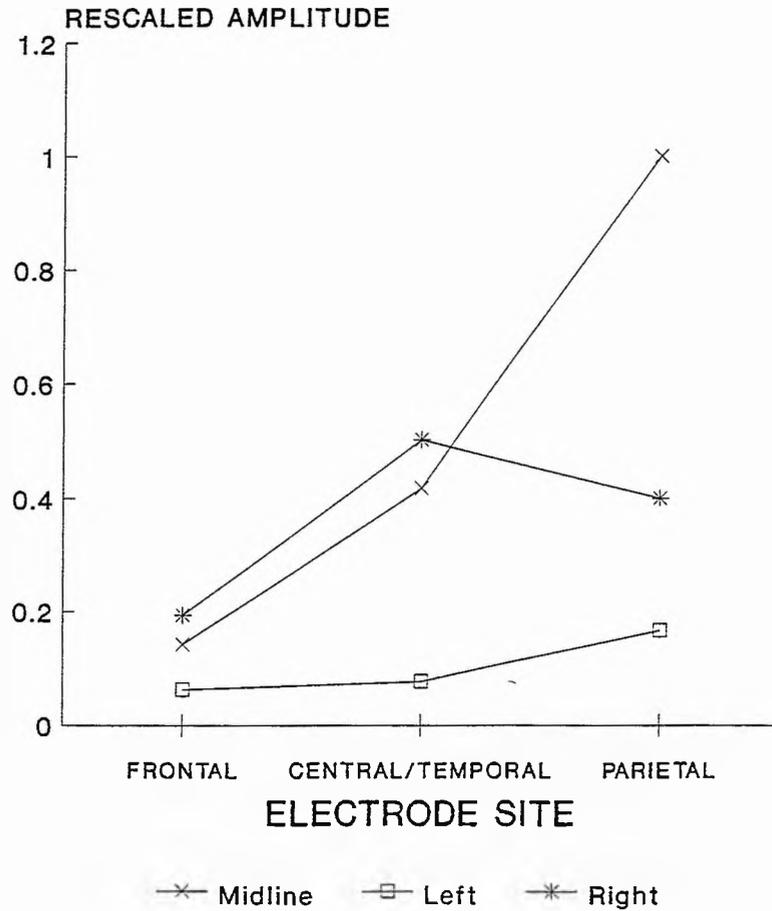


Figure 4.5b

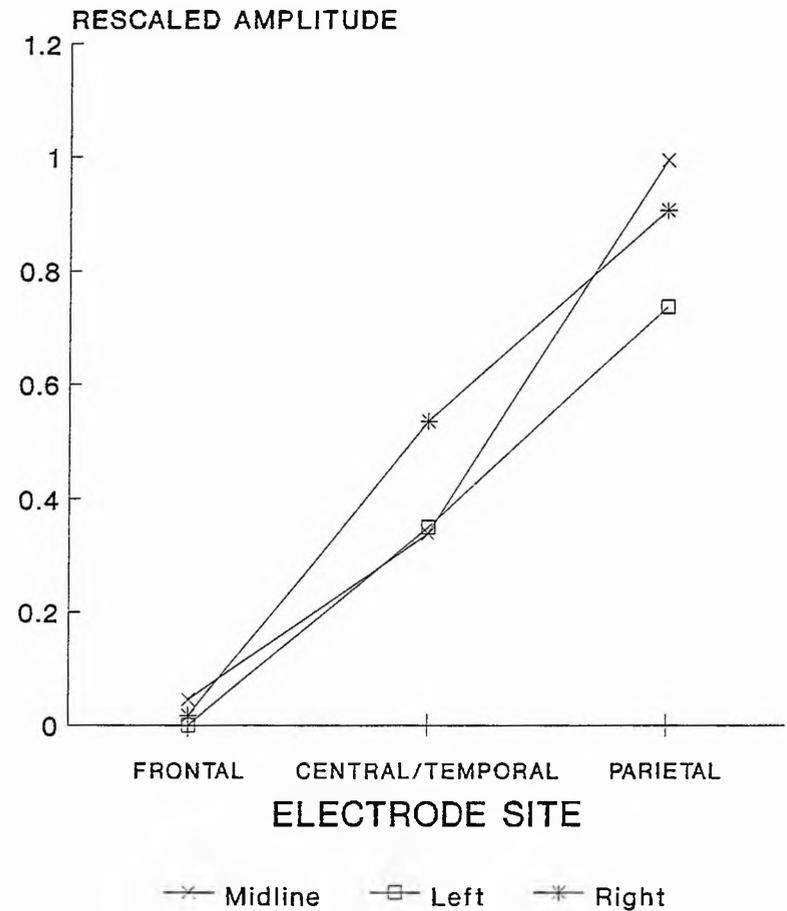


Figure 4.5a and 4.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 4.5a) and rare nontarget (Figure 4.5b) stimuli in Experiment 2.

500 - 850 msec Latency Range

ANOVA of the mean amplitude evoked within the 500 - 850 msec latency range produced a significant main effect of condition (see Table 4.6 of the Appendix). *Post hoc* analysis demonstrated that target and rare nontarget stimuli evoked greater mean amplitude in comparison to that evoked in response to frequent stimuli.

Post hoc analysis of the three way interaction involving the factors of condition, chain and site demonstrated that mean amplitude evoked by frequent and rare nontarget stimuli was equally large across the three sites along all three chains. Target stimuli evoked the greatest amplitude at the parietal site along the midline chain. Along the left chain amplitude was greater at the parietal site than at the frontal site. Along the right chain the temporal site exhibited greater mean amplitude than the frontal site.

Scalp Distribution

ANOVA of rescaled amplitude produced a significant three way interaction involving the factors of condition, chain and site (see Table 4.6 of the Appendix). *Post hoc* analysis demonstrated that the response to frequent stimuli (see Figure 4.6a) along the midline chain revealed a parietal site maximum amplitude distribution (Pz demonstrated greater amplitude than either the Cz or Fz electrodes). Target stimuli (see Figure 4.6b) along the midline chain of electrodes revealed a posterior amplitude distribution (Pz demonstrated greater amplitude than Fz). Along the lateral chains frequent and target stimuli demonstrated an equipotential amplitude distribution. Rare nontarget stimuli (see Figure 4.6c) demonstrated an amplitude distribution that was equipotential across the scalp along all three chains.

150 - 350msec Latency Range at Lateral Parietal Sites

ANOVA of the mean amplitude within the 150 - 350 msec latency range produced a significant two way interaction involving the factors of procedure and condition (see Table 4.7 of the Appendix). *Post hoc* analysis revealed that rare nontarget stimuli within the circle procedure evoked greater mean amplitude than either target or frequent stimuli (see Figure 4.7b). Target stimuli evoked greater mean amplitude than that evoked in response to frequent stimuli. Within the triangle procedure the amplitude evoked by rare nontarget stimuli was greater in comparison to that evoked by frequent or target stimuli (see Figure 4.7a).

Figure 4.6a

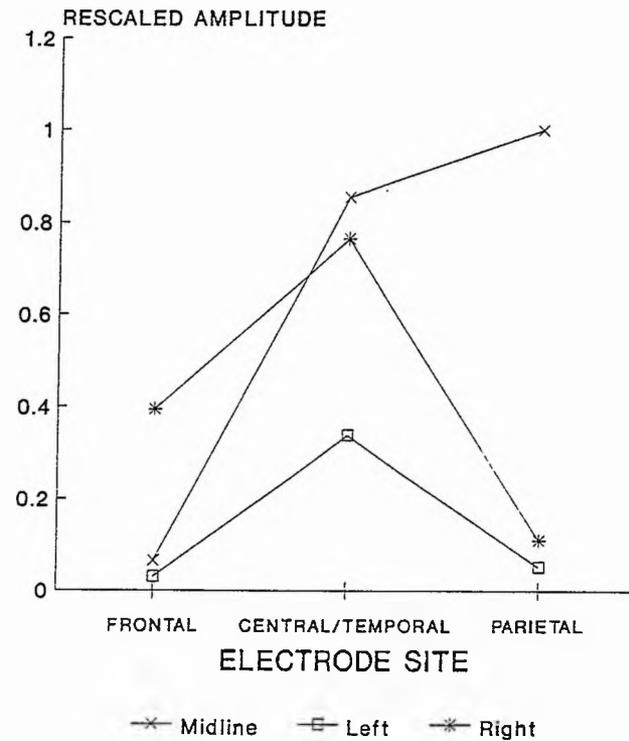


Figure 4.6b

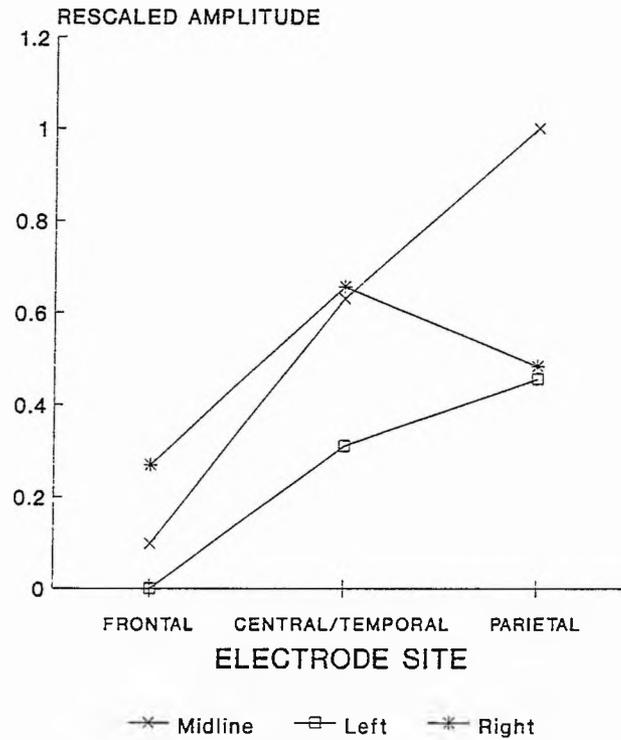


Figure 4.6c

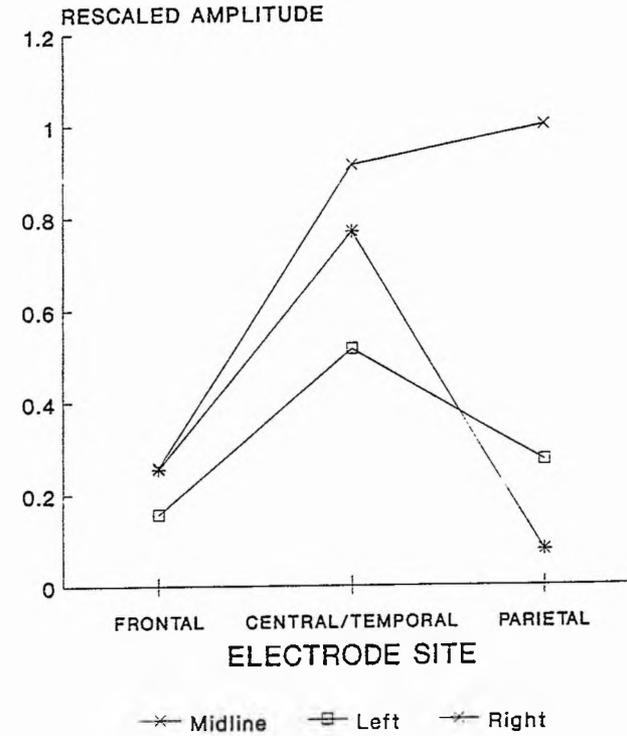


Figure 4.6a, 4.6b and 4.6c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by frequent (Figure 4.6a), target (Figure 4.6b) and rare nontarget (Figure 4.6c) stimuli.

Figure 4.7a

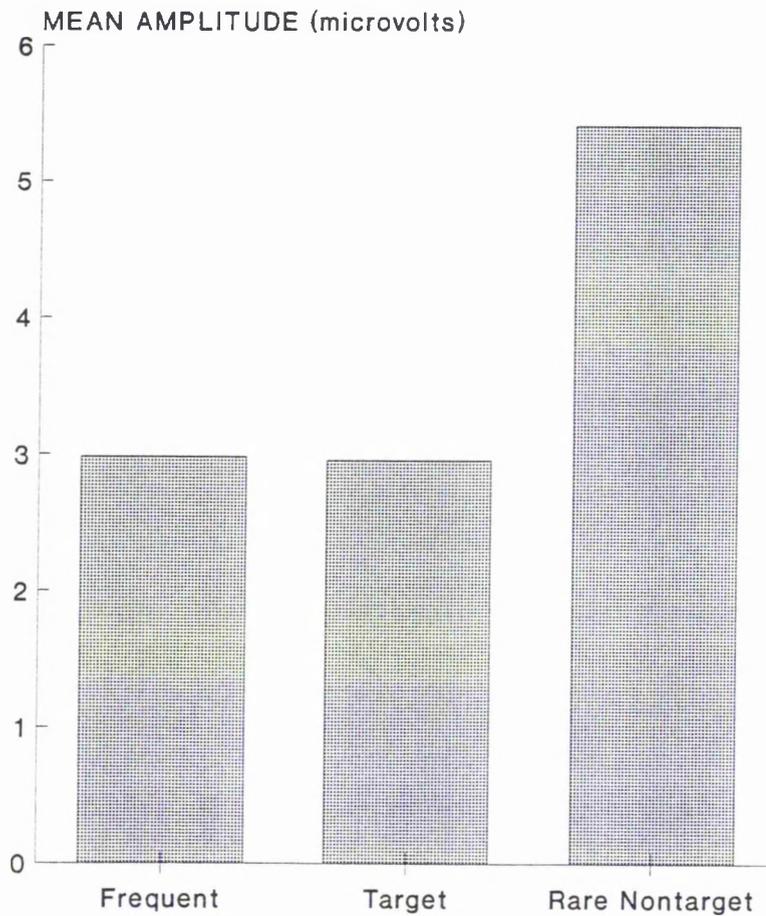


Figure 4.7b

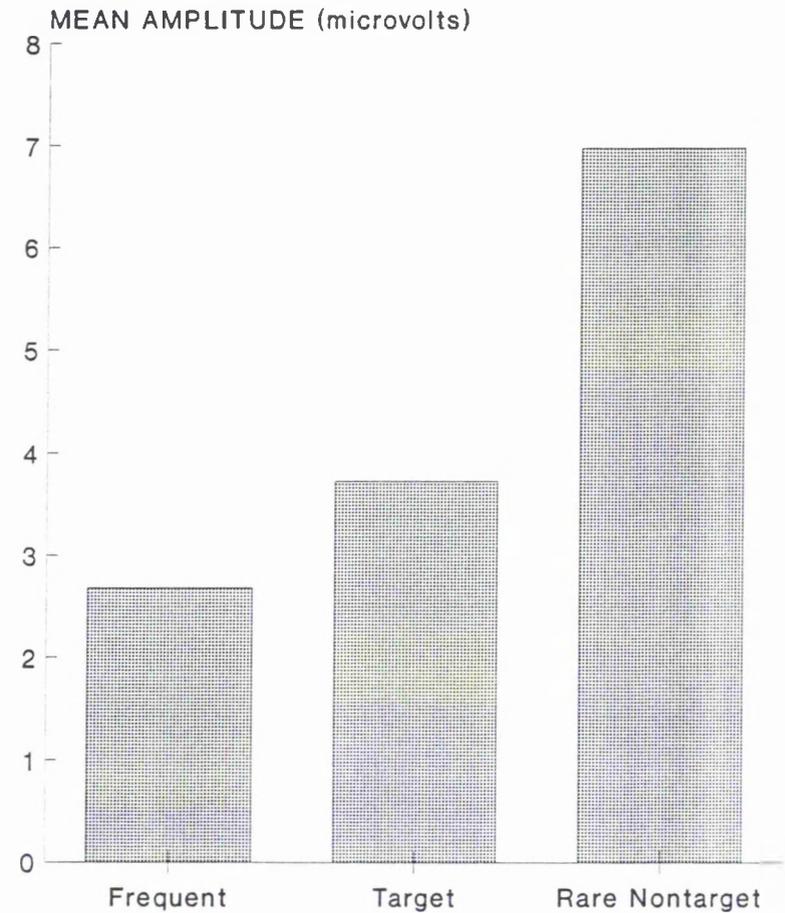


Figure 4.7a and 4.7b Bar diagram illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the triangle (Figure 4.7a) and circle (Figure 4.7b) procedures between 150 - 350 msec at lateral parietal sites in Experiment 2.

4.5 Discussion

Experimental procedure (triangle procedure or circle procedure) failed to produce a significant difference of reaction time in response to target stimuli. Similarly it would appear that the underlying P300 neural generators are insensitive to differences in the contour outline of experimental stimuli.

Target and rare nontarget stimuli both elicited a positive deflection of the waveform within the P300 latency range (250-450 msec). As reported previously stimuli with a low subjective probability and random presentation are reported to elicit a P300 deflection (for instance Squires *et al.* 1975). The results obtained failed to support a dissociation of P300 target and rare nontarget responses on the basis of scalp amplitude distribution as reported by Knight (1991; personal communication). The response to rare nontarget stimuli demonstrated a temporo/centro-parietal maximum distribution along all three chains. Such a visual rare nontarget P300 response, with an anterior amplitude distribution, has been reported by Courchesne *et al.* (1975; 1978) and Knight (1991; personal communication).

The distribution of the target P300 response failed to replicate the scalp amplitude distribution reported by Knight (1991; personal communication). Target stimuli demonstrated a centro/temporo-parietal distribution along the midline and right chains. Along the left chain a posterior distribution was obtained; the parietal electrode evoked significantly greater amplitude than the frontal electrode. Courchesne *et al.* (1975; 1978) and Knight (1991; personal communication) reported a parietal maximum distribution in response to target stimuli. Within the studies reported by Knight (1991; personal communication) and Courchesne *et al.* (1975; 1978) the dissociation of the responses of target and rare nontarget stimuli within the P300 latency range on the basis of scalp amplitude distribution presumably reflects the output of a unique combination of underlying neural generators. Within the present experiment the same combination of neural generators would appear to be responsible for the evoked responses to both target and rare nontarget stimuli.

As reported previously, Courchesne *et al.* (1978) reported that the greater the contrast between the rare and the background stimuli the greater the amplitude of the P300 deflection evoked. The amplitude of the P300 deflections evoked in response to target and rare nontarget stimuli failed to demonstrate a significant difference. Collapsed across chain and site, mean amplitude evoked by target and rare nontarget stimuli was similar. Rare nontargets evoked a deflection with a mean amplitude of 10.1 microvolts while targets evoked a deflection with a mean amplitude of 10.3 microvolts.

Overlap with other components within the waveform would not appear to account for the failure to dissociate the P300 responses on the basis of amplitude distribution. The slow wave activity (500 - 850 msec latency range) in response to target stimuli along the midline revealed a posterior amplitude distribution. Along the lateral chains amplitude was distributed equipotentially across the sites. The response evoked in response to rare nontarget stimuli demonstrated an equipotential amplitude distribution along all three chains of electrodes. As described by Ruchkin *et al.* (1988) a more positive posterior amplitude distribution in comparison to that evoked in response to rare nontarget stimuli indicates that activity within this latency range demonstrates task relevance characteristics in contrast to stimulus characteristics. However, such an explanation fails to account for the parietal site maximum obtained in response to frequent stimuli. The greater mean amplitude evoked by target stimuli at parietal sites in comparison to that evoked at frontal and central sites along the midline chain presumably reflects the increased task demands of such stimuli. Both frequent and rare nontarget stimuli demonstrated that the mean amplitude evoked was equally large at each site along all three chains, such equipotential amplitude reflects the similar task demands of such stimuli.

The peak latency of the rare nontarget P300 response was significantly earlier than that of the target response. Similarly the N200 peak latency was earlier in response to rare nontarget in comparison to that of target stimuli. The latencies of the N100 deflections did not demonstrate such a dissociation between experimental conditions. Such findings suggest that the intrusive nature of the rare nontargets required less evaluation to determine if a behavioural response was required than did targets.

Such a finding suggests that the deviant physical nature of the rare nontargets enabled subjects to categorise them earlier than targets as requiring either a behavioural response or not. However, the deviant physical nature of the rare nontargets in comparison to the target stimuli was not sufficiently great as to elicit a greater P300 deflection in response to the rare nontargets as previously reported by Courchesne *et al.* (1975). It would appear that both classes of rare stimuli were perceived to contrast to the background frequent stimuli by a similar amount.

Within the N100 latency range, frequent and target stimuli evoked responses with greater negative deflections than that evoked in response to rare nontarget stimuli. As previously described (see section 3.7.1) Näätänen and Picton (1987) proposed that the N100 generating neurons become refractory upon repeated presentations of the same stimulus. Such a proposal would lead to the

hypothesis that target and rare nontarget responses would demonstrate a greater negative deflection in comparison to that obtained in response to frequent stimuli. A possible explanation for the difference between frequent and target deflections in comparison to that obtained in response to rare nontarget stimuli is that other components whose generator neurons do not become refractory on repeated presentations of the stimulus overlap the rare nontarget N100 component. However, given the similar scalp distribution of the three classes of experimental stimuli which suggests that the same neural generator, or combination of neural generators, is responsible for the generation of the N100 deflection, such an explanation is difficult to support. As discussed in section 3.7.2, Näätänen and Picton (1987) based their findings and conclusions largely upon auditory data. The validity of generalising such findings across modalities is, therefore, uncertain (see section 9.7).

Within the N200 latency range it was demonstrated that the response elicited by rare nontarget stimuli demonstrated a greater anterior scalp amplitude distribution to that observed in response to target stimuli. The opposite dissociation has been reported elsewhere (for instance see Rugg *et al.* 1988). As previously described Rugg *et al.* (1988) claims that target stimuli elicit a frontally distributed "N2b" component while rare nontarget stimuli elicit a more posterior centro-frontal "N2a" (also known as the MMN) component within the auditory modality. However, as discussed in section 3.7.2, within an active oddball task subjects attend to all stimuli, it is therefore, possible that the "fronto-central" N200 wave is a composite of the N2a and N2b components which overlap in time and scalp distribution. As outlined in section 1.5.4.1, it is difficult to dissociate the target and rare nontarget responses on the basis of scalp amplitude distribution within an active oddball paradigm. Caution should, therefore, be employed when attempting to dissociate the N200 results reported above on the basis of scalp amplitude distribution (see section 7.5 for a more comprehensive discussion of this point).

Rare nontarget stimuli demonstrated greater mean amplitude within the 150 - 350 msec latency range in comparison to that evoked in response to frequent and target stimuli at lateral parietal sites. As reported in section 3.7.2, such an observation supports the claim made by Wijers *et al.* (1989a; 1989b) that ERPs evoked by attended stimuli show a prolonged negative shift compared to ERPs evoked to unattended stimuli if the two classes of stimuli may be discriminated on the basis of simple physical stimulus attributes. As described in section 1.5.4.3 the appearance of occipital negativities is a common finding for visual

discrimination tasks (Harter and Previc 1978; Harter and Guido 1980). Harter and Aine (1984) have related such occipital negative waves to the processing negative component(s) of auditory selective attention experiments.

In conclusion it did not prove possible to dissociate the target and rare nontarget responses within the latency range of the P300 deflection on the basis of scalp amplitude distribution. Such a result suggests that the visual P300 deflection evoked in response to both target and rare nontarget stimuli were produced by the same (or the same combination) of underlying neural generators. Similarly it did not prove possible to dissociate the effects of target and rare nontarget stimuli within the latency range of the N200 deflection. However, within both the latency range of 500 - 850 msec (slow wave activity) and 150 - 350 msec at lateral parietal sites (occipital negativity) the effects of target and rare nontarget responses were able to be dissociated.

Summary

The dissociation of target and rare nontarget P300 deflections on the basis of scalp amplitude distribution previously reported by Knight (1991; personal communication) was not replicated.

Target and rare nontarget stimuli both elicited P300 deflections with a centro-parietal maximum scalp amplitude distribution along the midline chain of electrodes.

Chapter 5

Experiment 3: Dissociation of Responses to Rare Stimuli Employing Spatially Deviant Rare Nontarget Stimuli

5.1 Introduction

Courchesne *et al.* (1978) reported that the greater the contrast between a rare stimulus and the background stimuli the greater the amplitude of the P300 deflection evoked. The results of the auditory experiment discussed in Chapter 3 demonstrated that the mean amplitude evoked by rare nontarget stimuli was significantly greater than the amplitude evoked by target stimuli. However, the results of the visual experiments discussed in Chapters 3 and 4 failed to demonstrate such a dissociation of the mean amplitude evoked in response to target and rare nontarget stimuli. Such results, within the visual modality, suggests that the rare nontarget stimuli were not viewed as deviating from the frequent stimuli to any greater extent than the target stimuli to the frequent stimuli. An explanation for the failure of the rare nontarget stimuli to elicit greater mean amplitude is that the rare nontarget stimuli were not viewed as being "deviant" to a large enough degree; that is, the rare nontarget stimuli were not regarded by subjects as being dissimilar to a great enough degree from the target stimuli.

Experimental manipulations that altered the amplitude of a P300 deflection, without changing the scalp distribution of the deflection evoked in response to the experimental condition, may be regarded as simply altering the strength with which underlying neural generators produce output. A change of the scalp amplitude distribution with or without a change of the mean amplitude would suggest a different combination of neural generators are being activated in response to each class of experimental stimuli.

Previous reports have demonstrated differences in the amplitude, scalp distribution and refractory period of visual ERPs to peripheral and foveal stimuli (Neville *et al.* 1983; 1987; Perry *et al.* 1965;). However, in these studies subjects were not required to differentially process the visual stimuli which may have revealed a dissociation of responses on the basis of amplitude distribution.

The aim of this experiment was to determine if manipulation of the spatial location of rare nontarget stimuli would lead to a dissociation of target and rare

nontarget P300 responses on the basis of scalp amplitude distribution. Such a manipulation was hypothesised to increase the intrusive nature of rare nontarget stimuli such that subjects automatically attended to them upon presentation.

It was predicted from this experiment that rare nontarget stimuli presented randomly around the periphery of the screen would prove to be intrusive in comparison to the target and frequent stimuli being presented at the point of fixation. The intrusive nature of the stimuli presented offcentre were predicted to elicit a more anterior P300 response than that elicited by target stimuli presented at a fixed spatial location.

5.2 Method

Subjects

The subjects were 16 university students (mean age 24.6 years, range 19-29, six females). Three subjects had previously participated in ERP experiments.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram activity were recorded from the scalp montage described in section 2.5 using a proprietary electrode cap.

Stimuli

Stimuli were adapted from the triangle procedure described in section 4.23. Two procedures were employed in this experiment to determine if the contour characteristics of the stimuli would alter the signature of the waveform.

In both procedures frequent and target stimuli were either an inverted or upright single white line triangle subtending a visual angle of 2 degrees. Frequent and target stimuli were presented at the same spatial position upon a VDU. In the first procedure rare nontarget stimuli consisted of either the inverted or upright single line triangle presented in one of eight possible locations around the periphery of the VDU. This procedure will be referred to as the single line procedure.

In the second procedure rare nontarget stimuli consisted of a heterogeneous set of 45 mutilated single line triangles with fragmented outlines (see Figure 7 of the Appendix) presented around the periphery of the VDU. This procedure will be referred to as the fragmented procedure. Frequent and target stimuli were alternated across subjects.

Within both the single line and fragmented procedure rare nontarget stimuli were presented 4 degrees of visual angle off-centre in comparison to the position where both frequent and target stimuli were presented. Rare nontarget stimuli were randomly presented at 0, 45, 90, 135, 180, 225, 270 and 315 degrees from the central position where target and frequent stimuli were presented.

Procedure

Each subject performed both a single line and fragmented procedure. Presentation of procedures was alternated between subjects. Each procedure consisted of 300 experimental stimuli presented in blocks of 100 with a one minute rest period between blocks. Between experimental procedures a rest period of five minutes was provided.

As described in section 2.4 a practice block of 15 stimuli were presented to the subjects with the instructions to respond to the target stimuli. Following the block of practice trials the experimental run was presented. Subjects were informed that their task was the same as during the practice trials. They were also told that they would occasionally see triangles (either single line or fragmented) presented off-centre but were to refrain from responding to them.

5.3 Data Analysis

Latency Data

See section 2.6.2 for a description of the peak latencies measured. Latency values were determined for both procedures. ANOVAs were performed on the data for each component separately employing experimental procedure as a factor. The ANOVAs took the form of Subject X Procedure X Condition X Site. In the case of the N200 deflection it was not possible to measure a deflection for one subject and this analysis was therefore carried out employing 15 subjects.

Amplitude Data

See section 2.6.3 for a description of the ANOVAs performed on amplitude data. Experimental procedure was employed as a factor. Such ANOVAs took the form of Subject X Procedure X Condition X Chain X Site. A further analysis was performed on the mean amplitude within a latency range of 150 - 350 msec across the three experimental conditions at lateral parietal sites. This ANOVA took the form of Subject X Procedure X Condition X Site.

Scalp Distribution

As described in section 2.6.4 to examine the scalp distribution of the responses evoked by the experimental conditions of each component ANOVAs were carried out upon rescaled amplitude data employing experimental procedure as a factor. Such ANOVAs took the form of Subject X Procedure X Condition X Chain X Site.

5.4 Results

Behavioural Performance

Mean reaction time to target stimuli within the single line procedure was 443 msec with a standard deviation across subjects of 97 msec. The mean rate for correctly detected targets was 98.8% and the mean false positive rate was 1.25%.

Mean reaction time to target stimuli within the fragmented procedure was 479 msec with a standard deviation across subjects of 114 msec. The mean rate for correctly detected targets was 97.5% and the mean false positive rate was 2.91%.

A t-test demonstrated that there was no significant difference between the reaction times of the two procedures in response to target stimuli ($t(15) = -1.06$ $p = 0.31$).

ERP Data

Grand average waveforms (see Figure 5.1a and 5.1b) were produced for both single line and fragmented procedures.

Table 5.0 Mean (range) number of trials making up each waveform for frequent, target and rare nontarget stimuli within each experimental procedure.

	Single Line Procedure	Fragmented Procedure
Frequent	193 (138-196)	169 (147-196)
Target	36 (28-44)	37 (27-44)
Rare Nontarget	38 (29-44)	40 (32-44)

The grand average waveforms formed from the two experimental procedures are similar (see Figure 5.1a and 5.1b). Within both procedures all three classes of experimental stimuli evoked an N100 deflection which was largest at lateral parietal sites. An N200 deflection was observed at anterior scalp sites.

Following the resolution of the N200 deflection a P300 deflection evoked in response to target and rare nontarget stimuli was observed. This deflection was maximum at posterior scalp sites. The P300 deflection was followed by a period of sustained positivity at parietal sites, this activity was not evident at frontal sites.

Following the resolution of the N100 deflection and the peak of the P300 deflection rare nontarget stimuli demonstrated a period of sustained positivity in comparison to both frequent and target stimuli at lateral parietal electrode sites. This increased positivity in response to rare nontarget stimuli appeared greater within the fragmented rare nontarget procedure in comparison to the single line procedure.

Table 5.8.1 and 5.8.2 of the Appendix demonstrate the mean amplitude and the mean rescaled amplitude elicited within the single line procedure by experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain. Similarly Table 5.8.3 and 5.8.4 demonstrate the mean amplitude and the mean rescaled amplitude elicited within the fragmented procedure.

P300 Deflection

ANOVA of the target and rare nontarget P300 latencies along the midline chain produced a significant effect of condition (see Table 5.1 of the Appendix). Examination of the mean of the latencies, collapsed across sites, demonstrated that rare nontarget stimuli evoked a significantly earlier response than that of target stimuli (348 msec v 370 msec - see Table 5.2 of the Appendix).

ANOVA of the mean amplitude evoked by target and rare nontarget stimuli failed to demonstrate a significant main effect of experimental procedure or condition (see Table 5.3).

Post hoc analysis of the three way interaction involving the factors of procedure, condition and site demonstrated that both target and rare nontarget

Figure 5.1a

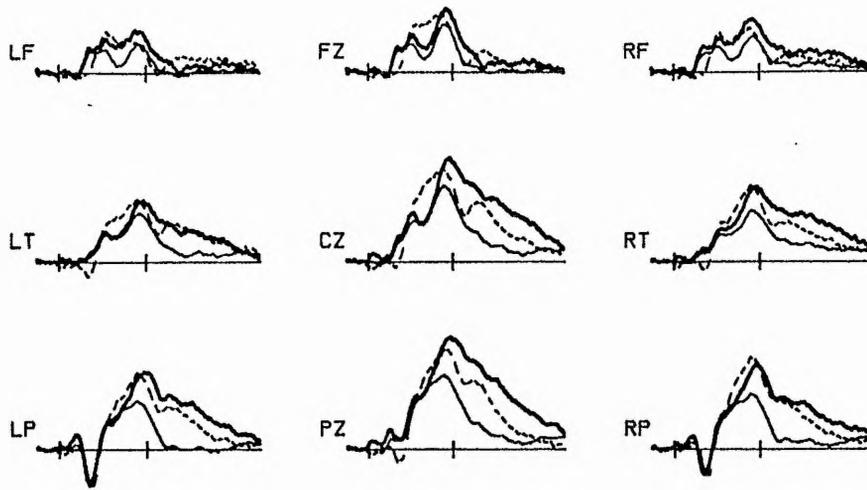


Figure 5.1b

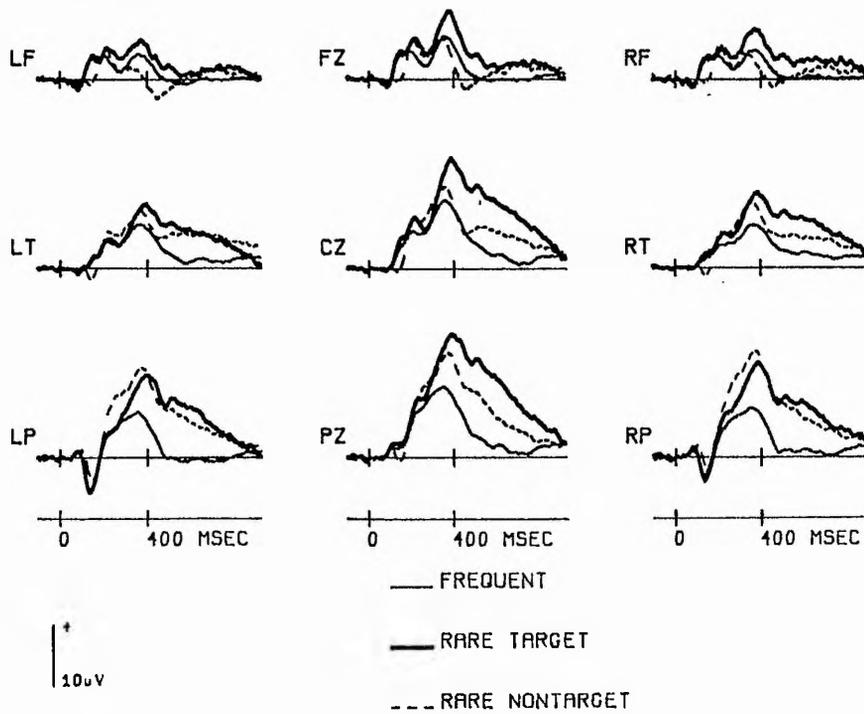


Figure 5.1a and 5.1b Waveforms, averaged across 16 subjects, for each condition of the "single line" (Figure 5.1a) and "fragmented" (Figure 5.1b) procedure in Experiment 3.

Table 5.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by target and rare nontarget stimuli.

Main Effects				
Procedure PR	1,15	0.933	0.347	45.778
Condition CC	1,15	1.930	0.186	130.577
Chain CH	1.7,26.2	25.540	0.000*	53.122
Site ST	1.7,25.2	58.899	0.000*	68.342
Interactions				
PR X CC	1,15	3.976	0.065	61.463
PR X CH	1.8,26.9	0.068	0.918	2.356
PR X ST	1.3,19.7	26.450	0.000*	4.385
CC X CH	1.6,23.9	4.025	0.039*	10.260
CC X ST	1.7,25.4	4.570	0.025*	16.719
CH X ST	2.3,35.0	2.242	0.114	8.942
PR X CC X CH	1.6,24.3	2.342	0.126	3.998
PR X CC X ST	1.5,22.0	12.151	0.001*	5.565
PR X CH X ST	3.0,44.8	3.030	0.039*	0.990
CC X CH X ST	2.7,40.9	13.227	0.000*	1.761
PR X CC X CH X ST	2.2,33.0	0.629	0.552	0.956
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.080	0.781	0.273
Condition CC	1,15	1.933	0.185	0.654
Chain CH	1.7,26.1	25.924	0.000*	0.286
Site ST	1.7,25.1	56.201	0.000*	0.367
Interactions				
PR X CC	1,15	0.001	0.974	0.256
PR X CH	1.4,21.3	6.545	0.011*	0.013
PR X ST	1.3,19.2	3.540	0.067	0.028
CC X CH	1.6,23.3	3.927	0.043*	0.052
CC X ST	1.7,25.5	3.088	0.071	0.088
CH X ST	2.3,34.2	2.389	0.101	0.048
PR X CC X CH	1.7,25.3	5.121	0.018*	0.021
PR X CC X ST	1.5,22.2	2.847	0.092	0.029
PR X CH X ST	2.8,42.2	3.095	0.040*	0.005
CC X CH X ST	2.7,40.7	12.985	0.000*	0.009
PR X CC X CH X ST	2.3,34.5	0.862	0.443	0.005

* denotes a p value statistically significant at the 0.05% level or greater.

stimuli within the single line procedure evoked greatest mean amplitude across centro/temporo-parietal sites. Within the fragmented procedure target stimuli evoked greatest amplitude across centro/temporo-parietal sites. Mean amplitude evoked by rare nontarget stimuli was greatest at parietal sites.

Analysis of the three way interaction involving the factors of procedure, chain and site demonstrated that the single line procedure evoked greatest mean amplitude across centro/temporo-parietal sites along all three chains. The fragmented procedure evoked greatest mean amplitude at centro-parietal sites along the midline chains. Along the lateral chains amplitude was greatest at parietal sites.

Post hoc analysis of the three way interaction involving the factors of condition, chain and site demonstrated that target stimuli evoked greatest amplitude across centro-parietal sites along the midline chain. Along the lateral chains greater amplitude was evoked at parietal sites than at frontal sites. Rare nontarget stimuli evoked greatest mean amplitude across centro/temporo-parietal sites along all three chains.

Scalp Distribution

A three way interaction involving the factors of condition, chain and site was obtained (see Table 5.3). *Post hoc* analysis demonstrated that target stimuli evoked a maximum amplitude distribution at centro/temporo-parietal sites along the midline and right chains. Along the left chain greater amplitude was distributed over the parietal site than the frontal site (see Figure 5.2a). Rare nontarget stimuli evoked a maximum amplitude distribution at centro/temporo-parietal sites along the midline and left chains. Along the right chain a parietal site maximum amplitude distribution was obtained (see Figure 5.2b).

Post hoc analysis of the three way interaction involving the factors of procedure, condition and chain demonstrated that both classes of rare stimuli within the single line procedure evoked a maximum amplitude distribution along the midline chain (see Figure 5.3a). Within the fragmented procedure target stimuli evoked a maximum amplitude distribution along the midline chain of electrodes. Rare nontarget stimuli evoked an equipotentially distributed response along the three chains of electrodes (see Figure 5.3b).

Post hoc analysis of the interaction involving the factors of procedure, chain and site demonstrated that the single line procedure evoked a maximum distribution at centro/temporo-parietal sites along all three chains (see Figure 5.4a). The fragmented procedure evoked a maximum response at centro/temporo-parietal sites along both the midline and left chains. Along the

Figure 5.2a

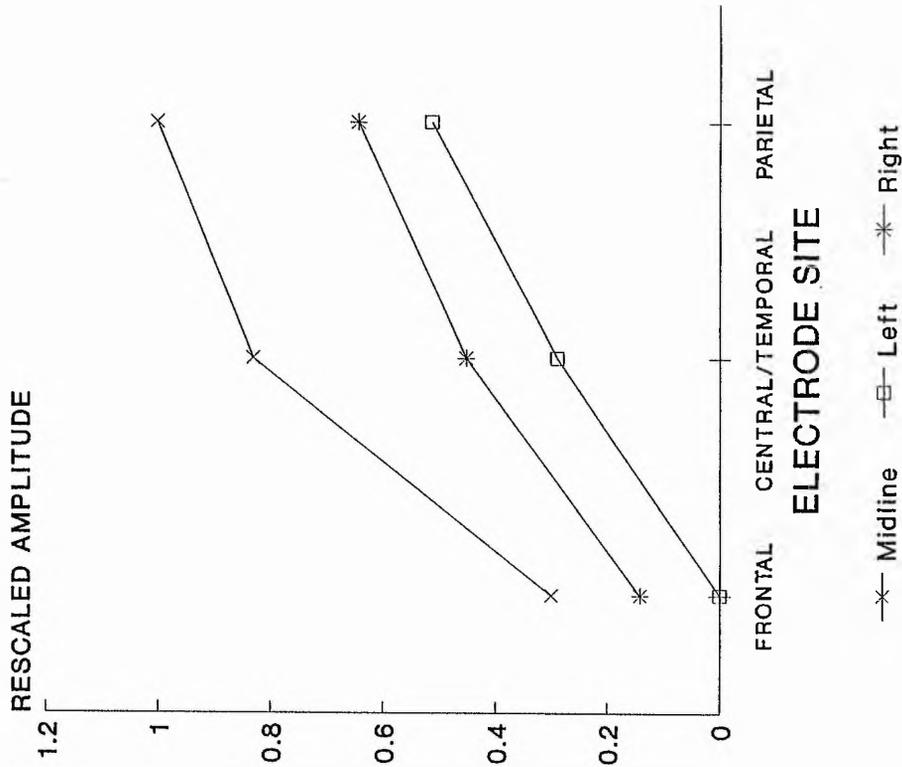


Figure 5.2b

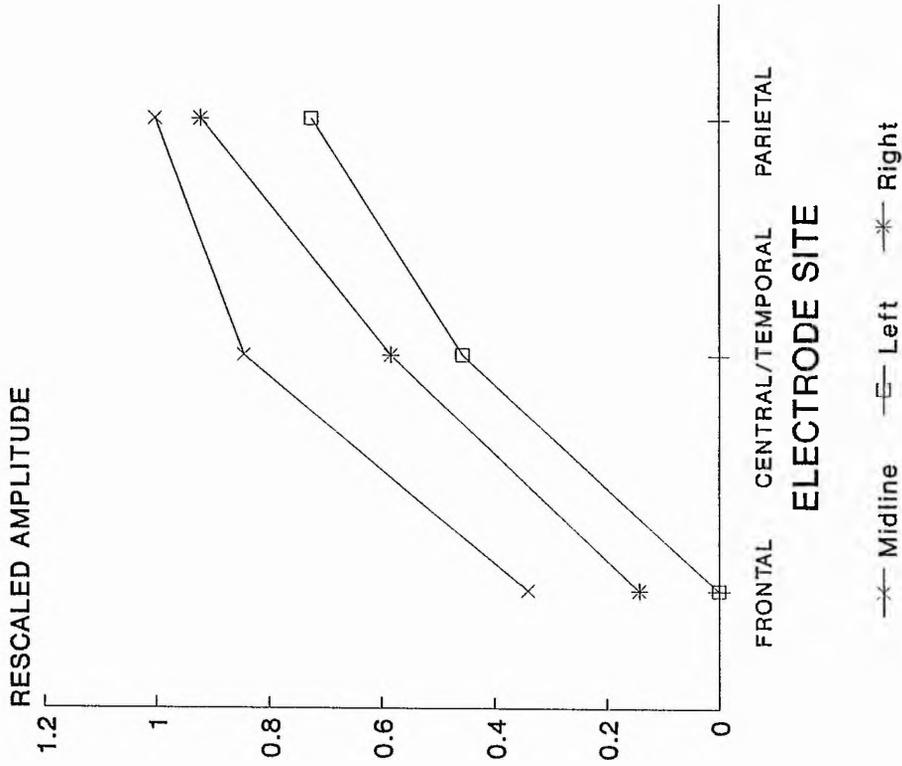


Figure 5.2a and 5.2b Graph illustrating the distributed, across electrode site, of rescaled amplitude of the P300 deflection elicited by target (Figure 5.2a) and rare nontarget (Figure 5.2b) stimuli in Experiment 3.

Figure 5.3a

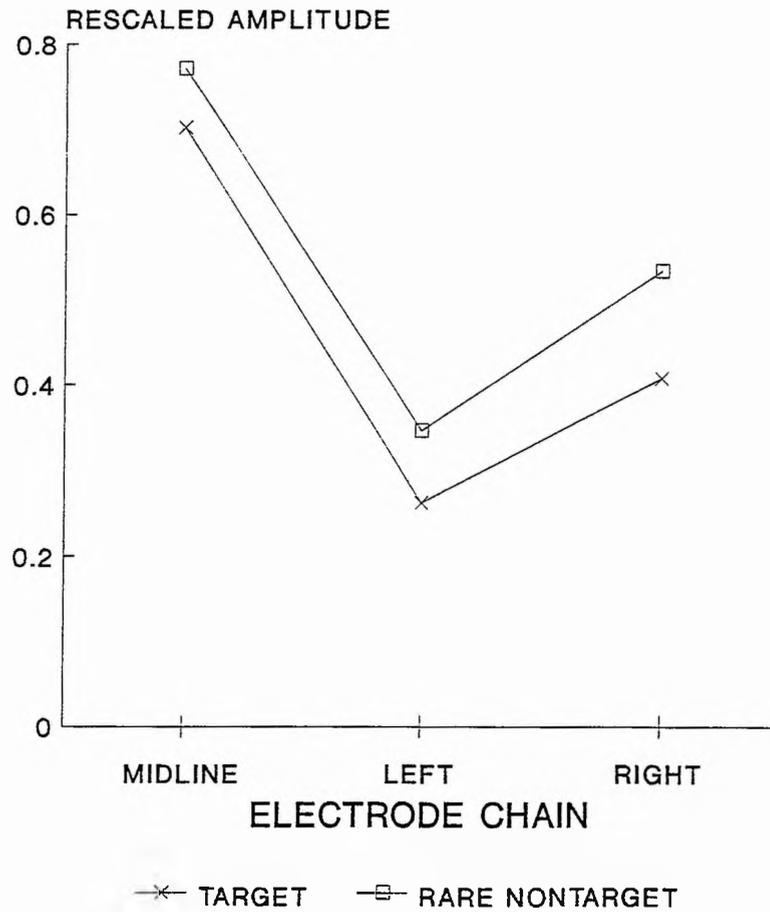


Figure 5.3b

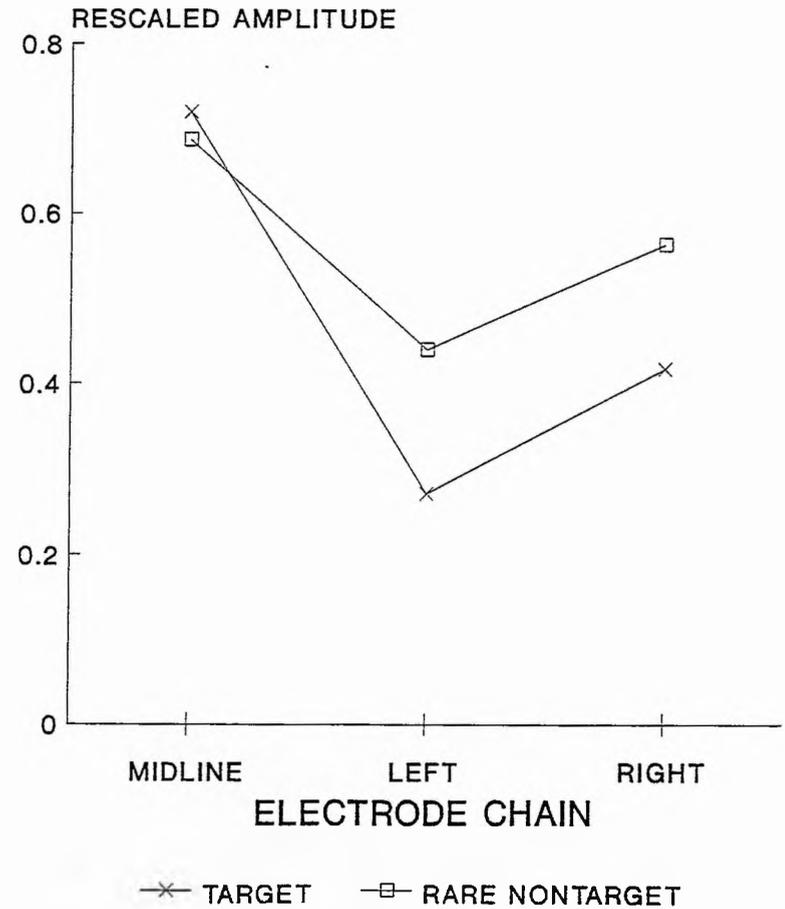
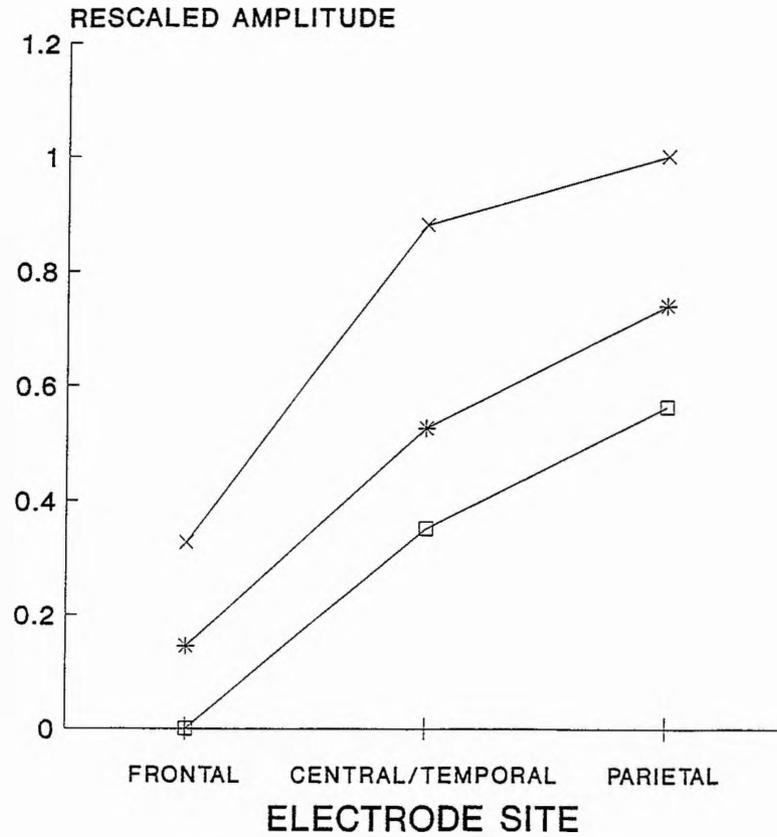


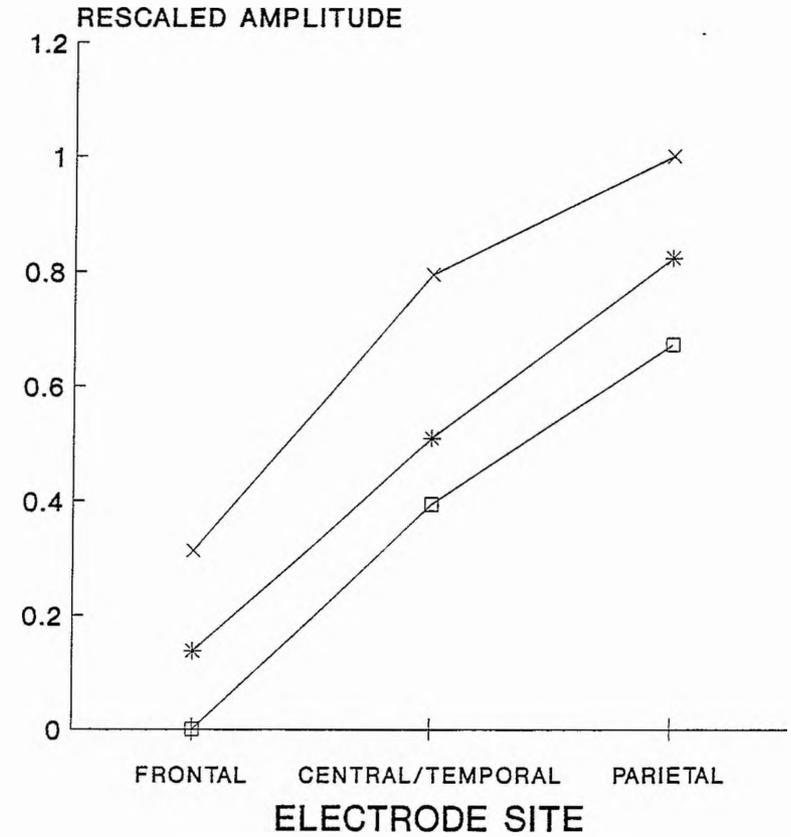
Figure 5.3a and Figure 5.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by the single line (Figure 5.3a) and fragmented (Figure 5.3b) procedures in Experiment 3.

Figure 5.4a



—x— Midline —□— Left —*— Right

Figure 5.4b



—x— Midline —□— Left —*— Right

Figure 5.4a and Figure 5.4b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by the single line (Figure 5.4a) and fragmented (Figure 5.4b) procedures in Experiment 3 (collapsed across experimental condition).

right chain a parietal site maximum amplitude distribution was obtained (see Figure 5.4b).

N100

ANOVA of the frequent, target and rare nontarget latencies along the midline revealed two significant main effects (see Table 5.1 of the Appendix). Analysis of the condition main effect demonstrated that frequent stimuli evoked an N100 deflection significantly earlier than either target or rare nontarget stimuli. However, target stimuli evoked a response that was earlier than that evoked by rare nontarget stimuli.

Analysis of the site effect demonstrated that collapsed across conditions N100 deflections were evoked earlier at frontal and central sites in comparison to the latency demonstrated at parietal sites.

ANOVA of the mean amplitude evoked by the three experimental conditions demonstrated a significant main effect of condition (see Table 5.4 of the Appendix). *Post hoc* analysis demonstrated that rare nontarget stimuli evoked greater amplitude than either the target or frequent stimuli.

A significant four way interaction involving the factors of procedure, condition, chain and site was obtained. *Post hoc* analysis demonstrated that within the single line procedure all three classes of experimental stimuli evoked greatest amplitude at parietal sites along the lateral chains. Along the midline chain the parietal site demonstrated greater amplitude than the frontal or central sites.

Within the fragmented procedure frequent and target stimuli evoked greatest amplitude at parietal sites along the lateral chains. Along the midline the parietal sites demonstrated greater amplitude than either the frontal or central sites. In response to rare nontarget stimuli greater amplitude was demonstrated at the parietal site than at the frontal or central sites along the left chain. Along the right chain the central and parietal site demonstrated greater amplitude than the frontal site. Along the midline amplitude was equally great at each site.

Scalp Distribution

No interaction involving the factors of condition or procedure was found to be significant (see Table 5.4 of the Appendix).

N200 Deflection

ANOVA of the target and rare nontarget N200 latencies along the midline chain failed to demonstrate any significant effects (see Table 5.1 of the Appendix).

ANOVA of the mean amplitude evoked by target and rare nontarget stimuli failed to produce a significant main effect of condition (see Table 5.5 of the Appendix).

A significant four way interaction involving the factors of procedure, condition, chain and site was obtained. *Post hoc* analysis demonstrated that within the single line procedure target stimuli evoked greatest amplitude at frontal sites along the midline and right chains. Along the left chain the temporal site demonstrated greater amplitude than the parietal site. Rare nontarget stimuli evoked greatest amplitude at the frontal sites along the midline and right chains. Along the left chain amplitude was equally great at each of the three sites.

Within the fragmented procedure target stimuli evoked greatest amplitude at frontal sites along the midline and right chains. Along the left chain amplitude was greatest at temporo-frontal sites. Rare nontarget stimuli evoked greatest amplitude at frontal sites along all three chains.

Scalp Distribution

ANOVA of the rescaled amplitude of the N200 deflections produced a significant four way interaction involving the factors of procedure, condition, chain and site (see Table 5.5 of the Appendix). *Post hoc* analysis demonstrated that within the single line procedure target stimuli demonstrated a frontal site maximal amplitude distribution along the midline chain. Along the lateral chains an equipotential amplitude distribution was obtained (see Figure 5.5a). Rare nontarget stimuli similarly demonstrated a frontal site maximal distribution along the midline and right chains. Along the left chain an equipotential amplitude distribution was obtained (see Figure 5.5b).

Within the fragmented procedure target stimuli demonstrated a frontal site amplitude distribution along the midline and right chains (see Figure 5.7a). Along the left chain an equipotential scalp amplitude distribution was obtained. Rare nontarget stimuli demonstrated a frontal distribution along all three chains (see Figure 5.7b).

Figure 5.5a

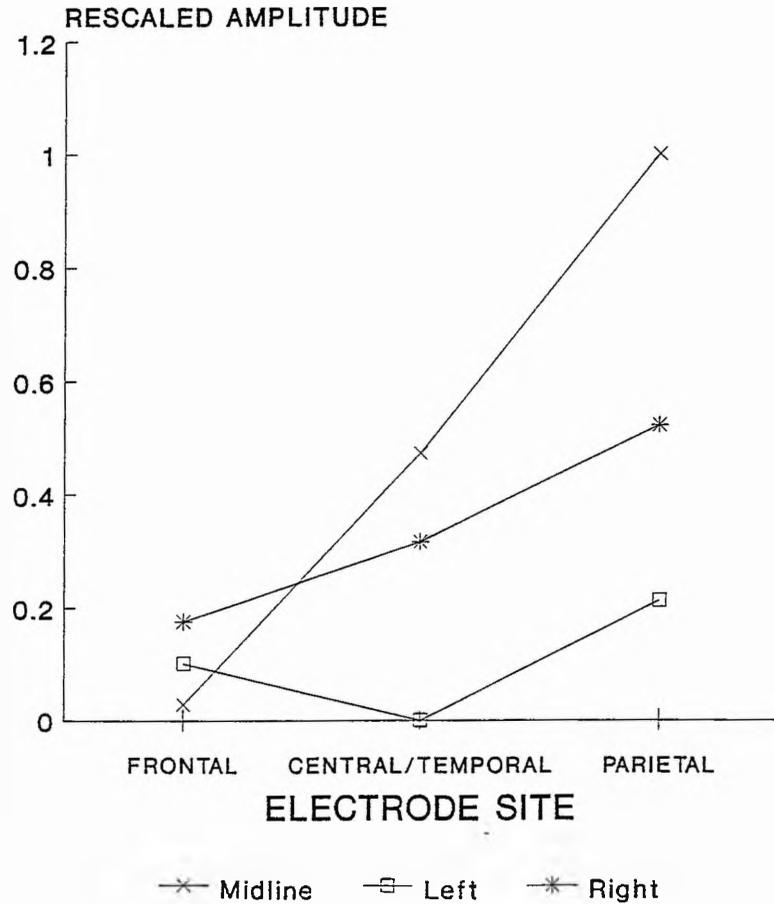


Figure 5.5b

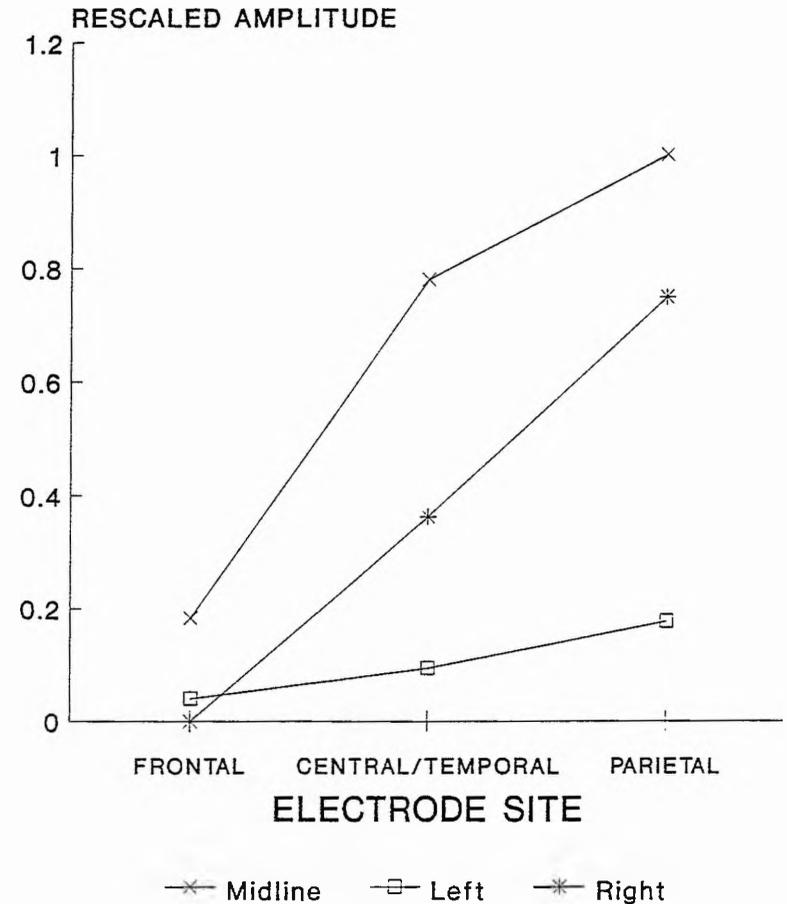


Figure 5.5a and 5.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 5.5a) and rare nontarget (Figure 5.5b) stimuli within the single line procedure of Experiment 3.

Figure 5.6a

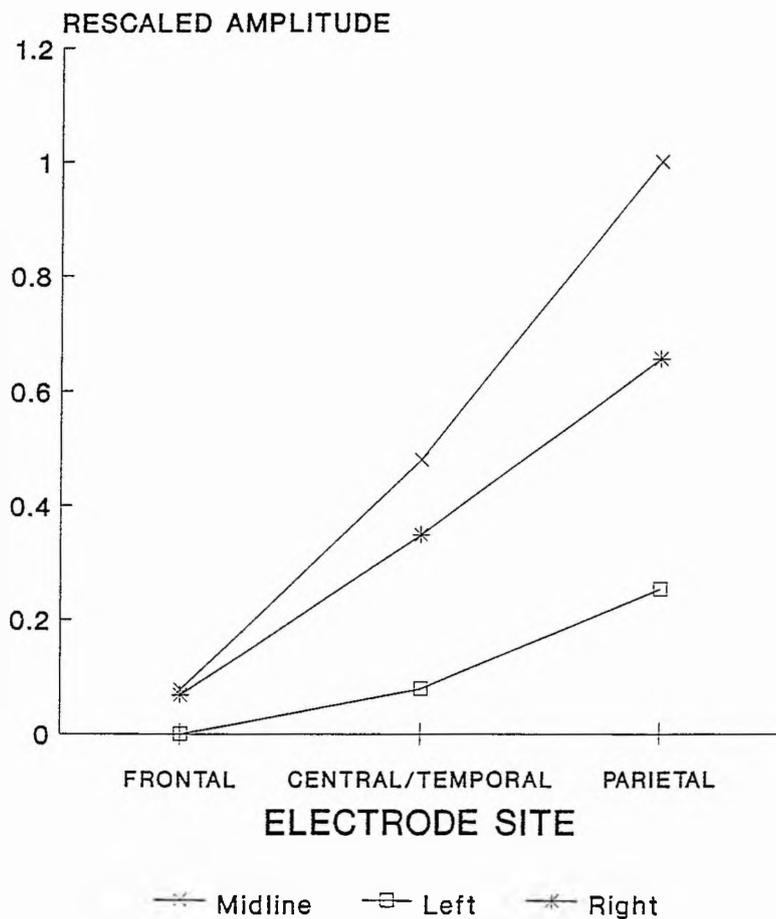


Figure 5.6b

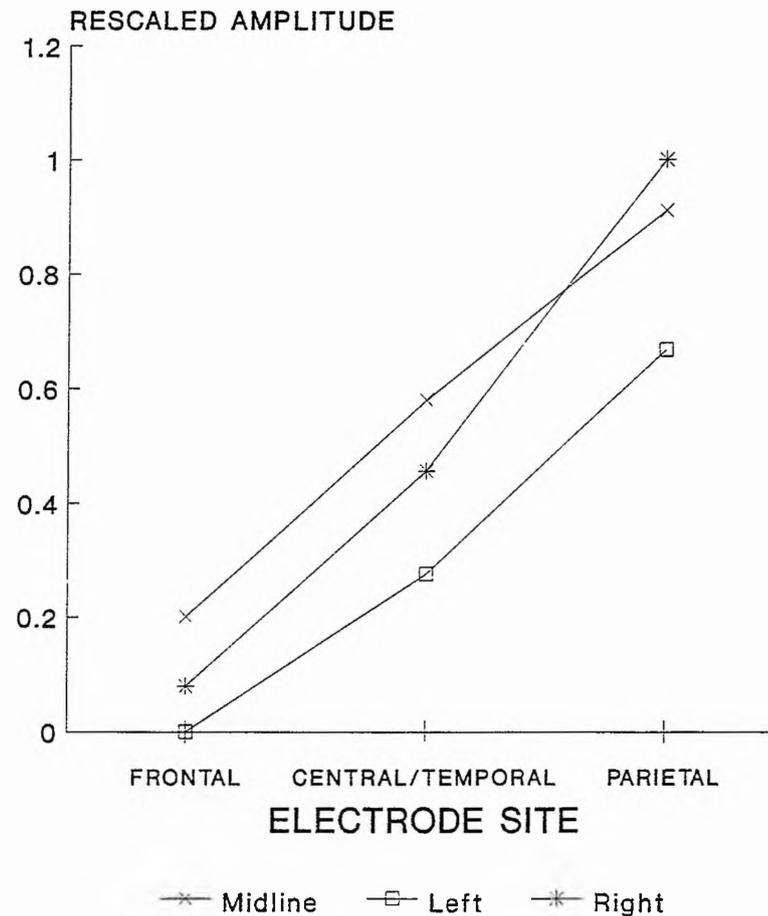


Figure 5.6a and 5.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by target (Figure 5.6a) and rare nontarget (Figure 5.6b) stimuli within the fragmented procedure of Experiment 3.

500 - 850 msec Latency Range

No interaction involving the factor of experimental procedure was significant (see Table 5.6 of the Appendix).

Post hoc analysis of the condition main effect demonstrated that target stimuli evoked greater amplitude than either frequent or rare nontarget stimuli. However, the rare nontarget stimuli evoked greater amplitude than the frequent stimuli.

A significant three way interaction was obtained involving the factors of condition, chain and site. *Post hoc* analysis demonstrated that in response to frequent stimuli along the lateral chains greater amplitude was evoked at the temporal sites than at either the frontal or parietal sites. Along the midline chain equipotential amplitude was evoked at each site. In response to target stimuli the parietal electrode along the midline and left chains demonstrated greatest amplitude. Along the right chain the parietal and temporal sites demonstrated greater amplitude than the frontal site. In response to rare nontarget stimuli the parietal and centro/temporal sites demonstrated greater amplitude than the frontal site along the midline and right chains. Along the left chain the temporal site evoked the greatest amplitude.

Scalp Distribution

A significant three way interaction was obtained involving the factors of procedure, chain and site (see Table 5.6 of the Appendix). *Post hoc* analysis demonstrated that within both procedures the lateral chains demonstrated a temporal site maximal amplitude distribution. Within the single line procedure the central and parietal sites demonstrated greater amplitude distribution than the frontal site along the midline. Within the fragmented procedure the central site demonstrated greater amplitude distribution than either the frontal or parietal sites.

Post hoc analysis of the three way interaction involving the factors of condition, chain and site demonstrated that along the midline chain frequent stimuli evoked a centro-parietal maximum amplitude scalp distribution. Along the lateral chains a central site maximum amplitude distribution was obtained (see Figure 5.8a). Target stimuli evoked a centro-parietal maximum amplitude distribution along the midline chain. Along the lateral chains a parietal site maximum amplitude was obtained (see Figure 5.8b). Rare nontarget stimuli evoked a centro/temporo-parietal maximum amplitude distribution along all three chains (see Figure 5.8c).

Figure 5.7a

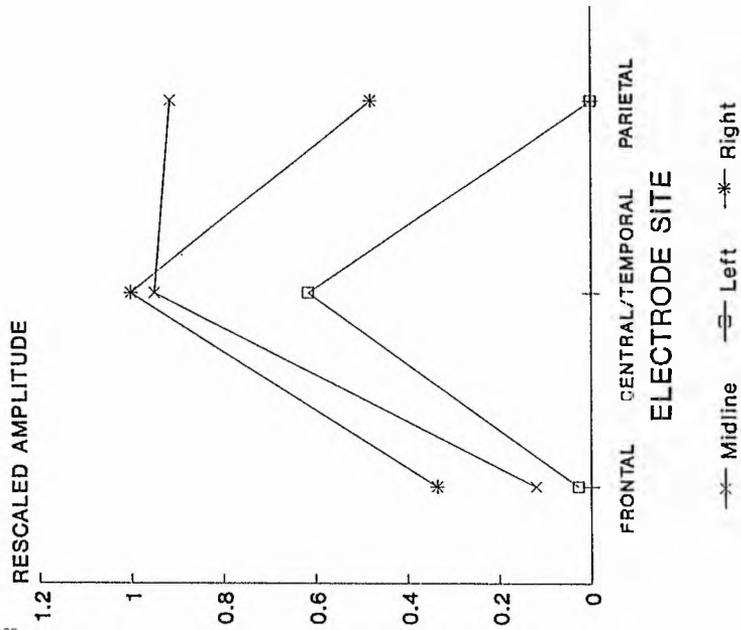


Figure 5.7b

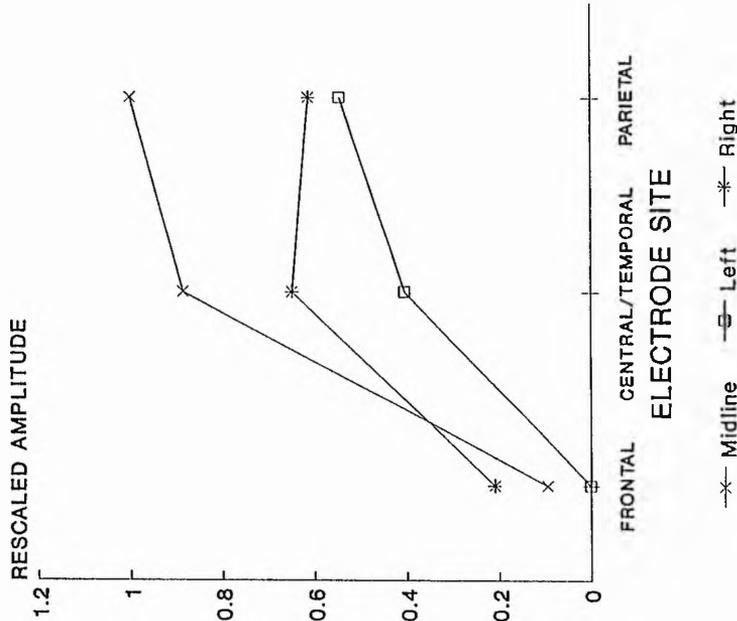


Figure 5.7c

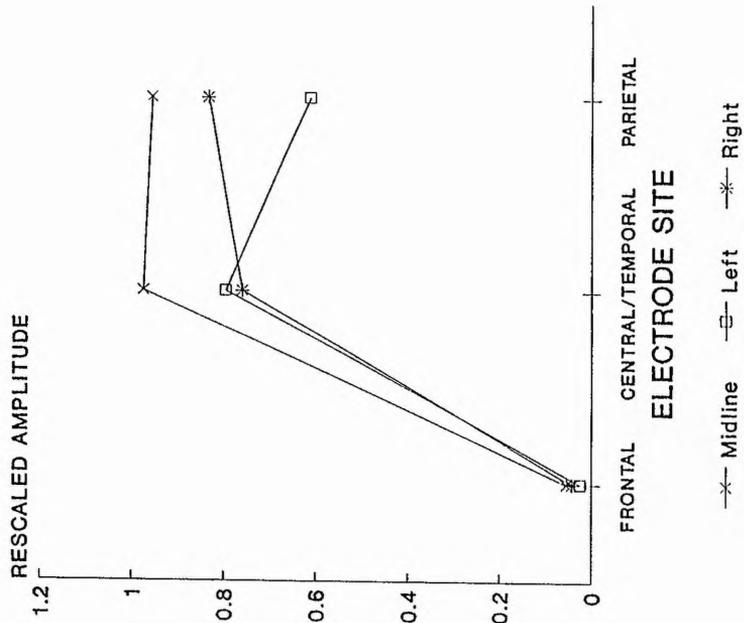


Figure 5.7a, 5.7b and 5.7c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited by frequent (Figure 5.7a), target (Figure 5.7b) and rare nontarget (Figure 5.7c) stimuli in Experiment 3 (collapsed across experimental procedure).

150 - 350 msec Latency Range at Lateral Parietal Sites

ANOVA of the mean amplitude in the latency range 150 - 350 msec produced a significant two way interaction involving the factors of procedure and condition (see Table 5.7 of the Appendix). *Post hoc* analysis demonstrated that within the single line procedure all three classes of experimental stimuli evoked mean amplitude that was similar (see Figure 5.9a). Within the fragmented line procedure rare nontarget stimuli evoked greater mean amplitude than that evoked by either target or frequent stimuli (see Figure 5.9b).

5.5 Discussion

The aim of this experiment was to determine whether manipulations of the spatial location of rare nontarget stimuli would produce a dissociation of target and rare nontarget responses on the basis of scalp amplitude distribution. It was predicted that rare nontarget stimuli would elicit a P300 response with a more anterior scalp distribution than that obtained in response to target stimuli.

Target and rare nontarget stimuli both elicited positive deflections within the latency range of the P300 component. Both deflections evoked a response with a maximum scalp amplitude distribution along the midline chain across centroparietal sites. Similar deflections were reported in Chapters 3 and 4 in response to visual target and rare nontarget stimuli. The results failed to support a dissociation of P300 target and rare nontarget responses on the basis of scalp amplitude distribution as previously reported by Courchesne *et al.* (1975; 1978) and Knight (1991; personal communication).

As reported previously, Courchesne *et al.* (1978) argued that the greater the contrast (dissimilarity) between the rare stimuli and the frequent background sequence of stimuli the greater the amplitude of the P300 deflection evoked. Varying the spatial location of the rare nontarget stimuli in relation to the spatial location of frequent and target stimuli was predicted to increase the contrast between rare nontarget and frequent stimuli in comparison to the contrast between target and frequent stimuli. However, varying the spatial location of rare nontarget stimuli failed to increase the so-called "deviant" nature of the stimuli since, collapsed across sites and experimental procedure, both classes of stimuli evoked comparable mean amplitude. Rare nontarget stimuli evoked a deflection with a mean amplitude of 12.9 microvolts while target stimuli evoked a deflection with a mean amplitude of 11.6 microvolts.

Figure 5.8a

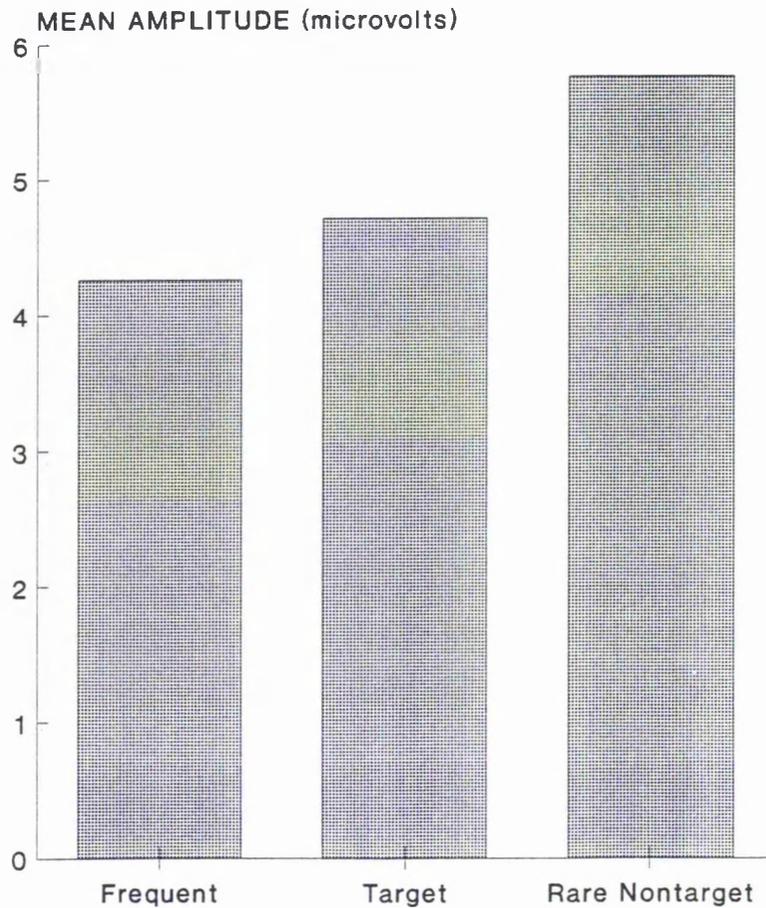


Figure 5.8b

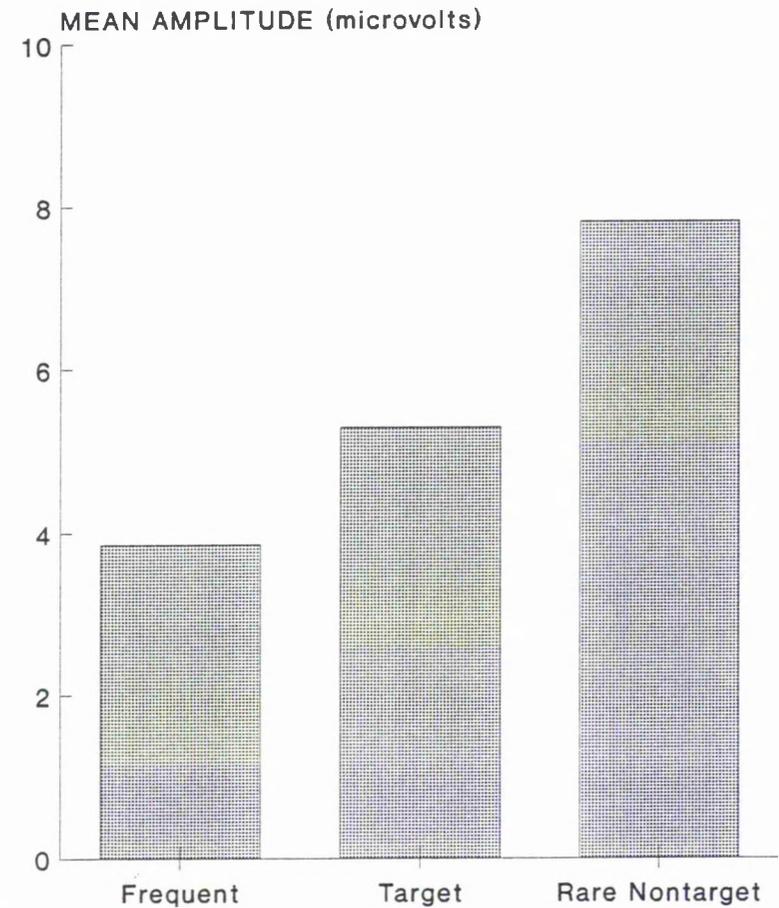


Figure 5.8a and 5.8b Bar diagrams illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the single line (Figure 5.8a) and fragmented (Figure 5.8b) procedures between 150 - 350 msec at lateral parietal electrode sites (collapsed across electrode sites) in Experiment 3.

As reported in Chapter 4 the peak latency of the rare nontarget P300 response was significantly earlier than that of the target response. In contrast to findings reported in Chapter 4 no difference was obtained between the peak latencies of the target and rare nontarget N200 responses. Within the N100 latency range frequent stimuli evoked an N100 deflection with a significantly shorter latency in comparison to either target or rare nontarget stimuli. However, target stimuli evoked a response with a significantly shorter latency than that evoked in response to rare nontarget stimuli. Such an effect was not obtained in either Experiment 1 or 2. A possible explanation to account for the difference in latency of the N100 ERP between frequent and rare nontarget stimuli is that rare nontarget stimuli were presented in the periphery of the screen and so subjects may not have immediately attended to them since their attention was directed towards the centre of the screen. However, such an explanation fails to account for the difference in latency obtained between target and frequent stimuli both of which were presented at the same spatial location.

The N100 deflection elicited by rare nontarget stimuli evoked greater mean amplitude (collapsed across sites) than that evoked in response to frequent or target stimuli. The reduced amplitude evoked in response to frequent stimuli in comparison to that evoked in response to rare nontarget stimuli may be due to the N100 generating neurons becoming refractory upon repeated presentation of the same stimulus (Näätänen and Picton 1987). However, such an explanation fails to account for the similar mean amplitude evoked in response to both target and frequent stimuli. On the basis of a refractory explanation it would be hypothesised that frequent stimuli would evoke a response with less mean amplitude than that evoked in response to target stimuli. As previously discussed (see section 3.7.2 and 4.5), the modality specificity of the refractory nature of the N100 neurons discussed by Näätänen and Picton (1987) is uncertain. All three classes of experimental stimuli evoked similar centroparietal distributions along the midline chain. Such an amplitude distribution would suggest that a similar generator, or combination of generators, are responsible for the generation of the N100 deflection across experimental conditions.

Target and rare nontarget responses within the N200 latency range demonstrated a dissociation of responses across the two experimental procedures. Within the fragmented line procedure both target and rare nontarget responses demonstrated an N200 deflection. As described in section 1.5.4.1 the response obtained in response to target stimuli may correspond to

an N2b component. An N2b component may be elicited by deviants in active discrimination paradigms (Näätänen 1992). While the response obtained in response to rare nontarget stimuli may correspond to a MMN (N2a) component. As previously stated (see section 3.7.2) in an oddball task when subjects are attending to all stimuli it is possible that the "fronto-central" N200 deflection is a composite of MMN (N2a) and N2b components which overlap in time and scalp distribution.

Within the single line procedure the N200 deflection evoked in response to rare nontarget stimuli appeared to be less negative in comparison to the deflection evoked in response to rare nontarget stimuli within the fragmented line procedure (see Figure 5.1a and 5.1b). Such a reduction of a possible MMN (N2a) component of the N200 deflection may be caused by a reduction of deviance of the rare nontarget stimuli within the single line procedure. The response to target stimuli, a possible N2b component of the N200 deflection, failed to demonstrate such a dissociation between procedures (see Figure 5.1a and 5.1b). This similarity between procedures may be explained by the fact that the N2b component of the N200 deflection is elicited by the allocation of attention to the eliciting stimuli (that is the target stimuli).

The observed dissociation between the rare nontarget stimuli between experimental procedures (fragmented versus single line procedures) was greater than any dissociation observed between experimental conditions (target versus rare nontarget condition) within experimental procedures (see Figure 5.5b and 5.7b). This may reflect the difficulty of accurately measuring the N200 deflection. The possibility exists that the rare nontarget N200 deflection within the single line procedure may have been made more "positive" going by the P300 rare nontarget response.

Rare nontarget stimuli within the fragmented line procedure elicited greater mean amplitude in comparison to that evoked in response to frequent and target stimuli at lateral parietal sites within a latency range of 150 - 350 msec. As previously reported in Chapter 3 and 4 such a result supports the claim made by Wijers *et al.* (1989a; 1989b) that ERPs evoked by attended stimuli show a prolonged negative shift compared to ERPs to unattended stimuli if the two classes (to be attended; not to be attended) may be discriminated on the basis of simple physical attributes. Within the present procedure stimuli were able to be discriminated on the basis of stimulus contour.

However, within the single line procedure no occipital negativity was obtained. Such a result may be hypothesised to have occurred since no selection cue (see Wijers *et al.* 1989a; 1989b) existed between the attended and

unattended stimuli. Target stimuli were discriminated from rare nontarget stimuli on the basis of a spatial cue rather than a physical attribute since all three classes of experimental stimuli had similar contour characteristics. In comparison within the fragmented line procedure stimuli could be discriminated on the basis of a physical characteristic (contour of the stimulus) as well as on the basis of a spatial cue.

The experimental condition variable in the form of rare nontarget stimuli being presented around the periphery of the screen failed to affect the P300 or any other measured component of the waveform. However the experimental procedure variable in the form of whether rare nontarget stimuli consisted of either fragmented or single line rare nontarget stimuli influenced the mean amplitude evoked within the 150 - 350 msec latency range and the N200 deflections. However, experimental procedure failed to affect the P300 deflections.

The prediction that altering the spatial location of rare nontarget stimuli would increase the intrusive nature of such stimuli and hence alter the scalp amplitude distribution of the rare nontarget P300 response was not supported by the experimental data. Alteration of the spatial position of the rare nontarget stimuli failed to increase the output of the underlying neural generators in comparison to the output obtained in response to target stimuli.

Summary

Target and rare nontarget stimuli both elicited P300 deflections with a centro-parietal scalp amplitude distribution along the midline chain of electrodes.

Chapter 6

Experiment 4: Investigation of Mean Amplitude and Scalp Amplitude Distribution Evoked by Three Classes of Equiprobable Stimuli.

6.1 Introduction

As discussed in section 1.3 the amplitude of the P300 deflection evoked within an oddball task is modulated by stimulus probability. The amplitude varies as an inverse function of stimulus probability (Polich 1990; Tueting *et al.* 1971). Overall stimulus probability may be made up from either temporal or sequential probability.

Karlin and Martz (1973) presented subjects with three different tones. Two of the tones signalled the pressing of one button and the third the pressing of a second button. P300 amplitude depended upon the probability of the response more than the probability of the stimulus. Similar effects were observed when subjects responded to a particular target event within a sequence of varying nontarget stimuli each of which had a probability equal to or lower than that of the targets. The nontarget stimuli elicited a small P300 deflection despite their individually low probabilities because the nontarget stimuli together had a high category probability. Such findings indicate that subjects compute expectancies in terms of task related stimulus categories that call for particular cognitive or motor responses.

Courchesne *et al.* (1977) argued that a straightforward relationship does not exist between the amplitude of the P300 deflection and *a priori* stimulus probability. It was reported that the P300 responses to targets consisting of the letter "B" or pseudo-random letters and numbers were all similar in amplitude even though the *a priori* probability of each "B" was more than 20 times greater than that of each letter or number.

As described in section 1.5.4.3 target stimuli, and stimuli with features in common with task-relevant stimuli, elicit modality specific (posterior) negative waves, the so-called selection negativity deflections (Czigler and Csibra 1992). Harter and Guido (1980) presented subjects with three equiprobable visual stimuli in random order. One class of stimulus, a diffuse flash, was very different from the remaining two stimuli which were similar to each other, one being a patterned flash with horizontal, the other with vertical, gratings. The

subject's task was to press a button as quickly as possible to one of the three stimuli designated as the target. Harter and Guido (1980) reported that occipital (Oz) potentials following relevant, as compared to irrelevant, flashes were relatively more negative between 150 and 250 msec. This attentional negativity was reflected by an increased negativity over occipital cortex, a small increase in positivity at central (Cz) and larger positivity at frontal (Fz) cortex.

Harter and Guido (1980) further postulated that the positive deflections reported at approximately 300 and 370 msec post stimulus presentation may have reflected two underlying processes. The anterior deflection was reported to be largest in amplitude to nontarget stimuli and had a central-frontal distribution. This deflection was thought to reflect selection only between diffuse and patterned stimuli. The later deflection was widely distributed with maximum amplitude over central-occipital cortex. This deflection was thought to reflect selection between the orientations of stimuli or selection of the target *per se*. The characteristics of these two deflections are similar to those associated with the P3a and P3b components previously reported (Courchesne *et al.* 1975; Squires *et al.* 1975; Ford *et al.* 1976; Snyder and Hillyard 1976). However, the earlier latency centro-frontal positive deflection occurred in the Harter and Guido (1980) study in response to equiprobable rather than rare, ignored stimuli.

The results of previous experiments employing visual stimuli (see Chapter 4 and 5) demonstrated that target and rare nontarget stimuli evoked similar mean P300 amplitude (collapsed across sites). The scalp distribution of the P300 deflections evoked by target and rare nontarget stimuli were also similar. The aim of this experiment was to determine whether rare nontarget stimuli were classified by subjects as simply another form of frequent, to be ignored stimuli. That is, the aim was to determine whether subjects treated the three stimulus oddball procedure consisting of target, rare nontarget and frequent stimuli as simply a two stimulus oddball procedure of target stimuli and a metaclass of frequent nontarget stimuli. Subjects may be hypothesised to detect the lower probability of occurrence of the rare nontarget stimuli within the metaclass of frequent nontarget stimuli, however, cognitive processing may proceed no further than a proposed "no target therefore ignore" stage. Such a perceived lower probability may account for the increased amplitude of the rare nontarget P300 response in comparison to the frequent P300 response. If in previous experiments rare nontarget stimuli were categorised as another class of frequent to be ignored stimuli within this experiment a similar mean

P300 amplitude and scalp amplitude distribution would be expected between the simple and complex stimuli. Similar results would be expected since each class of stimuli had identical probabilities of occurrence and neither required an overt behavioural response to be made on the part of the subject.

Within the present experiment, within one procedure, the overall subjective probability of the three classes of stimuli was the same (each of 33.3%). If rare nontarget stimuli were regarded as another class of frequent to be ignored stimuli it would be predicted that similar mean amplitude and scalp distributions would be obtained between "frequent" and "rare nontarget" stimuli.

Within a second procedure target stimuli were presented with a probability of 33.3% while nontarget stimuli were presented with a probability of 66.6%. Between procedures it would be predicted that similar mean amplitudes and scalp distributions would be obtained for target stimuli P300 deflections since across procedures similar subjective probabilities and task relevant characteristics existed for the class of target stimuli.

6.2 Method

Subjects

The subjects were 16 university students (mean age 23.4 years, range 20 - 32 years, eight females). Three subjects had previously participated in ERP experiments.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram activity was recorded from the scalp montage described in section 2.5 using a proprietary electrode cap.

Stimuli

Stimuli were adapted from the triangle procedure described in section 4.2.3. Three classes of experimental stimuli were employed. Target stimuli consisted of either an inverted or upright single line triangle subtending a visual angle of 2 degrees (see Figure 4 and 5 in the Appendix).

Two classes of nontarget stimuli were employed. The first class consisted of either an upright or inverted single line triangle. The target stimuli within this procedure were the opposite of the employed nontarget stimuli (*i.e.* either an

inverted or upright triangle) such nontarget stimuli will be referred to as "simple" stimuli. The second class of stimuli consisted of a set of 45 heterogeneous mutilated single line triangles with broken or distorted outlines (see Figure 6 of the Appendix). Each stimulus was presented two or three times during the experimental run. This class of stimuli will be referred to as the "complex" stimuli. Target and simple nontarget stimuli were alternated across subjects.

Procedure

Two procedures were employed in this experiment to examine the effect of probability upon the amplitude and scalp distribution of the P300. In the first procedure three classes of stimuli each with an probability of 33.3% were employed. This procedure will be referred to as the "three condition" procedure.

In the second procedure only target and simple stimuli were presented. Target stimuli occurred with a probability of occurrence of 33.3% while simple stimuli occurred with a probability of 66.6%. In order to maintain the same temporal probability of target stimuli between procedures the same stimulus sequence lists were employed. Each complex stimulus which occurred within the three condition procedure was substituted for a simple stimulus. This procedure will be referred to as the "two condition" procedure.

Each subject performed both a three and two condition procedure. Order of presentation of procedures was alternated between subjects. Each procedure consisted of 300 experimental stimuli presented in blocks of 100 with a one minute rest period between blocks. Between experimental procedures a rest period of five minutes was provided.

As described in section 2.4 a practice block of 15 stimuli was presented to the subjects with the instructions to respond to the target stimuli. Following the block of practice trials the experimental run was presented. In the case of the two condition procedure subjects were informed that their task was the same as during the practice block. In the case of the three condition procedure subjects were informed that the task was the same as during the practice trials they were also told that they would see "fragmented single white line shapes" but were to refrain from responding to them.

6.3 Data Analysis

Latency Data

Peak latencies were determined for the P300, N100 and N200 deflections. In the case of the two condition procedure latency values were determined for each deflection elicited by the simple and target stimuli. In the case of the three condition procedure latency values were determined for each deflection elicited by the simple, target and complex stimuli. ANOVAs were performed on the data for each component for each experimental procedure separately. Such ANOVAs took the form of Subject X Condition X Site.

Amplitude Data

See section 2.6.3 for a description of the ANOVAs performed upon the amplitude data. Separate ANOVAs were carried out upon the data for each component from each experimental procedure. Separate latency windows were determined for each deflection of the waveform for each class of experimental stimuli within each subject. The ANOVAs took the form of Subject X Condition X Chain X Site. In the case of the three condition procedure a further analysis was performed on the mean amplitude within a latency range of 150 - 350 msec across the three classes of experimental stimuli at lateral parietal sites.

Further ANOVAs were performed in order to compare the mean amplitude of P300 target and simple deflections between experimental procedures. Such ANOVAs took the form of Subject X Procedure X Chain X Site.

Scalp Distribution

As described in section 2.6.4 in order to examine the scalp distribution of the responses evoked in response to the various classes of experimental stimuli ANOVAs were performed upon the rescaled amplitude data for each component within each procedure separately. The ANOVAs took the form of Subject X Condition X Chain X Site.

Further ANOVAs were performed in order to compare the scalp amplitude distribution of P300 target and simple stimuli deflections between experimental procedures. Such ANOVAs took the form of Subject X Procedure X Chain X Site.

6.4 Results

6.4.1 Behavioural Performance

The mean reaction time to target stimuli within the two condition procedure was 438 msec with a standard deviation across subjects of 103 msec. The mean rate for correctly detected targets was 99.7% and the mean false positive rate was 0.41%.

The mean reaction time to target stimuli within the three condition procedure was 435 msec with a standard deviation across subjects of 93 msec. The mean rate for correctly detected targets was 99.1% and the mean false positive rate was 0.66%. A t-test demonstrated that there was no significant difference between reaction times of the two procedures in response to target stimuli ($t(15) = -1.17$ $p = 0.13$).

6.4.2 ERP Data

Grand average waveforms (see Figure 61.a and 61.b) were produced for both the two and three condition procedures.

Table 6.0 Mean (range) number of trials making up each waveform within each procedure.

	Two Condition	Three Condition
Simple Stimuli	162 (148-194)	89 (61-99)
Target Stimuli	87 (60-99)	92 (69-100)
Complex Stimuli	Not Applicable	88 (66-98)

Both classes of stimuli within the two condition procedure evoked an N100 deflection that was largest at lateral parietal sites (see Figure 6a.1). Following the resolution of the N100 deflection an N200 deflection was observed at anterior scalp sites that demonstrated greater negativity in response to simple stimuli in comparison to target stimuli.

A P300 deflection was evoked by both classes of stimuli, however, across the scalp sites the deflection evoked by the target stimuli was more positive in comparison to that evoked by the simple stimuli. The P300 deflection was

followed by a period of sustained positivity at posterior sites in comparison to anterior sites in response to target stimuli.

All three classes of stimuli within the three condition procedure evoked an N100 deflection that was largest at lateral parietal sites (see Figure 6b.1). The N100 deflection was followed by an N200 deflection that demonstrated greater negativity at anterior scalp sites in comparison to that at posterior sites. Both target and complex stimuli evoked a more negative N200 deflection in comparison to that evoked in response to simple stimuli. A P300 deflection was evoked by all three classes of stimuli, however, greater positivity was evoked by complex and target stimuli in comparison to the simple stimuli at posterior sites.

Following the resolution of the P300 deflection target stimuli demonstrated a period of sustained positivity at posterior sites. Complex stimuli demonstrated greater positivity across the scalp in comparison to simple stimuli. Following the resolution of the N100 deflection and the peak of the P300 deflection complex stimuli demonstrated a period of sustained positivity in comparison to both simple and target stimuli.

Table 6.13.1 and 6.13.2 of the Appendix demonstrate the mean amplitude and the mean rescaled amplitude elicited within the two condition procedure by experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain. Mean amplitude evoked by the three classes of stimuli at lateral parietal sites within a 150 - 350 msec latency range are also shown. Similarly Table 6.13.3 and 6.13.4 demonstrate the mean amplitude and the mean rescaled amplitude elicited within the three condition procedure.

6a.4 Two Condition Procedure

P300 Deflection

ANOVA of the P300 peak latencies evoked by simple and target stimuli along the midline chain produced no significant main effect or interaction (see Table 6.1 of the Appendix).

ANOVA of the mean amplitude evoked by the two classes of stimuli produced a significant main effect of condition (see Table 6.3). Examination of the means of the mean amplitude revealed that target stimuli evoked significantly greater amplitude than simple stimuli.

Figure 6a.1

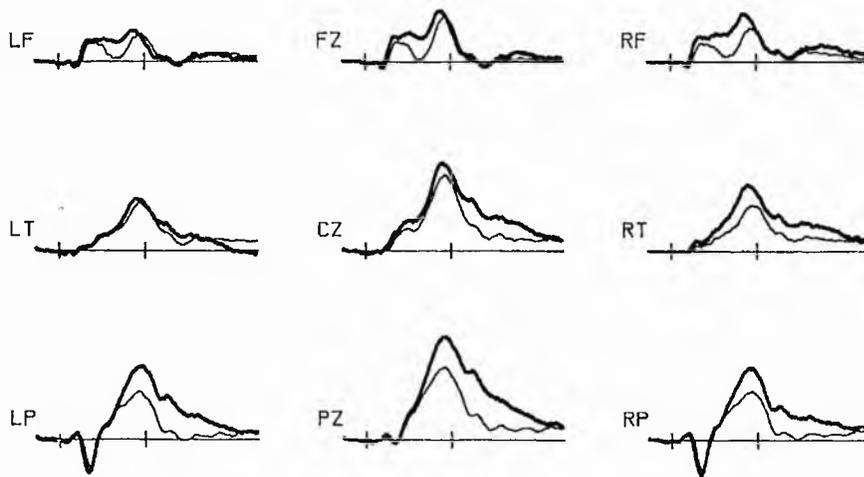


Figure 6b.1

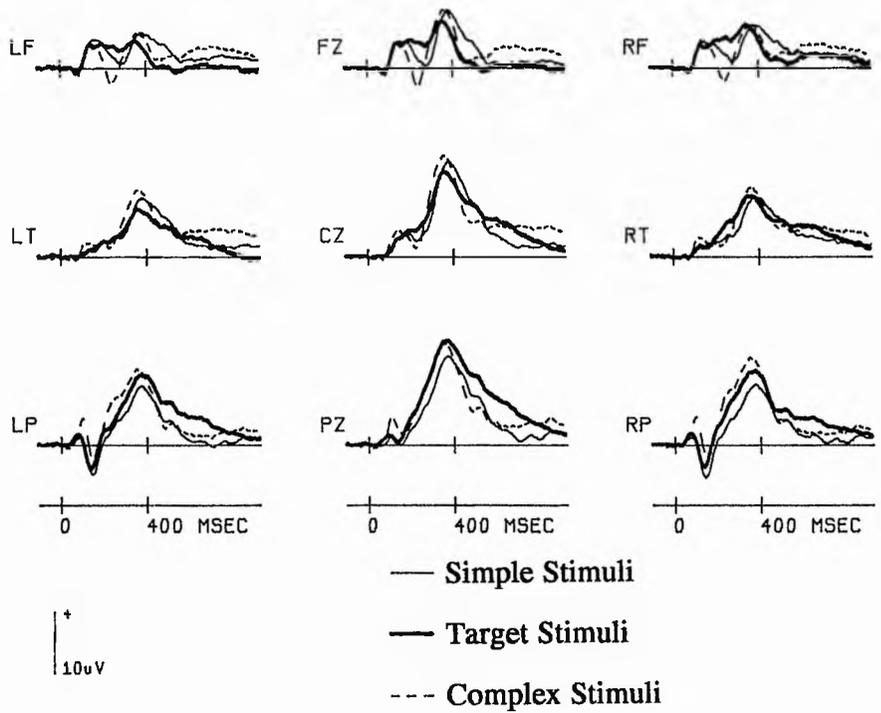


Figure 6a.1 and 6b.1, Waveforms, averaged across 16 subjects, for each condition of the two condition procedure (Figure 6a.1) and three condition procedure (Figure 6b.1) in Experiment 4.

Table 6.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by simple and target stimuli within the two condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,15	19.973	0.000*	44.482
Chain CH	1.9,29.2	31.315	0.000*	13.224
Site ST	1.5,21.8	26.346	0.000*	27.867
Interactions				
CC X CH	1.9,27.9	5.172	0.014*	2.804
CC X ST	1.6,23.8	7.059	0.006*	5.612
CH X ST	2.7,39.8	16.194	0.000*	2.019
CC X CH X ST	3.1,46.3	13.093	0.000*	0.482
Rescaled Amplitude				
Main Effects				
Condition CC	1,15	0.055	0.816	0.606
Chain CH	1.9,28.4	31.382	0.000*	0.163
Site ST	1.5,22.0	25.908	0.000*	0.272
Interactions				
CC X CH	1.7,25.4	7.128	0.005*	0.030
CC X ST	1.6,24.6	2.917	0.082	0.051
CH X ST	2.7,40.4	15.629	0.000*	0.020
CC X CH X ST	2.9,42.8	10.683	0.000*	0.005

* denotes a p value statistically significant at the 0.05% level or greater.

A significant three way interaction involving the factors of condition, chain and site was obtained. *Post hoc* analysis demonstrated that simple stimuli evoked greater mean amplitude at parietal and central sites in comparison to the frontal site along the midline chain. Along the lateral chains equal mean amplitude was obtained at each site. In response to target stimuli greater mean amplitude was evoked at parietal and central sites in comparison to the frontal site along the midline. Along the left chain greater mean amplitude was obtained at the parietal site in comparison to the frontal site. Along the right chain equal amplitude was obtained at each site.

Scalp Distribution

ANOVA of the mean rescaled amplitude evoked by the two classes of experimental stimuli produced a significant three way interaction involving the factors of condition, chain and site (see Table 6.3). *Post hoc* analysis demonstrated that simple stimuli demonstrated a centro/temporo-parietal maximum scalp amplitude distribution along both the midline and left chains. Along the right chain an equipotential amplitude scalp distribution was obtained (see Figure 6.2a).

In response to target stimuli a centro-parietal maximum scalp amplitude distribution was obtained along the midline. Along the left chain greater amplitude was distributed at the parietal in comparison to the frontal site. Along the right chain an equipotential amplitude distribution was obtained (see Figure 6.2b).

N100 Deflection

ANOVA of the peak latencies of the experimental stimuli along the midline chain demonstrated a significant main effect of electrode site (see Table 6.1 of the Appendix). *Post hoc* analysis demonstrated that, collapsed across experimental conditions, the frontal site demonstrated an earlier peak latency in comparison to both the parietal and central sites (see Table 6.2 of the Appendix).

ANOVA of the mean amplitude evoked by the three classes of experimental stimuli produced no significant main effect or interaction involving the factor of experimental condition (see Table 6.4 of the Appendix). A significant two way interaction involving the factors of chain and site was obtained. *Post hoc* analysis demonstrated that along the midline chain equipotential mean amplitude was obtained across the sites. Along the lateral chains the parietal

Figure 6.2a

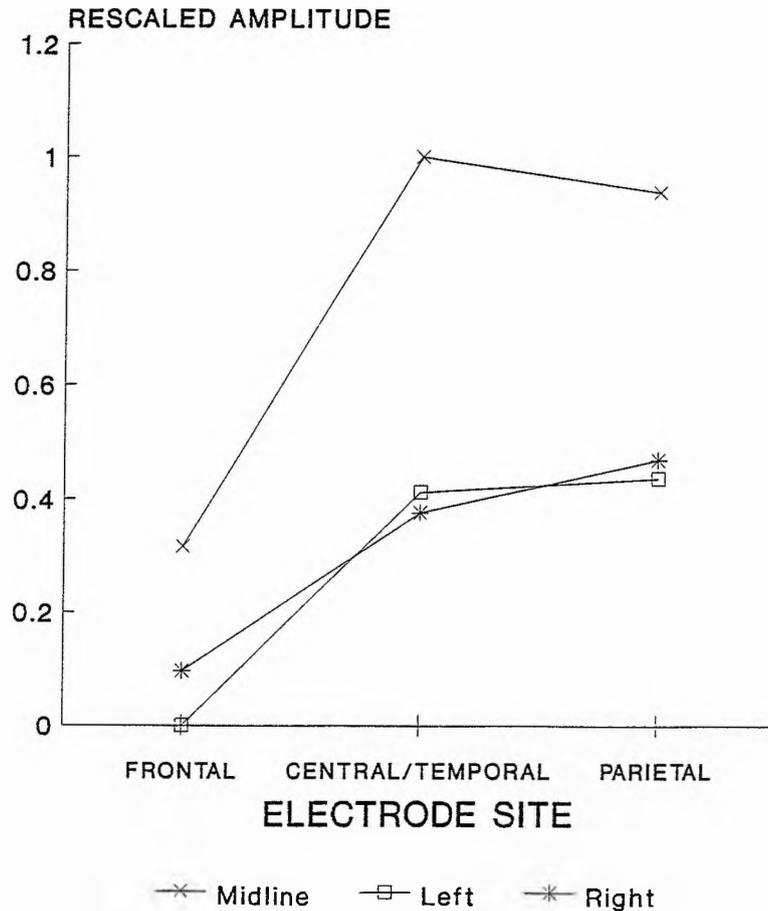


Figure 6.2b

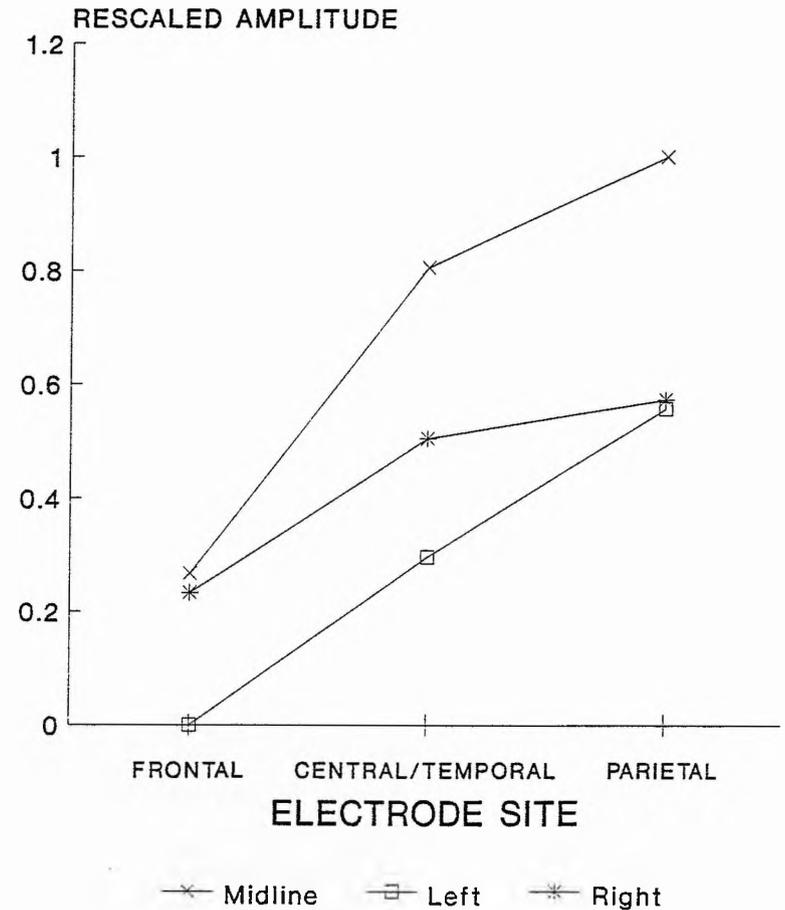


Figure 6.2a and 6.2b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by simple (Figure 6.2a), target(Figure 6.2b) stimuli within the two condition procedure in Experiment 4.

sites demonstrated greater mean amplitude in comparison to the frontal and temporal sites.

Scalp Distribution

As may be seen in Table 6.4 of the Appendix ANOVA of the mean rescaled amplitude evoked by the three classes of experimental stimuli produced a significant two way interaction involving the factors of chain and site. *Post hoc* analysis demonstrated that along the midline chain an equipotential amplitude distribution was obtained across the sites. Along the lateral chains a parietal site maximum scalp amplitude distribution was obtained (see Figure 6.3).

N200 Deflection

ANOVA of the simple and target stimuli peak latencies along the midline chain revealed a significant main effect of electrode site (see Table 6.1 of the Appendix). *Post hoc* analysis demonstrated that, collapsed across experimental conditions, peak latencies were shorter at the parietal site in comparison to the frontal and central sites (see Table 6.2 of the Appendix).

ANOVA of the mean amplitude evoked by the two classes of stimuli produced a significant two way interaction involving the factors of condition and site (see Table 6.5 of the Appendix). *Post hoc* analysis demonstrated that simple stimuli evoked a more negative going N200 deflection at frontal sites in comparison to parietal and central/temporal sites. Target stimuli evoked equipotential mean amplitude across each electrode site.

Scalp Distribution

A significant three way interaction involving the factors of condition, chain and site was obtained (see Table 6.5 of the Appendix). *Post hoc* analysis demonstrated that the simple stimuli evoked a response that demonstrated greater amplitude distribution at the frontal site in comparison to the parietal along all three chains (see Figure 6.4a). Target stimuli demonstrated a maximum amplitude distribution at the frontal site in comparison to the parietal site along the midline chain. Along the lateral chains an equipotential amplitude distribution was obtained (see Figure 6.4b).

Figure 6.3

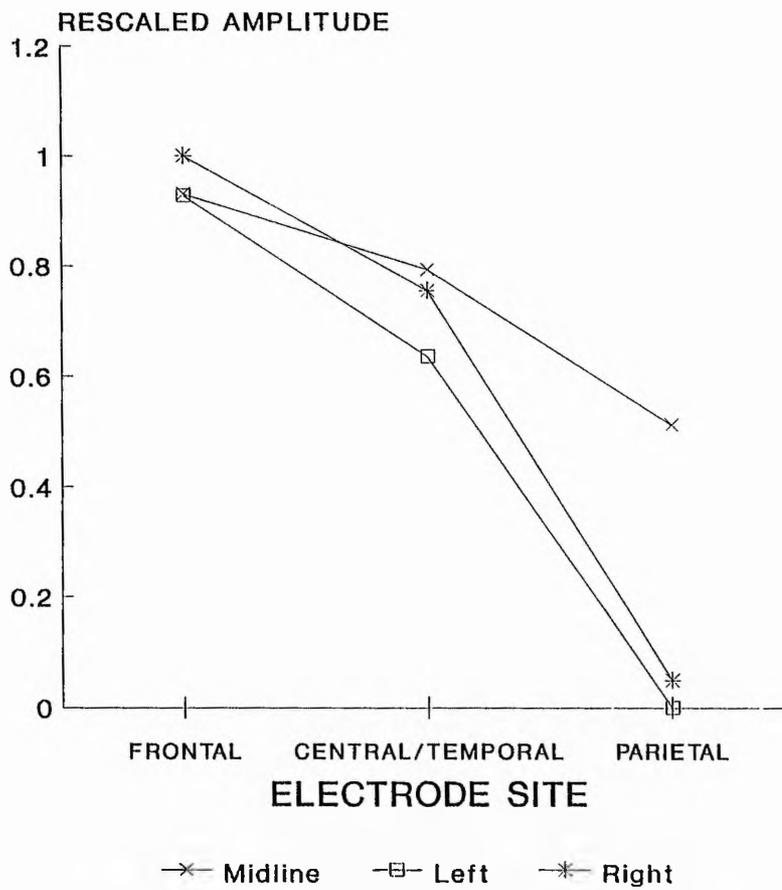


Figure 6.3 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by the two condition procedure in Experiment 4 (collapsed across experimental condition).

Figure 6.4b

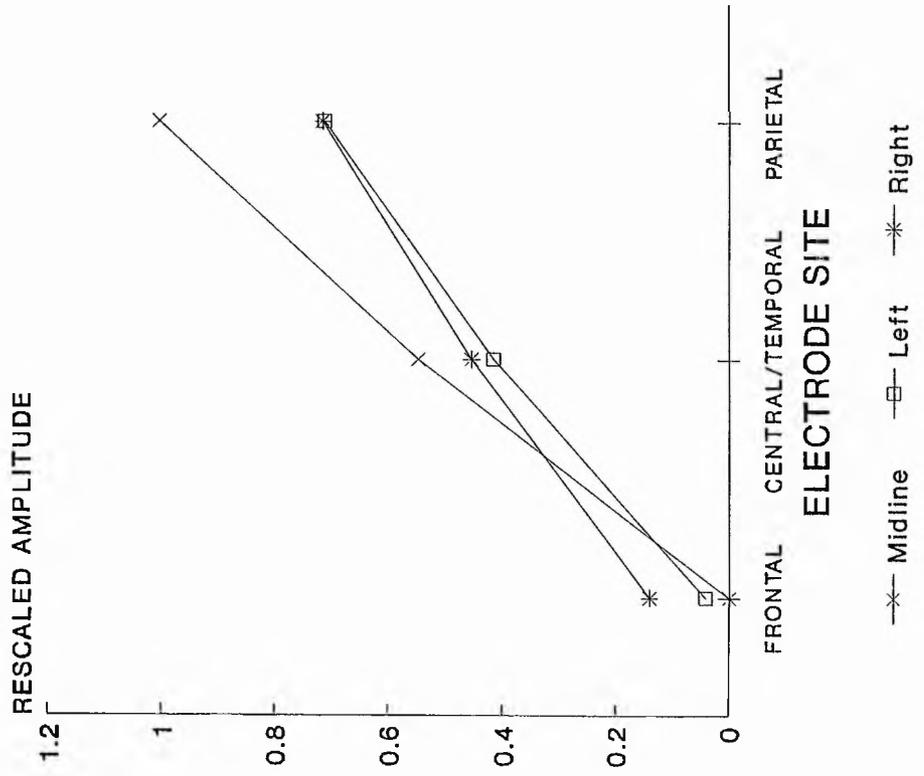


Figure 6.4a

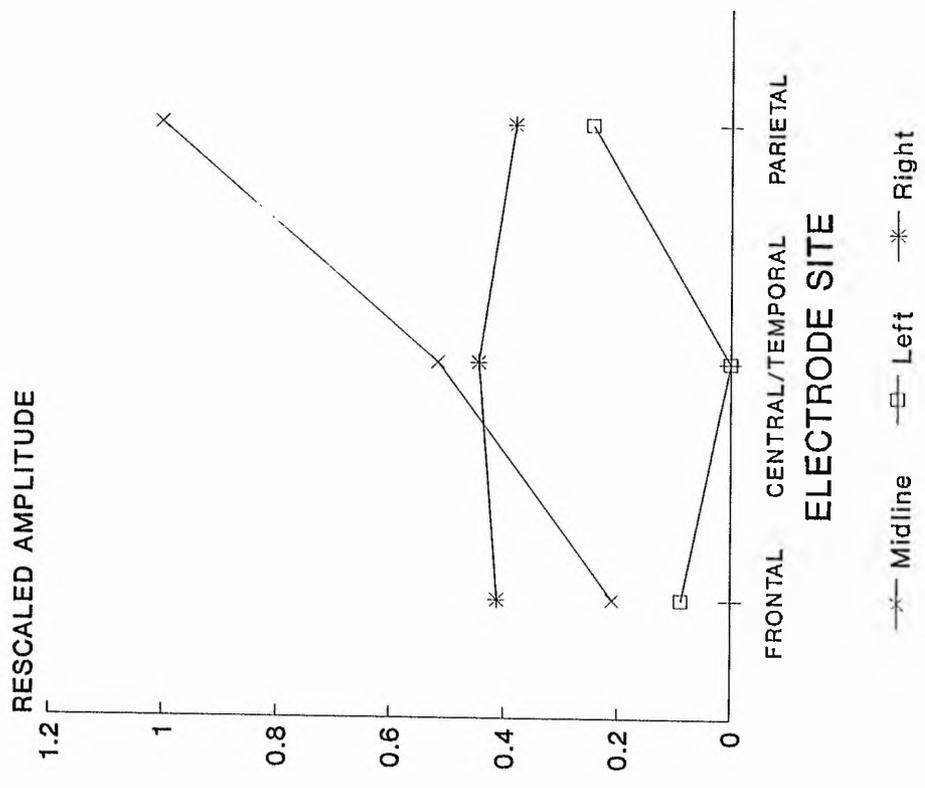


Figure 6.4a and 6.4b Graph illustrating the distribution, across electrode site, of

rescaled amplitude of the N200 deflection elicited by simple (Figure 6.4a) and target

(Figure 6.4b) stimuli within the two condition procedure in Experiment 4.

500 - 850 Mean Latency Range

A significant main effect of condition was obtained (see Table 6.6 of the Appendix). Examination of the means of the mean amplitude demonstrated that target stimuli evoked greater mean amplitude in comparison to that evoked in response to simple stimuli.

A significant three way interaction involving the factors of condition, chain and site was obtained. *Post hoc* analysis demonstrated that in response to simple stimuli equipotential mean amplitude was obtained across the sites along all three chains. In response to target stimuli greater mean amplitude was obtained at central and parietal sites in comparison to the frontal site along the midline chain. Along the left chain the parietal site demonstrated greater mean amplitude in comparison to the frontal site. Along the right chain equal mean amplitude was obtained across the sites.

Scalp Distribution

A significant three way interaction involving the factors of condition, chain and site was obtained (see Table 6.6 of the Appendix). *Post hoc* analysis demonstrated that simple stimuli demonstrated a centro-parietal maximum scalp amplitude distribution along the midline. Along the lateral chains an equipotential scalp amplitude distribution was obtained (see Figure 6.5a). Target stimuli demonstrated that along the midline chain the parietal site demonstrated greater scalp amplitude distribution in comparison to the frontal site. Along the lateral chains an equipotential scalp amplitude distribution was obtained (see Figure 6.5b).

6b.4 Three Condition Procedure

P300 Deflection

ANOVA of the peak latencies of the deflections evoked by the three classes of experimental stimuli revealed a significant interaction involving the factors of condition and site (see Table 6.1 of the Appendix). *Post hoc* analysis demonstrated that target stimuli evoked an earlier response at the frontal site in comparison to the central and parietal sites. Peak latencies evoked in response to both simple and complex stimuli demonstrated nonsignificant differences along the midline chain (see Table 6.2 of the Appendix).

ANOVA of the mean amplitude evoked by the three classes of stimuli produced a significant main effect (see Table 6.7). *Post hoc* analysis

Figure 6.5a

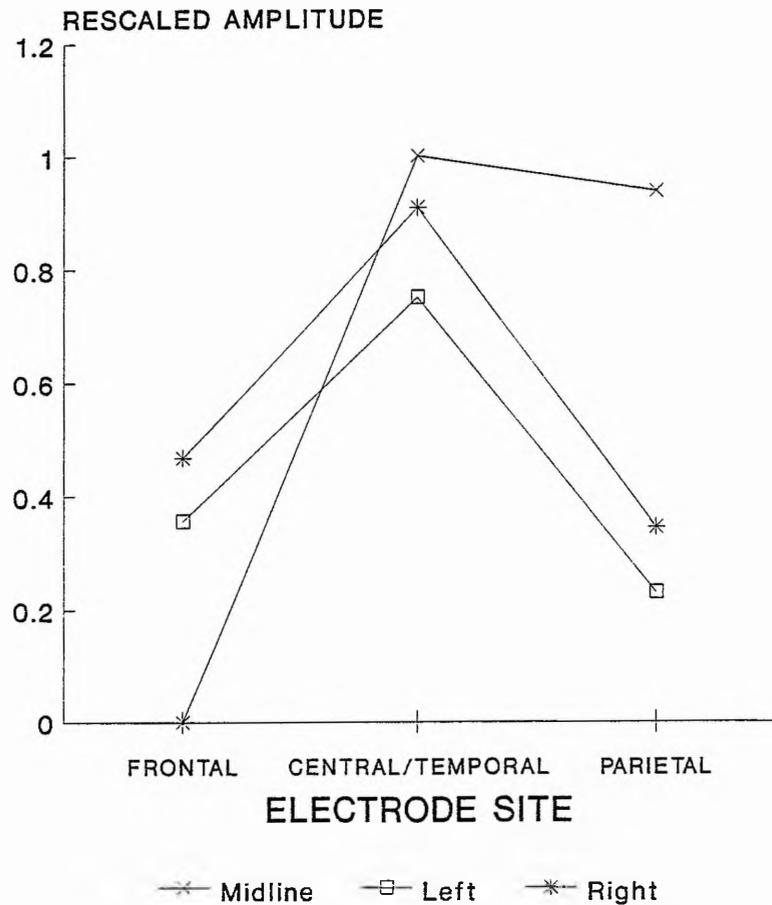


Figure 6.5b

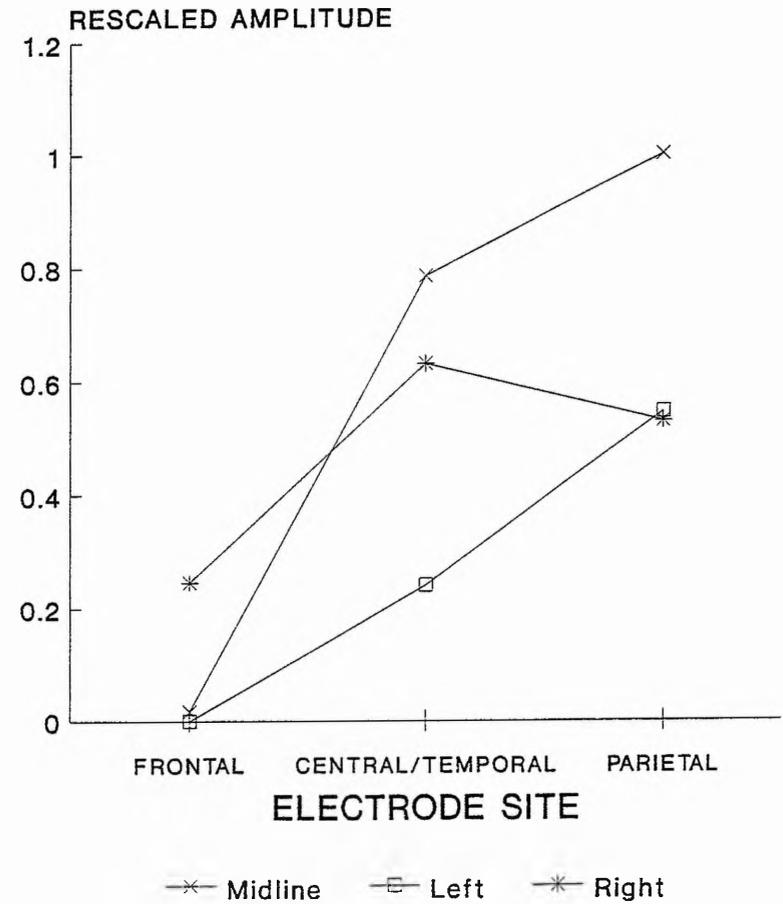


Figure 6.5a and 6.5b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec by simple (Figure 6.5a) and target (6.5b) stimuli within the two condition procedure in Experiment 4.

Table 6.7 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by simple, target and complex stimuli within the three condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.3,19.0	4.42	0.041*	44.810
Chain CH	1.9,28.4	34.175	0.000*	26.280
Site ST	1.5,22.1	42.771	0.000*	40.912
Interactions				
CC X CH	3.1,46.5	2.519	0.068	2.516
CC X ST	2.3,34.7	11.228	0.000*	6.160
CH X ST	3.1,47.1	12.113	0.000*	3.192
CC X CH X ST	4.7,70.6	8.277	0.000*	0.739
Rescaled Amplitude				
Main Effects				
Condition CC	1.4,21.7	0.837	0.410	0.399
Chain CH	1.9,28.2	34.130	0.000*	0.202
Site ST	1.5,22.4	40.747	0.000*	0.309
Interactions				
CC X CH	2.9,44.0	5.610	0.003*	0.021
CC X ST	2.8,42.1	6.562	0.001*	0.044
CH X ST	3.1,46.6	11.847	0.000*	0.025
CC X CH X ST	4.7,70.2	7.148	0.000*	0.006

* denotes a p value statistically significant at the 0.05% level or greater.

demonstrated that both target and complex stimuli evoked greater mean amplitude than that evoked in response to simple stimuli

A significant three way interaction involving the factors of condition, chain and site was obtained. *Post hoc* analysis demonstrated that simple stimuli evoked equipotential mean amplitude across the sites along all three chains. Target stimuli evoked greater mean amplitude at central and parietal sites in comparison to the frontal site along the midline chain. Along the lateral chains the parietal sites demonstrated greater mean amplitude in comparison to frontal sites. The response evoked by complex stimuli demonstrated that along both the midline and left chains greater mean amplitude was demonstrated at parietal and central/temporal sites in comparison to frontal sites. Along the right chain greater mean amplitude was demonstrated at parietal site in comparison to the frontal site.

Scalp Distribution

A significant three way interaction involving the factors of condition, chain and site was obtained (see Table 6.7). *Post hoc* analysis demonstrated that simple stimuli evoked a centro-parietal maximum scalp amplitude distribution along the midline. Along the lateral chains an equipotential scalp amplitude distribution was obtained (see Figure 6.8a). In response to target stimuli a centro-parietal maximum amplitude scalp distribution was obtained along the midline chain. Along the left chain greater amplitude was distributed at the parietal site in comparison to the frontal site. Along the right chain amplitude was distributed equipotentially across the sites (see Figure 6.6b). In response to complex stimuli a centro/temporo-parietal maximum scalp amplitude distribution was obtained along the midline and left chains. Along the right chain the parietal site demonstrated greater amplitude distribution in comparison to the frontal site (see Figure 6.6c).

N100 Deflection

ANOVA of the peak latencies evoked in response to the experimental stimuli demonstrated a significant main effect of site (see Table 6.1 of the Appendix). *Post hoc* analysis demonstrated that, collapsed across experimental conditions, the frontal site demonstrated an earlier peak latency in comparison to those demonstrated at the central and parietal sites (see Table 6.2 of the Appendix).

ANOVA of mean amplitude evoked by the three classes of stimuli demonstrated a significant main effect of condition (see Table 6.8 of the

Figure 6.6a

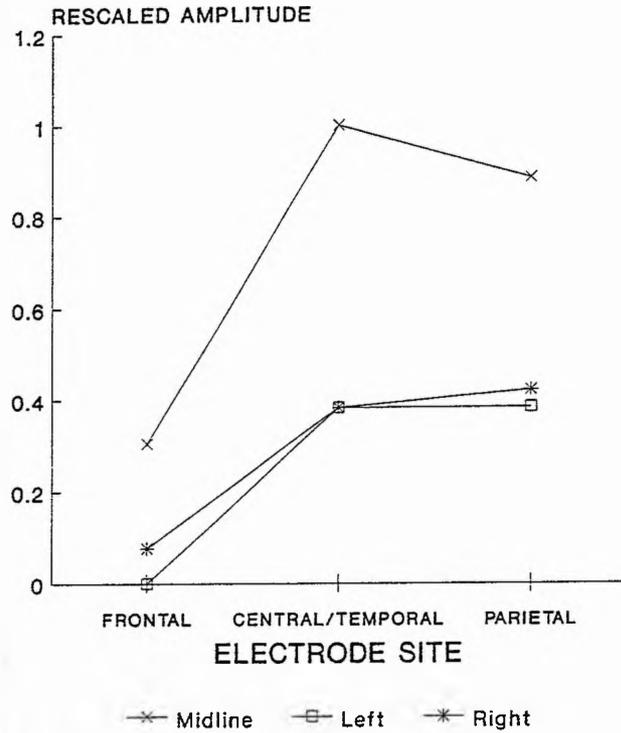


Figure 6.6b

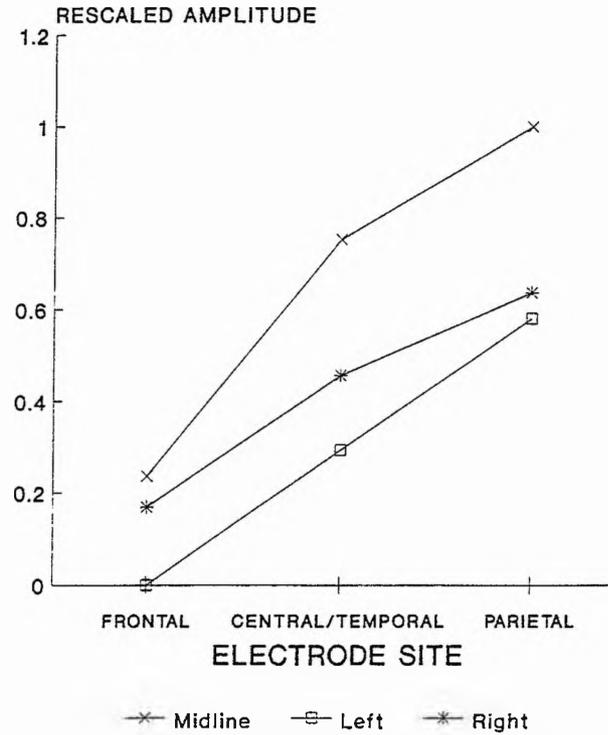


Figure 6.6c

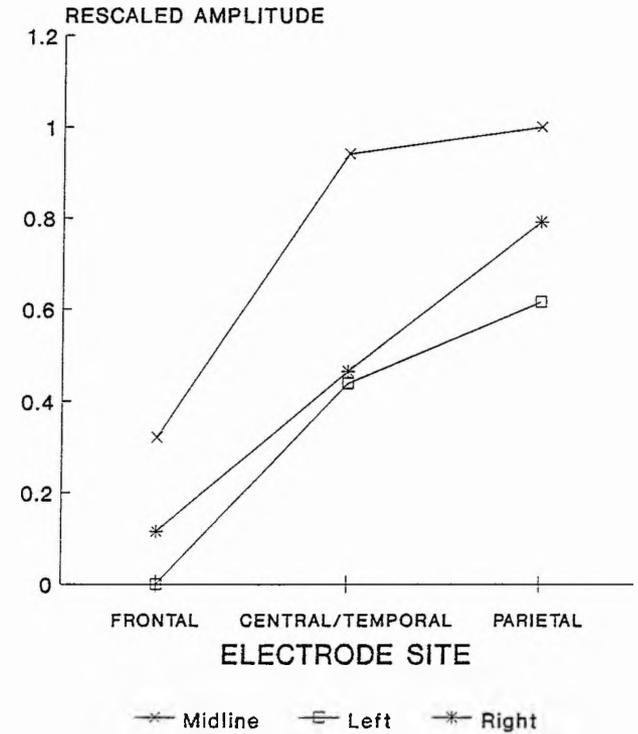


Figure 6.6a, 6.6b and 6.6c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by simple (Figure 6.6a), target (Figure 6.6b) and complex (Figure 6.6c) stimuli within the three condition procedure in Experiment 4.

Appendix). *Post hoc* analysis demonstrated that frequent stimuli evoked a greater deflection in comparison to that evoked in response to complex stimuli. A significant two way interaction involving the factors of condition and site was also obtained. *Post hoc* analysis demonstrated that simple stimuli evoked a greater deflection at the parietal site in comparison to that evoked at either central or frontal sites along the midline. Along the lateral chains both target and complex stimuli evoked greater deflections at parietal sites in comparison to that evoked at frontal sites.

Scalp Distribution

ANOVA of rescaled amplitude demonstrated a two way interaction involving the factors of chain and site (see Table 6.8 of the Appendix). *Post hoc* analysis demonstrated that equipotential amplitude was evoked along the midline chain (collapsed across experimental conditions). Along the lateral chains greater amplitude was evoked at parietal sites in comparison to both temporal and frontal sites (see Figure 6.7).

N200 Deflection

ANOVA of the N200 peak latencies evoked by the three classes of experimental stimuli along the midline produced a significant main effect of both condition and site (see Table 6.1 of the Appendix). *Post hoc* analysis of the condition main effect demonstrated that complex stimuli evoked a significantly earlier peak latency than those evoked in response to target and simple stimuli. *Post hoc* analysis of the site main effect demonstrated that, (collapsed across experimental conditions) the central and parietal sites demonstrated a significantly earlier peak latency in comparison to that evoked at the frontal site (see Table 6.2 of the Appendix).

ANOVA of mean amplitude evoked by the three classes of stimuli demonstrated a significant three way interaction involving the factors of condition, chain and site (see Table 6.9 of the Appendix). *Post hoc* analysis demonstrated that target stimuli evoked equipotential mean amplitude at each site along all three chains. Simple stimuli evoked a greater negative deflection at the frontal site in comparison to the parietal site along the midline chain. Complex stimuli evoked a greater negative deflection at frontal and central/temporal sites in comparison to the parietal sites along all three chains.

Figure 6.7

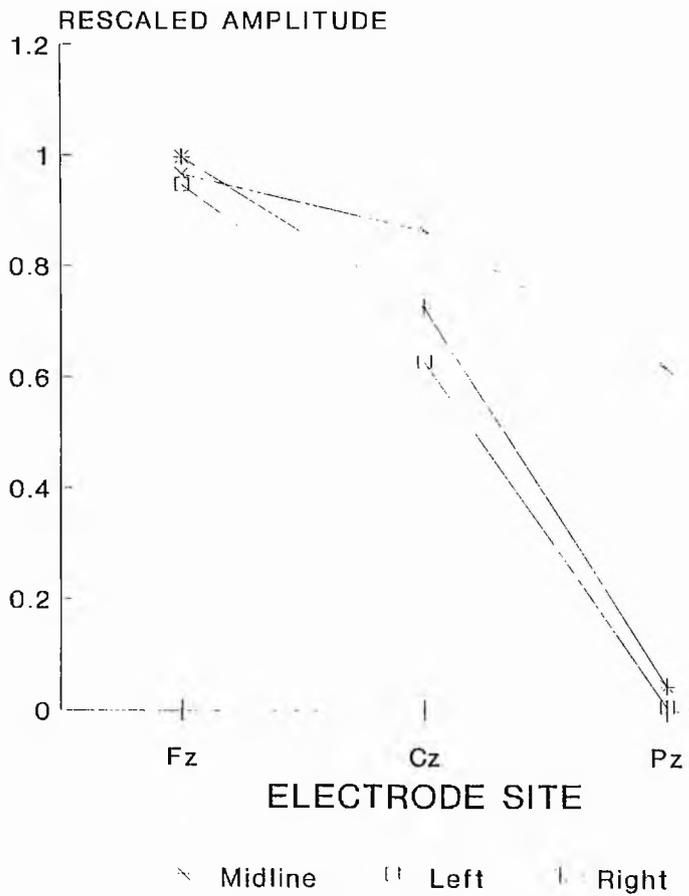


Figure 6.7 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by the three condition procedure in Experiment 4 (collapsed across experimental condition).

Scalp Distribution

A significant three way interaction involving the factors of condition, chain and site was obtained (see Table 6.9 of the Appendix). *Post hoc* analysis demonstrated that simple stimuli demonstrated a frontal site maximum amplitude distribution along the midline chain. Along the lateral chains amplitude was distributed equipotentially across the sites (see Figure 6.8a). Target stimuli demonstrated a fronto-central site maximum amplitude distribution along the midline chain, along the lateral chains amplitude was equipotentially distributed (see Figure 6.8b). Complex stimuli demonstrated a frontal site maximum amplitude distribution along all three chains of electrodes (see Figure 6.8c).

500 - 850 Latency Range

ANOVA of the mean amplitude within the latency range 500 - 850 msec across the three classes of experimental stimuli demonstrated a significant three way interaction involving the factors of condition, chain and site (see Table 6.10 of the Appendix). *Post hoc* analysis demonstrated that both simple and complex stimuli evoked equal mean amplitude across the sites along all three chains. Target stimuli evoked greater mean amplitude at the central, and parietal sites in comparison to the frontal site along the midline chain. Along the right chain greater mean amplitude was evoked at the parietal site in comparison to the frontal site. Along the left chain mean amplitude was equally great at each site.

Scalp Distribution

ANOVA of rescaled mean amplitude within the latency range 500 - 850 msec across the three classes of experimental stimuli produced a significant three way interaction involving the factors of condition, chain and site (see Table 6.10 of the Appendix). *Post hoc* analysis demonstrated that both simple and target stimuli evoked a centro-parietal scalp amplitude distribution across the midline. Along the lateral chains rescaled amplitude evoked in response to target stimuli was equipotentially distributed. Rescaled amplitude evoked by simple stimuli demonstrated a more anterior scalp distribution. Greater amplitude was distributed at temporal sites in comparison to that at parietal sites along the lateral chains (see Figure 6.9a and 6.9b). Complex stimuli evoked a response that demonstrated a central/temporal amplitude distribution along all three chains (see Figure 6.9c).

Figure 6.8a

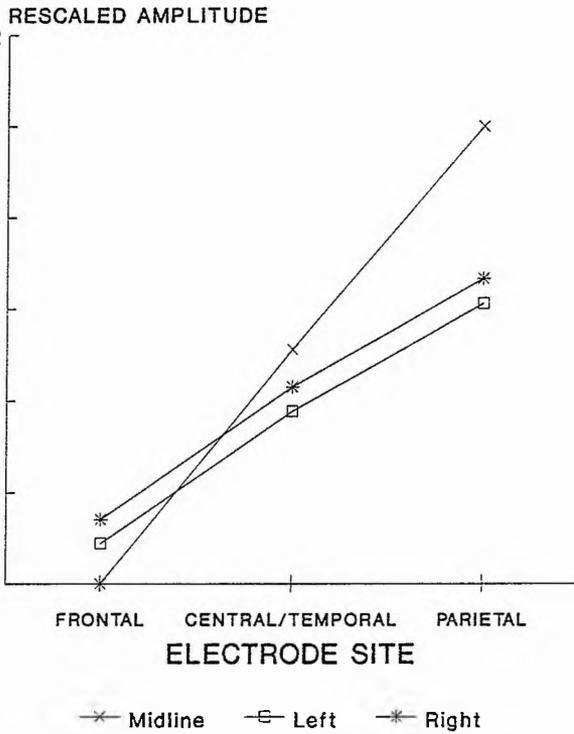


Figure 6.8b

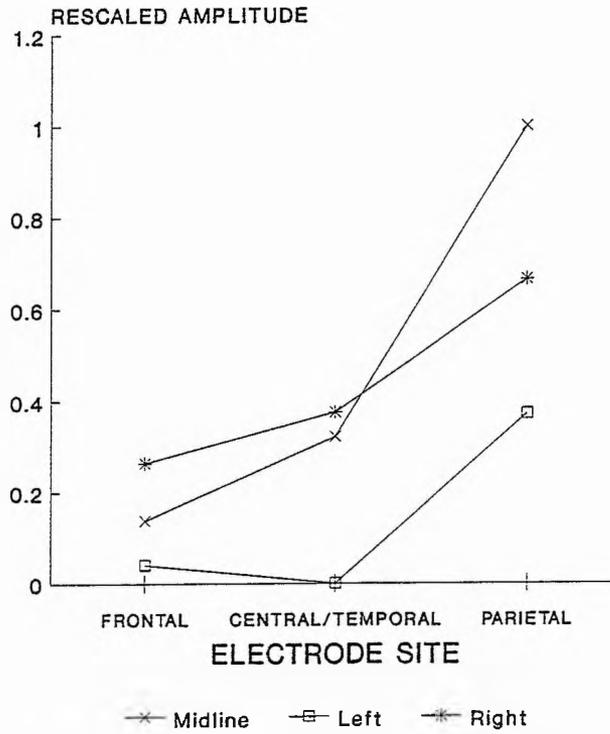


Figure 6.8c

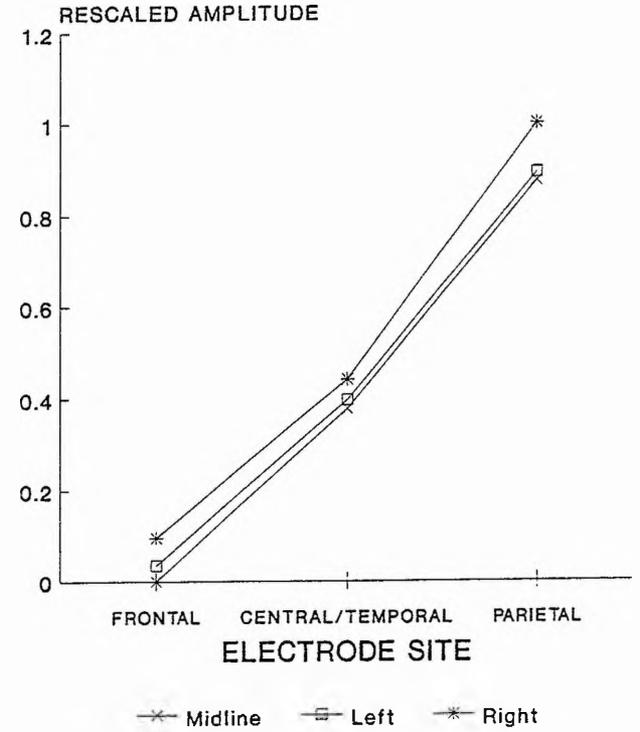


Figure 6.8a, 6.8b and 6.8c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by simple (Figure 6.8a), target (Figure 6.8b) and complex (Figure 6.8c) stimuli within the three condition procedure in Experiment 4.

Figure 6.9a

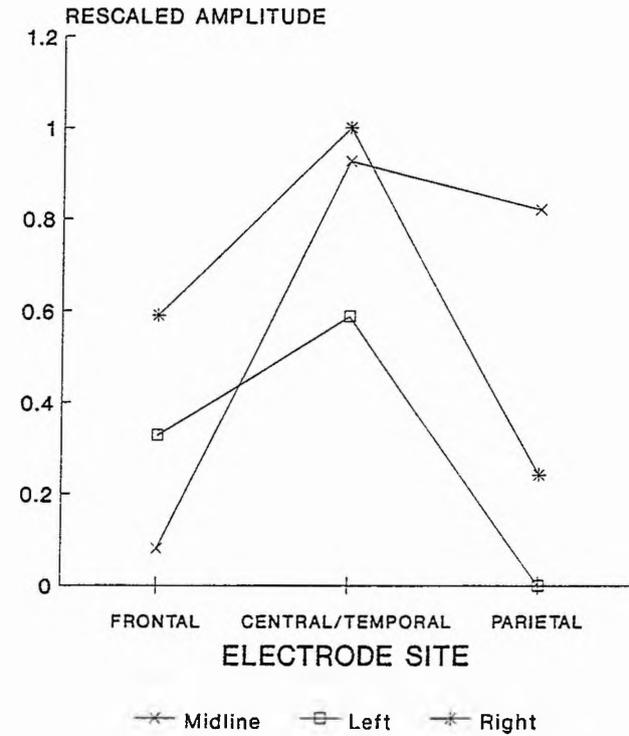


Figure 6.9b

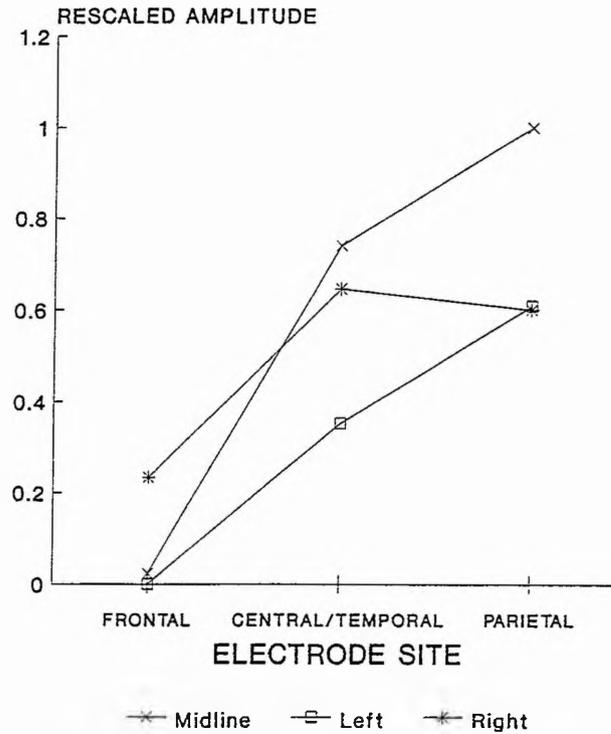


Figure 6.9c

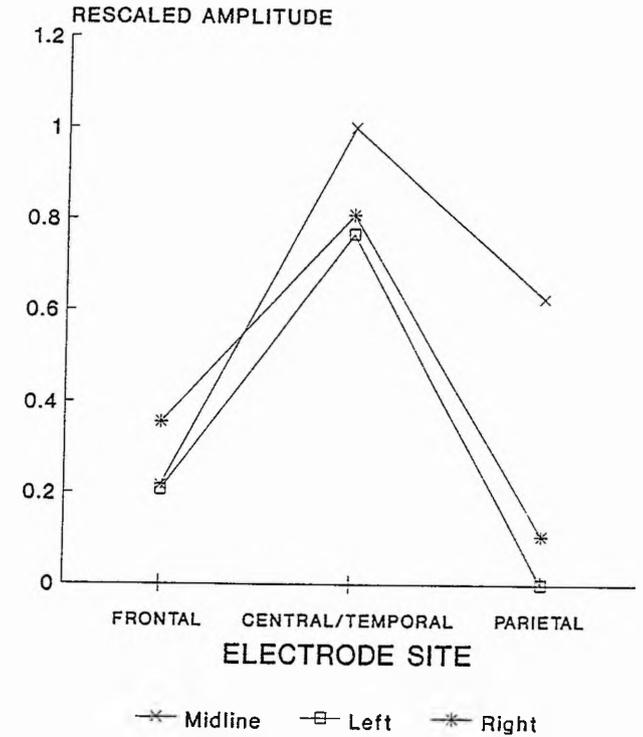


Figure 6.9a, 6.9b and 6.9c Graph illustrating the distribution, across electrode site, of rescaled amplitude elicited within the latency range 500 - 850 msec by simple (Figure 6.9a), target (6.9b) and complex (Figure 6.9c) stimuli within the three condition procedure in Experiment 4.

150 - 350 msec Latency Range at Lateral Parietal Sites

ANOVA of the mean amplitude evoked by the three classes of experimental stimuli within the latency range 150 - 350 msec demonstrated a significant main effect of condition (see Table 6.11 of the Appendix). *Post hoc* analysis demonstrated that complex stimuli evoked greater mean amplitude than either simple or target stimuli. However, target stimuli evoked greater mean amplitude than simple stimuli (see Figure 6.10).

6.5 Comparison Between Procedures

P300 Target Deflections

A significant main effect of condition was not obtained (see Table 6.12 of the Appendix). A significant two way interaction involving the factors of procedure and site was obtained. *Post hoc* analysis demonstrated that within the three condition procedure target stimuli evoked greatest mean amplitude at parietal sites. Within the two condition procedure both central/temporal and parietal sites evoked greater mean amplitude in comparison to the frontal sites.

Scalp Distribution

A significant three way interaction involving the factors of procedure, chain and site was obtained (see Table 6.12 of the Appendix). *Post hoc* analysis demonstrated that within the three condition procedure amplitude was maximally distributed at centro/temporo-parietal sites along the midline and right chains. Along the left chain the parietal site demonstrated a greater mean amplitude distribution in comparison to the frontal site. Within the two condition procedure amplitude was maximally distributed at centro-parietal sites along the midline. Along the left chain the parietal site demonstrated greater amplitude distribution in comparison to the frontal site. Along the right chain amplitude was equipotentially distributed across the sites.

P300 Simple Deflections

A significant main effect of procedure was obtained (see Table 6.12 of the Appendix). Mean amplitude within the three condition procedure was greater in comparison to that evoked in response to stimuli within the two condition procedure. No interaction involving the factor of procedure was obtained.

Figure 6.10

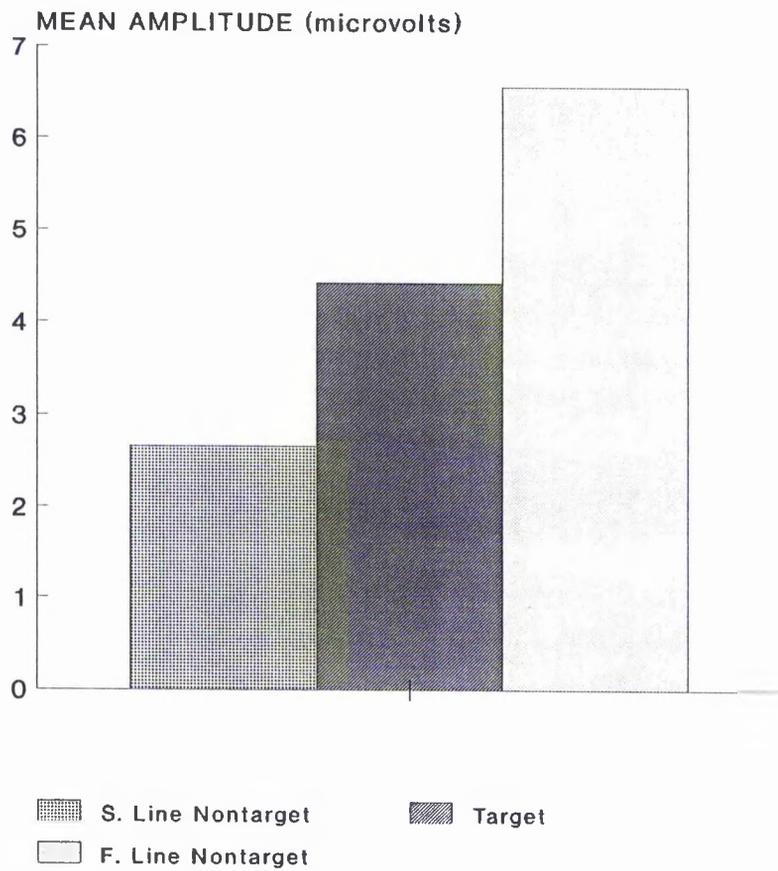


Figure 6.10 Bar diagram illustrating the mean amplitude evoked by simple, target and complex stimuli within the three condition procedure in Experiment 4.

Scalp Distribution

No significant interaction was obtained involving the factor of experimental procedure (see Table 6.12 of the Appendix).

6.6 Discussion

The aim of this experiment was to determine whether in previous experiments (see Chapter 4 and 5) the rare nontarget stimuli were categorised by subjects as another category of frequent to be ignored stimuli. If rare nontarget and frequent stimuli were being classified as a metaclass of frequent to be ignored stimuli it is possible the difference between the mean amplitude evoked in response to the three classes of stimuli were the result of differences between the subjective probability, stimulus complexity or task relevance each of which have been reported to determine the evoked amplitude of experimental stimuli (see section 1.5.1). As described in section 6.1 if it was the case that the rare nontarget (complex) stimuli were being classified as another class of frequent to be ignored stimuli within the three condition procedure a similar mean amplitude and scalp amplitude distribution across a number of ERP components (N200, P300 and Slow Wave) would be expected. Such a similarity between the simple and complex stimuli would be predicted since each had identical probabilities of occurrence and neither required an overt behavioural response to be made on the part of the subject. Since target stimuli were presented with the same probability of occurrence and required an overt behavioural response within both procedures a similar amplitude and amplitude distribution would be predicted across experimental procedures.

Both categories of stimuli within the two condition procedure elicited a positive deflection within the P300 latency range. However, target stimuli evoked greater mean amplitude in comparison to that evoked by the simple stimuli. This observation supports previous reports that a greater P300 response is elicited by stimuli with a lower subjective probability. On the basis of scalp amplitude distribution both responses demonstrated a centro-parietal amplitude distribution along the midline.

Similarly all three categories of stimuli within the three condition procedure elicited positive deflections within the P300 latency range. However, collapsed across scalp sites, greater mean amplitude was evoked in response to target and complex stimuli in comparison to that evoked in response to simple stimuli. On the basis of scalp amplitude distribution all three classes of experimental

stimuli evoked a centro-parietal scalp amplitude distribution. Within the three condition procedure the greater amplitude evoked in response to target stimuli in comparison to that evoked in response to simple stimuli may reflect the effect of task relevance upon the experimental procedure. The greater amplitude evoked in response to complex stimuli in comparison to that evoked in response to simple stimuli may reflect the greater stimulus complexity of the complex stimuli in comparison to the simple stimuli (see section 1.512). As previously reported Verbaten (1983) used patterned visual stimuli at two levels of complexity and found that larger P300s were elicited by the stimulus with the more complicated pattern.

A comparison of mean amplitude evoked between the two procedures demonstrated that greater mean amplitude was evoked by stimuli with lower probabilities of occurrence. Target stimuli with a probability of 33% within each procedure evoked comparable mean amplitudes. Simple stimuli with a probability of 33% evoked greater mean amplitude in comparison to that evoked by simple stimuli with a probability of 66%. As reported above this observation supports the finding that greater P300 deflections are elicited in response to stimuli with a low subjective probability. Previous reports of a dissociation of responses to target and rare nontarget stimuli on the basis of amplitude distribution within the visual modality have failed to determine the distribution of the deflection evoked in response to frequent stimuli.

P300 peak latencies failed to demonstrate a significant difference between experimental conditions in either of the experimental procedures. Similarly the N100 peak latencies failed to demonstrate a significant main effect between experimental conditions. N200 peak latencies within the two condition procedure failed to demonstrate a significant effect of condition. However, within the three condition procedure complex stimuli demonstrated a significantly shorter latency in comparison to either simple or target stimuli. In previous experiments employing similar visual stimuli (see Chapters 4 and 5), rare nontarget stimuli (corresponding to complex stimuli here) evoked P300 deflections with significantly shorter latencies than deflections evoked in response to target and simple stimuli. A possible explanation for the failure to obtain a significant difference between the latencies of the peak P300 deflections within the three condition procedure while within the N200 latency range complex stimuli demonstrated a significantly shorter latency in comparison to either target or simple stimuli may concern temporal jitter. The temporal jitter of the P300 complex deflection may be so great as to significantly alter the variability of the response across trials. Such an

explanation may also partially explain why increasing the probability of occurrence of stimuli reduced the mean amplitude of deflections since the opportunity for jitter between trials is also increased.

While the target and complex stimuli appear to have been processed by a similar combination of neural generators within the P300 latency range the response to such stimuli evoked within the N200 latency range demonstrated that they appeared to have been processed by a different combination of generators. The N200 deflection evoked in response to complex stimuli demonstrated a frontal site maximum amplitude distribution along all three chains of electrodes. Such an effect would not appear to be a task relevance effect obtained in a comparison of target and nontarget responses since simple stimuli (also designated as nontarget stimuli) failed to demonstrate such a frontal site distribution along the chains of electrodes. A negative deflection with such an anterior scalp distribution evoked in response to nontarget "deviant" stimuli may correspond to a MMN (N2a) component reported within the auditory modality (see section 1.5.4.1). A component with such a scalp distribution may correspond to a subject's responsiveness to low probability "deviant" stimuli within a standard oddball paradigm.

A more posterior maximum response was obtained in response to target stimuli. The fronto-central maximum target N200 response may correspond to an N2b component. A similarly distributed negative deflection was evoked in response to target stimuli within the two condition procedure, although the target N200 response demonstrated a frontal site maximum in comparison to the parietal site rather than a centro-frontal response obtained within the three condition procedure. Across both procedures the target N200 response demonstrated a more anterior amplitude distribution with greater amplitude being distributed at the frontal site in comparison to the parietal site along the midline chain. Along the lateral chains an equipotential amplitude distribution was obtained within both procedures. Since target stimuli were presented with a similar probability of occurrence across both experimental procedures such a similar distribution across procedures was predicted.

The more equipotential distribution of amplitude evoked in response to complex stimuli across the electrode chains in comparison to the midline chain maximum evoked in response to both target and simple stimuli may demonstrate a unique combination of underlying neural generators. Such a combination of generators may detect stimulus deviance within a sequence of stimuli. Such a system of neural generators is hypothesised to detect automatically unpredictably novel changes within the auditory modality.

Output from such a combination of generators may be recorded as the MMN (N2a) component (see section 1.5.4.1).

However, it is not possible to state that the N200 deflection evoked in response to complex stimuli within the three condition procedure is analogous to the MMN (N2a) component observed within the auditory modality since as previously described (see section 1.5.4.1) a classical MMN (N2a) component is elicited only in response to rare nontarget stimuli within periods of passive attention. Within the present experimental paradigm each sequential stimulus within the sequence was processed by the subject to determine if a behavioural response was required. Within such oddball paradigms the N200 deflection is made up of a composite of negative deflections evoked in response to both target and rare nontarget stimuli. It is, therefore, not possible to determine whether the N200 deflection evoked in response to complex stimuli was a pure MMN (N2a) component or a composite N200 deflection made up of a combination of MMN (N2a) and N2b components.

Ruchkin *et al.* (1988) reported that slow waves are present within ERP waveforms when task demand is high. They further reported that the scalp amplitude of such waves was inversely related to event probability. Such a claim is supported within the two condition procedure. Target stimuli had a lower probability of occurrence in comparison to simple stimuli and evoked a greater mean amplitude in comparison to that evoked in response to simple stimuli. Within the three condition procedure the three classes of stimuli occurred with an equal probability of occurrence. No significant main effect of condition was obtained within this procedure, such a result demonstrates that the three classes of stimuli evoked responses with similar mean amplitude.

Topographic differences as a function of task suggest that slow wave activity reflects the nature of additional processing in response to certain types of task demand. Different types of tasks may include different combinations of neural generators. Within the two condition procedure the response to target stimuli demonstrated a more posterior amplitude distribution in comparison to that evoked in response to simple stimuli. Within the three condition procedure target and simple stimuli evoked responses with a centro-parietal distribution along the midline chain. Complex stimuli, however, evoked a response with a central/temporal amplitude distribution along all three chains. Such a scalp amplitude distribution demonstrates that complex and simple stimuli were processed differently by subjects since such different scalp distributions presumably reflect the output of a different combination of neural generators responsible for the processing of the two classes of stimuli.

Within both the two and three condition procedures no evidence supporting Näätänen and Picton's (1987) claim that N100 generating neurons become refractory with repeated presentations of an experimental stimulus was elicited. However, as previously stated (see section 3.7.2) the modality specificity of such a reported effect is uncertain.

As previously reported complex stimuli demonstrated greater mean amplitude within the 150 - 350 msec latency range at lateral parietal sites in comparison to both target and simple stimuli. Similar effects have been reported previously (see Chapter 3, 4 and 5). Such a negative response on the part of the target stimuli in comparison to the response obtained in response to complex stimuli is believed to reflect selection negativity (see section 1.5.4.3).

As demonstrated a centro-parietal scalp amplitude distribution was obtained in response to each of the three classes of equiprobable experimental stimuli within the P300 latency range. Task relevance and stimulus complexity may have been responsible for the greater mean amplitude evoked in response to target and complex stimuli in comparison to that evoked in response to simple stimuli respectively. The possibility, therefore, arises that each class of stimuli (frequent, target and rare nontarget) in previous visual experiments evoked a scalp amplitude distribution with a centro-parietal maximum. The greater mean amplitude obtained in response to target and rare nontarget stimuli being evoked due to task relevance, stimulus complexity and subjective probability variables. Within the next experiment the extent to which task relevance and stimulus complexity variables affect the P300 complex will be examined. The scalp amplitude distribution of the P300 response evoked in response to frequent stimuli within a three stimulus visual oddball paradigm will also be determined.

6.7 Summary

On the basis of mean amplitude results it would appear that complex and simple stimuli are processed differently by subjects. Complex stimuli evoked a P300 deflection with significantly greater mean amplitude in comparison to that evoked in response to simple stimuli. Such differential processing may result from the stimulus complexity of the complex stimuli. Similarly such complexity may result in differential processing among the three classes of stimuli within a latency range of 150 - 350 msec at lateral parietal sites.

All three categories of stimuli evoked a P300 response with a centro-parietal scalp amplitude distribution along the midline chain of electrodes.

Complex and simple stimuli demonstrated different scalp distributions within the N200 latency range and within a slow wave latency range (500 - 850 msec). Such findings demonstrate that subjects did not appear to regard the complex and simple stimuli as one class of frequent to be ignored stimuli.

Chapter 7

Experiment 5: Investigation of Mean Amplitude and Scalp Amplitude Distribution Evoked by Increasing the Physical Contrast Between Frequent and Target Stimuli

7.1 Introduction

As discussed previously Courchesne *et al.* (1978) claimed that the greater the contrast between a rare stimulus and the ongoing sequence of background stimuli the greater the mean amplitude of the P300 deflection evoked. The results reported in Chapters 3, 4 and 5 indicated that subjects did not regard the dissimilarity between the stimulus characteristics of rare nontarget and frequent stimuli as being any greater than the contrast between target and frequent stimuli. The mean amplitude evoked by visual target and rare nontarget stimuli within each experiment was similar. The rare nontarget P300 (referred to as the P3a within the auditory modality) is elicited by novel nontarget stimuli (as contrasted with target stimuli, to which the subject must respond) and hence may reflect an orienting type response. Such novel stimuli are thought to automatically capture attention due to their intrusive characteristics. The intrusive nature of the rare nontarget stimuli is thought to be reflected by the increased mean amplitude elicited by such stimuli in comparison to that elicited by frequent to be ignored background stimuli. Within the auditory modality such an increase in mean amplitude elicited in response to rare nontarget stimuli is thought to be produced by a different combination of underlying neural generators in comparison to the combination of generators that produce the P300 deflection in response to target stimuli.

In each of the experiments described (Chapters 3, 4 and 5) the experimental procedure was such that frequent and target stimuli were one of two stimulus types alternated across subjects. Rare nontarget stimuli were deviant stimuli in comparison to the frequent and target stimuli. Due to the nature of the experimental stimuli rare nontarget stimuli differed from the target and frequent stimuli by an equal degree.

The aim of this experiment was to determine whether the mean amplitude and scalp distribution of the target and rare nontarget P300 responses would be altered by increasing the dissimilarity between frequent and target stimuli, and decreasing the contrast between frequent and rare nontarget stimuli. It was

predicted that increasing the contrast between frequent and target stimuli would increase the mean amplitude evoked by the target stimuli. It was further predicted that decreasing the contrast between the frequent and rare nontarget stimuli would decrease the mean amplitude evoked by rare nontarget stimuli. It was to be determined whether the predicted alteration of mean amplitude of target and rare nontarget stimuli was the product of an altered combination of underlying generators.

A further aim of the experiment was to determine the mean amplitude and the scalp amplitude distribution of the response evoked in response to frequent stimuli within a standard three stimulus visual oddball paradigm. This aim developed out of the observation that within the previous experiment (see Chapter 6) the three classes of equiprobable experimental stimuli each evoked a P300 response with a maximum amplitude distribution across centro-parietal scalp along the midline chain.

7.2 Method

Subjects

The subjects were 16 university students (mean age 22.9 years, range 18-32, seven female). Five subjects had previously participated in ERP experiments.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram activity were recorded from the scalp montage described in section 2.5 using a proprietary electrode cap.

Stimuli

Stimuli were adapted from the triangle procedure described in section 4.2.3.

Procedure

Two procedures were employed. In the first, which will be referred to as the "target homogeneous" procedure, frequent and target stimuli consisted of either inverted or upright single line triangles (alternated across subjects) subtending a visual angle of 2 degrees (see Figure 4 and 5 of the Appendix). Rare nontarget stimuli were a set of 45 heterogeneous mutilated (broken contour) line drawn triangles (see Figure 6 of the Appendix).

In the second procedure, the "target heterogeneous" procedure, frequent and rare nontarget stimuli consisted of either inverted or upright single line drawn triangles (alternated across subjects). Target stimuli consisted of a set of 45 heterogeneous mutilated line drawn triangles. The order of presentation of procedures was alternated across subjects.

Each procedure consisted of 300 experimental stimuli presented in blocks of 100 with a one minute rest period between blocks. Between procedures a rest period of five minutes was provided.

As described in section 2.4 a practice block of 15 stimuli was presented to the subjects with the instructions to respond to the target stimuli. Following the block of practice trials the experimental run was presented. Subjects were informed that their task was the same as during the practice trials. In the case of the target homogeneous procedure they were told that they would occasionally see "fragmented single line shapes" but were to refrain from responding to them. In the case of the target heterogeneous procedure they were told they would occasionally see single line triangles with the opposite orientation to the frequent stimuli but were to refrain from responding to them.

7.3 Data Analysis

Amplitude Data

Since a reduced amplitude was predicted in response to rare nontarget stimuli within the target heterogeneous procedure in order to measure activity evoked in response to such stimuli the latency window determined for target stimuli was applied to both classes of rare stimuli to determine the mean amplitude elicited by the stimuli. In order to maintain consistency a similar procedure was applied to the target and rare nontarget waveforms evoked within the target homogeneous procedure.

See section 2.6.3 for a description of the ANOVAs performed on amplitude data. Experimental procedure was employed as a factor. The ANOVAs took the form of Procedure X Condition X Chain X Site. A further analysis was performed on the mean amplitude within a latency range of 150-350 msec across the three experimental conditions at lateral parietal sites. This ANOVA took the form of Procedure X Condition X Site.

Scalp Distribution

As described in section 2.6.4 to examine the scalp distribution of the responses evoked by the experimental conditions of each component ANOVAs were carried out upon rescaled amplitude data employing experimental procedure as a factor. Such ANOVAs took the form of Procedure X Condition X Chain X Site.

Latency Data

Peak latencies were not determined within this experiment since the peak of the target deflection was to be employed to determine both target and rare nontarget deflections.

7.4 Results

Behavioural Performance

Mean reaction time to target stimuli within the target homogeneous procedure was 468 msec with a standard deviation across subjects of 83 msec. The mean rate for correctly detected targets was 99.2% and the mean false positive rate was 1.6%.

Mean reaction time to target stimuli within the target heterogeneous procedure was 435 msec with a standard deviation across subjects of 63 msec. The mean rate for correctly detected targets was 98.1% and the mean false positive rate was 0.97%.

A t-test demonstrated that there was no significant difference between the reaction times of the two procedures in response to target stimuli ($t(15) = -1.83$ $p = 0.087$).

ERP Data

Grand average waveforms (see Figure 7.1a and 7.1b) were produced for both target homogeneous and target heterogeneous procedures.

Table 7.0 Mean (range) number of trials making up each waveform for frequent, target and rare nontarget stimuli.

	Target Homogeneous	Target Heterogeneous
Frequent	164 (122-197)	165 (141-199)
Target	36 (31-45)	37 (30-44)
Rare Nontarget	36 (26-44)	35 (26-43)

The grand average waveform of the target homogeneous procedure is similar to that reported in section 4.4 in response to the triangle procedure (see Figure 7.1a). Stimuli in all three experimental conditions evoked an N100 deflection which was largest at lateral parietal sites. Following the resolution of the N100 deflection an N200 deflection was observed at anterior scalp sites. This deflection demonstrated greater negativity in response to rare nontarget stimuli in comparison to frequent and target stimuli. However, target stimuli demonstrated a greater negativity in comparison to frequent stimuli at anterior scalp sites.

Both target and rare nontarget stimuli evoked a P300 deflection of the waveform. This deflection was maximum at posterior scalp sites, the midline chain demonstrated a greater P300 deflection in comparison to the lateral chains. The P300 deflection was followed by a period of sustained positivity at posterior sites in response to both target and rare nontarget stimuli, this activity was less positive at frontal sites.

Following the resolution of the N100 deflection and the peak of the P300 deflection rare nontarget stimuli demonstrated a period of sustained positivity in comparison to both frequent and target stimuli at lateral parietal sites.

The grand average waveform of the target heterogeneous procedure is dissimilar to that of the target homogeneous procedure (see Figure 7.1a). Stimuli in all three experimental conditions evoked an N100 deflection which was largest at lateral parietal sites. Following the resolution of the N100 deflection an N200 deflection was observed at anterior scalp sites in response to target stimuli.

Figure 7.1a

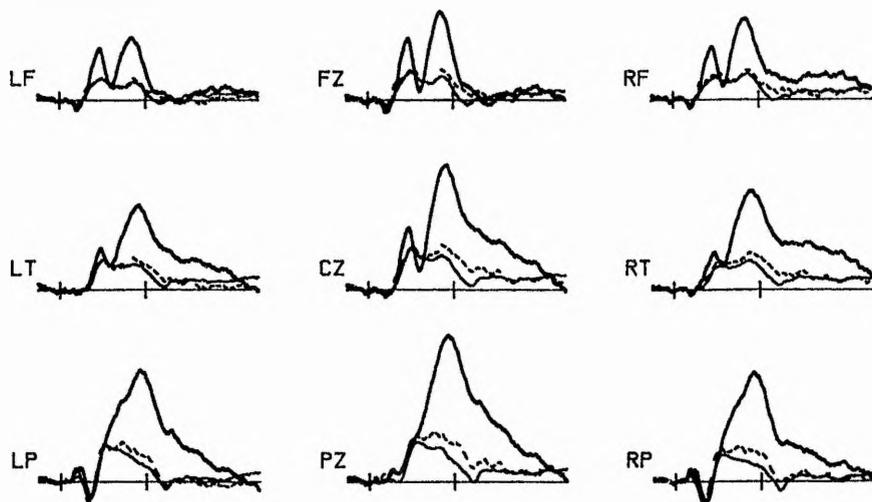


Figure 7.1b

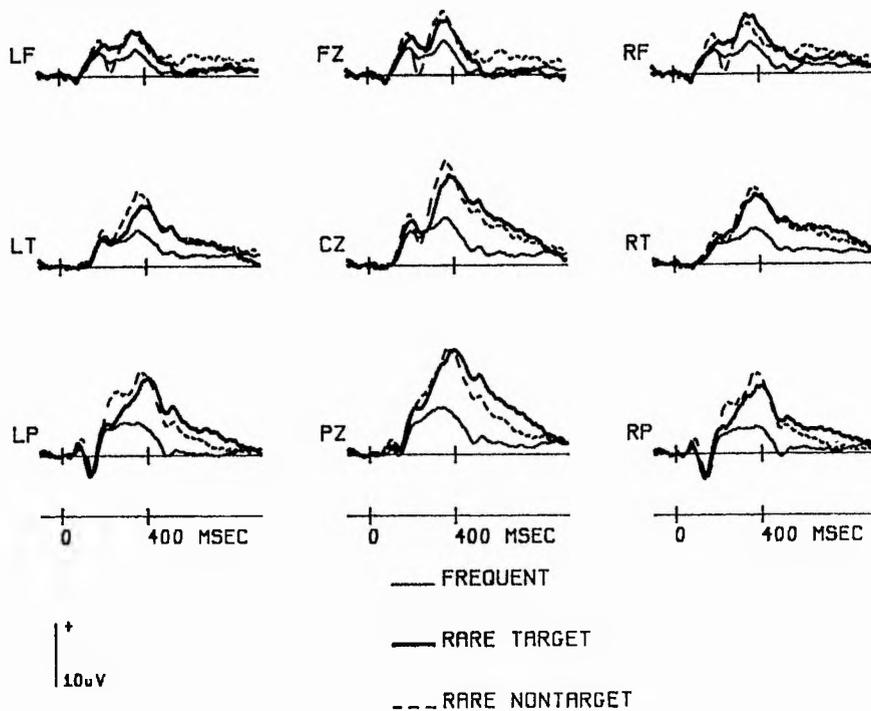


Figure 7.1a and 7.1b Waveforms, averaged across 16 subjects, for each condition of the target heterogeneous (Figure 7.1a) and target homogeneous (Figure 7.1b) procedure in Experiment 5.

A P300 deflection was evoked by target stimuli following the resolution of the N200 deflection. This deflection was maximum at posterior electrode sites. Rare nontarget stimuli failed to evoke such a prominent P300 deflection. However, rare nontarget stimuli evoked greater amplitude than frequent stimuli across the scalp. The P300 deflection evoked by target stimuli was followed by a period of sustained positivity which was maximum at posterior scalp sites.

Within the 500 - 850 msec latency range rare nontarget stimuli evoked mean amplitude that was similar across the scalp.

Table 7.8.1 and 7.8.2 of the Appendix demonstrate the mean amplitude and the mean rescaled amplitude elicited within the target homogeneous procedure by experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain. Similarly Table 7.8.3 and 7.8.4 demonstrate the mean amplitude and the mean rescaled amplitude elicited within the target heterogeneous procedure.

P300

ANOVA of the mean amplitude evoked by the three classes of stimuli within the latency range determined for the target P300 response revealed a significant two way interaction involving the factors of procedure and condition (see Table 7.1). *Post hoc* analysis demonstrated that within the heterogeneous target procedure target stimuli evoked greater mean amplitude than either the frequent or rare nontarget stimuli (target = 15.9 microvolts, rare nontarget = 5.5 microvolts and frequent stimuli = 3.9 microvolts). Within the homogeneous target procedure both target and rare nontarget stimuli evoked greater mean amplitude than that evoked by frequent stimuli (target = 11.5 microvolts, rare nontarget = 11.1 microvolts and frequent stimuli = 5.4 microvolts).

ANOVA of the mean amplitude evoked by the three classes of stimuli also revealed a significant three way interaction involving the factors of procedure, condition and site. *Post hoc* analysis revealed that within the heterogeneous target procedure both frequent and rare nontarget stimuli evoked mean amplitude that was equally great across each of the three sites. Target stimuli evoked mean amplitude that was greatest across centro-parietal sites. Within the homogeneous target procedure frequent stimuli evoked mean amplitude that

Table 7.1 ANOVA summary table for analysis of P300 amplitude and elicited by the three classes of experimental stimuli within the target heterogeneous and target homogeneous procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.008	0.931	20.897
Condition CC	1.8,27.6	1.095	0.346	44.429
Chain CH	1.8,26.5	1.235	0.304	37.704
Site ST	1.3,19.7	21.389	0.000*	67.337
Interactions				
PR X CC	1.7,25.2	2.639	0.099	18.433
PR X CH	1.9,28.2	0.609	0.539	2.235
PR X ST	1.2,17.7	0.258	0.656	5.575
CC X CH	3.1,46.4	3.907	0.014*	3.349
CC X ST	2.4,36.3	11.636	0.000*	6.044
CH X ST	2.4,36.1	3.372	0.038*	10.179
PR X CC X CH	2.6,39.2	6.345	0.002*	1.843
PR X CC X ST	1.6,23.4	13.621	0.000*	6.749
PR X CH X ST	3.2,47.7	2.209	0.096	0.673
CC X CH X ST	4,60.5	2.982	0.026*	0.802
PR X CC X CH X ST	3,45.3	2.567	0.066	0.798

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.2 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by the three classes of experimental stimuli within the target heterogeneous procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,8,27	157.497	0.000*	39.213
Chain CH	1,6,24.4	20.567	0.000*	15.405
Site ST	1,2,17.9	12.279	0.002*	46.476
Interactions				
CC X CH	2,1,32.1	26.185	0.000*	2.698
CC X ST	1,4,20.9	25.637	0.000*	10.457
CH X ST	1,8,26.5	10.093	0.001*	3.611
CC X CH X ST	3,45	5.180	0.004*	0.854
Rescaled Amplitude				
Main Effects				
Condition CC	1,5,22	0.045	0.913	3.600
Chain CH	1,6,24.7	9.875	0.001*	0.674
Site ST	1,3,19.5	5.914	0.018	1.360
Interactions				
CC X CH	2,4,35.5	0.536	0.618	0.159
CC X ST	2,5,37.7	6.069	0.003*	0.204
CH X ST	2,29.7	8.138	0.002*	0.138
CC X CH X ST	3,8,56.3	2.847	0.035*	0.035

Table 7.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by the three classes of experimental stimuli within the target homogeneous procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,9,28.8	38.770	0.000*	43.967
Chain CH	1,8,27	17.373	0.000*	22.439
Site ST	1,2,17.3	17.679	0.000*	47.416
Interactions				
CC X CH	2,4,36	5.477	0.006*	3.412
CC X ST	2,1,31.3	15.064	0.000*	8.393
CH X ST	2,3,34.2	10.384	0.000*	4.573
CC X CH X ST	4,7,71	9.776	0.000*	0.605
Rescaled Amplitude				
Main Effects				
Condition CC	1,2,18.5	0.238	0.681	1.524
Chain CH	1,7,25	14.081	0.000*	0.466
Site ST	1,2,17.3	10.921	0.003*	0.958
Interactions				
CC X CH	2,29.5	1.486	0.244	0.092
CC X ST	2,29.4	3.574	0.042*	0.203
CH X ST	2,1,31.4	8.493	0.001*	0.096
CC X CH X ST	2,8,42.1	2.937	0.047*	0.019

* denotes a p value statistically significant at the 0.05% level or greater.

was equally great across the three sites. Target and rare nontarget stimuli evoked amplitude that was greatest at centro-parietal sites.

Since a four way interaction involving the factors of procedure, condition, chain and site was not obtained in order to examine the effect of procedure across the three chains of electrodes for each experimental condition separate ANOVAs were performed on the data from each procedure.

Heterogeneous Target

ANOVA of the mean amplitude evoked by the three classes of experimental stimuli revealed a significant three way interaction involving the factors of condition, chain and site (see Table 7.2). *Post hoc* analysis demonstrated that both frequent and rare nontarget stimuli evoked amplitude that was equally great at each site along each of the three chains. Target stimuli evoked a response that was greatest at parietal sites along both midline and left chains. Along the right chain amplitude was greatest across temporo-parietal sites.

Homogeneous Target

ANOVA of the mean amplitude evoked by the three classes of experimental stimuli revealed a significant three way interaction involving the factors of condition, chain and site (see Table 7.3). *Post hoc* analysis demonstrated that frequent stimuli evoked amplitude that was equally large across the sites along all three chains. Rare nontarget stimuli evoked a response that was greatest at centro/temporo-parietal sites along all three chains. Target stimuli evoked a response that was greatest at centro-parietal sites along the midline. Along the left chain the parietal site demonstrated greater amplitude than the frontal site. Amplitude along the right chain was equally large across the sites.

Scalp Distribution

Heterogeneous Target

ANOVA of the rescaled amplitude evoked by the three classes of stimuli revealed a significant three way interaction involving the factors of condition, chain and site (see Table 7.2). *Post hoc* analysis demonstrated that across the midline chain frequent (see Figure 7.2a), target (see Figure 7.2b) and rare nontarget stimuli (see Figure 7.2c) stimuli demonstrated a centro-parietal maximum scalp amplitude distribution. Along the lateral chains all three classes of stimuli demonstrated an equipotential amplitude distribution.

Figure 7.2a

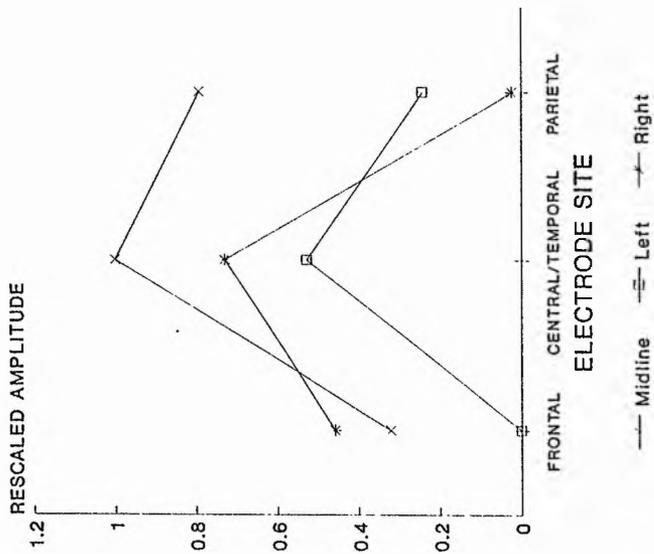


Figure 7.2b

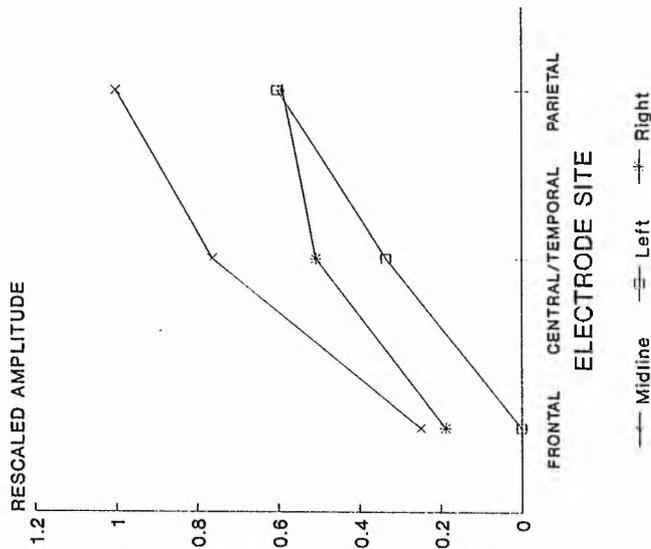


Figure 7.2c

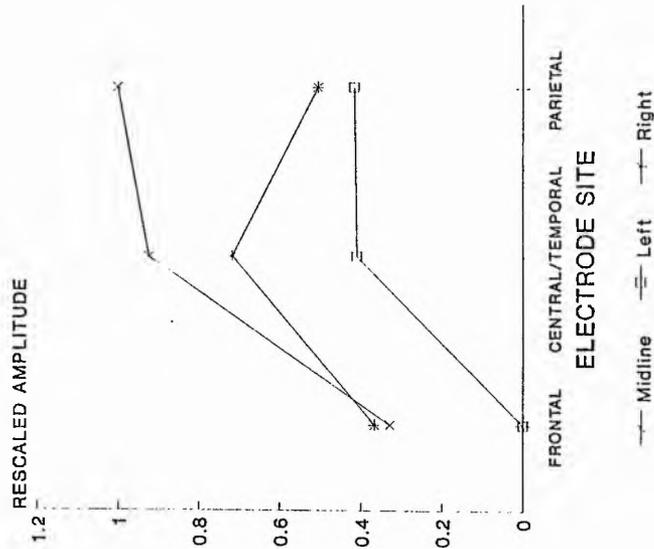


Figure 7.2a, 7.2b and 7.2c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by frequent (Figure 7.2a), target (Figure 7.2b) and rare nontarget (Figure 7.2c) stimuli within the target heterogeneous procedure in Experiment 5.

Homogeneous Target

ANOVA of the rescaled amplitude evoked by the three classes of stimuli revealed a significant three way interaction involving the factors of condition, chain and site (see Table 7.3). *Post hoc* analysis demonstrated that frequent (see Figure 7.3a), target (see Figure 7.3b) and rare nontarget (see Figure 7.3c) stimuli all demonstrated a centro-parietal maximum scalp amplitude distribution across the midline chain of electrodes. Along the lateral chains all three classes of stimuli demonstrated an equipotential amplitude distribution.

N100

ANOVA of the mean amplitude evoked by the three classes of stimuli failed to demonstrate a main effect of either procedure or condition (see Table 7.4 of the Appendix). A significant three way interaction involving the factors of condition, chain and site was obtained. *Post hoc* analysis demonstrated that along the lateral chains all three classes of stimuli evoked greater amplitude at parietal sites in comparison to frontal and temporal sites. Along the midline all three classes of stimuli evoked amplitude that was equally great across the electrode sites.

Scalp Distribution

ANOVA of the rescaled amplitude evoked by the three classes of stimuli failed to demonstrate a significant interaction involving the factors of procedure or condition (see Table 7.4 of the Appendix). A significant two way interaction involving the factors of chain and site was obtained. *Post hoc* analysis demonstrated that along the lateral chains a temporo-parietal scalp amplitude distribution was obtained (collapsed across experimental procedure and condition). Along the midline chain an equipotential amplitude distribution was obtained.

N200

ANOVA of mean amplitude evoked by the three classes of experimental stimuli revealed a significant three way interaction involving the factors of procedure, condition and site (see Table 7.5 of the Appendix). *Post hoc* analysis demonstrated that within the target heterogeneous procedure frequent and rare nontarget stimuli evoked equally great mean amplitude across the

Figure 7.3a

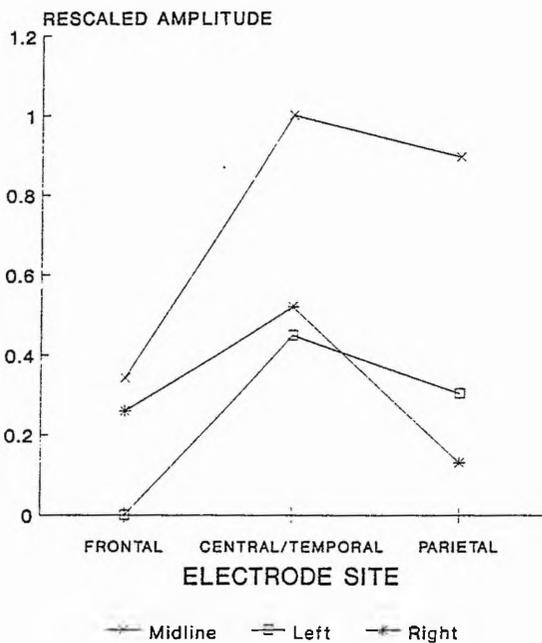


Figure 7.3b

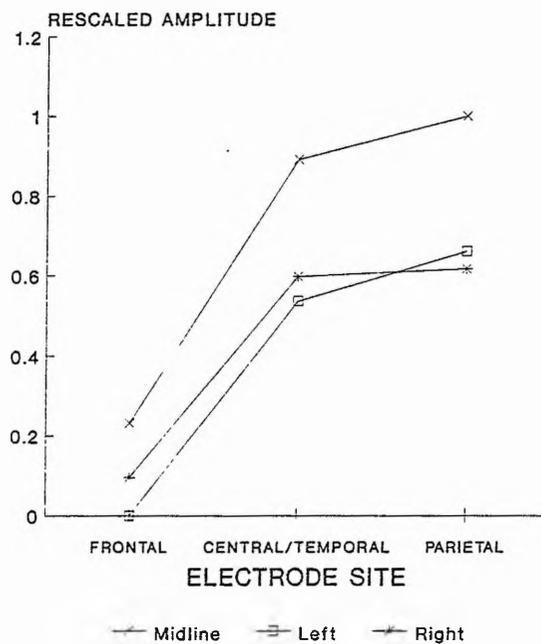


Figure 7.3c

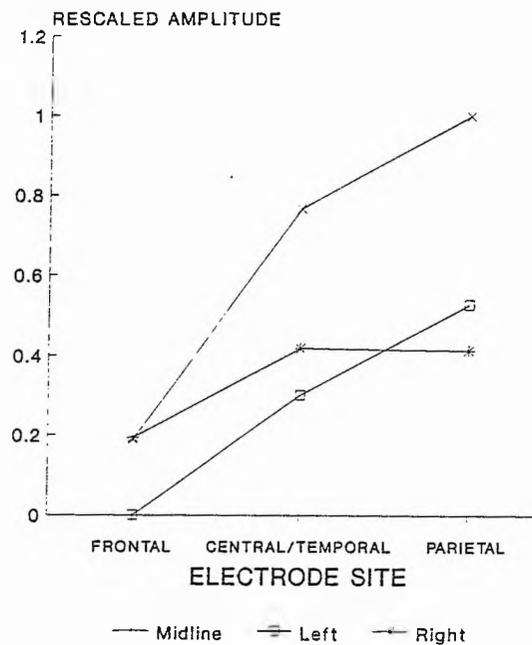


Figure 7.3a, 7.3b and 7.3c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the P300 deflection elicited by frequent (Figure 7.3a), target (Figure 7.3b) and rare nontarget (Figure 7.3c) stimuli within the target homogeneous procedure in Experiment 5.

sites. Target stimuli evoked greater deflections at frontal sites in comparison to central/temporal or parietal sites.

Within the target homogeneous procedure frequent and target stimuli evoked equally great mean amplitude across the sites. Rare nontarget stimuli evoked a greater deflection across centro/temporo-frontal sites in comparison to parietal sites.

Scalp Distribution

ANOVA of rescaled amplitude evoked by the three classes of stimuli revealed a significant four way interaction involving the factors of procedure, condition, chain and site (see Table 7.5 of the Appendix). Within the target heterogeneous procedure frequent and rare nontarget stimuli demonstrated an equipotential amplitude distribution across the scalp within the N200 latency range (see Figure 7.4a and 7.4b). Target stimuli evoked a centro-frontal amplitude distribution along the midline. Along the lateral chains the frontal sites demonstrated a greater amplitude distribution than the parietal sites (see Figure 7.4c).

Within the target homogeneous procedure both frequent and target stimuli evoked amplitude with a scalp distribution that was greater at the frontal site in comparison to the parietal site along the midline chain. Along the lateral chains an equipotential amplitude distribution was obtained (see Figure 7.5a and 7.5b). Rare nontarget stimuli evoked a N200 deflection that demonstrated a frontal site maximum scalp amplitude distribution along all three chains of electrodes (see Figure 7.5c).

500 - 850 msec Latency Range

ANOVA of the mean amplitude evoked by the three classes of stimuli within the latency range 500-850 msec across experimental procedures demonstrated a significant effect of procedure (see Table 7.6 of the Appendix). *Post hoc* analysis demonstrated that greater mean amplitude was evoked by stimuli within the target homogeneous than the target heterogeneous procedure.

Post hoc analysis of the two way interaction involving the factors of procedure and condition demonstrated that within the target heterogeneous procedure target stimuli evoked greater mean amplitude than either frequent or rare nontarget stimuli. Within the target homogeneous procedure both target and rare nontarget stimuli evoked greater mean amplitude than the frequent stimuli.

Figure 7.4c

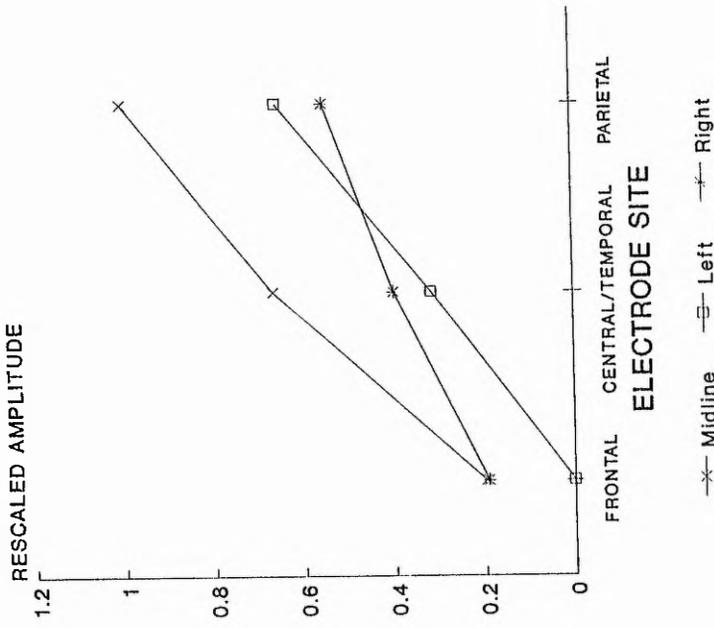


Figure 7.4b

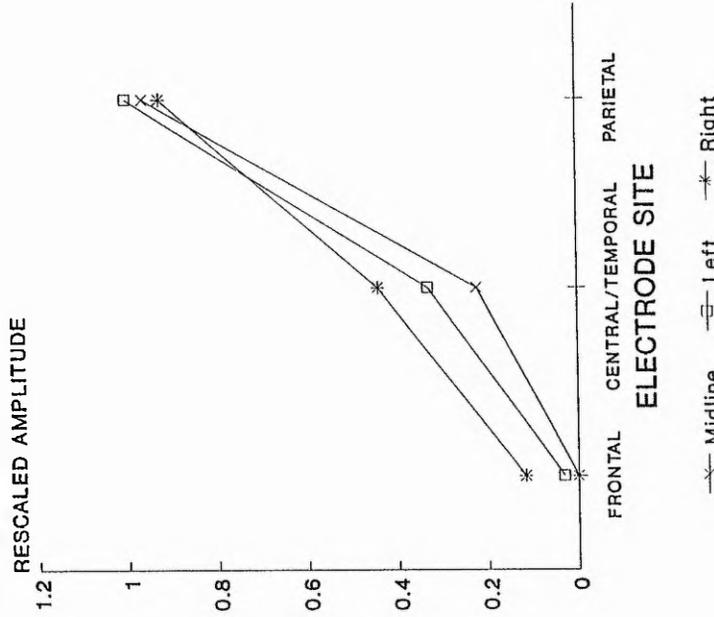


Figure 7.4a

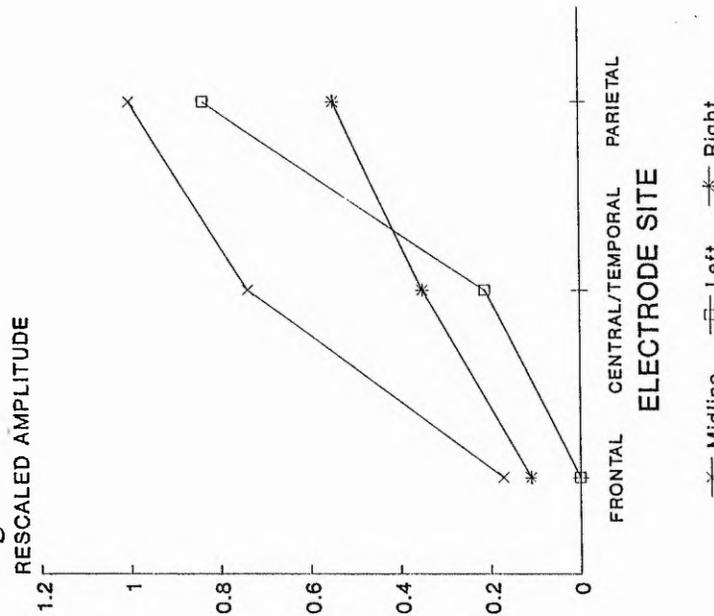


Figure 7.4a, 7.4b and 7.4c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by frequent (Figure 7.4a), target (Figure 7.4b) and rare nontarget (Figure 7.4c) stimuli within the target heterogeneous procedure in Experiment 5.

Figure 7.5a

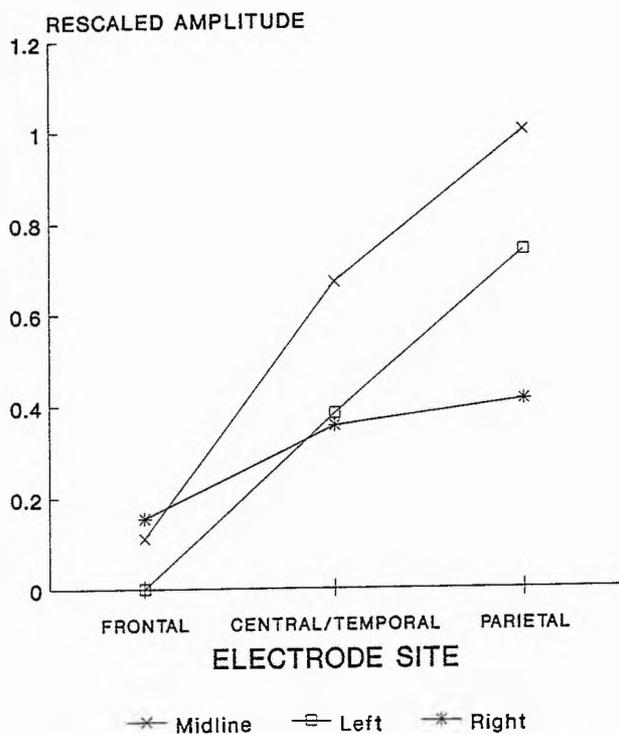


Figure 7.5b

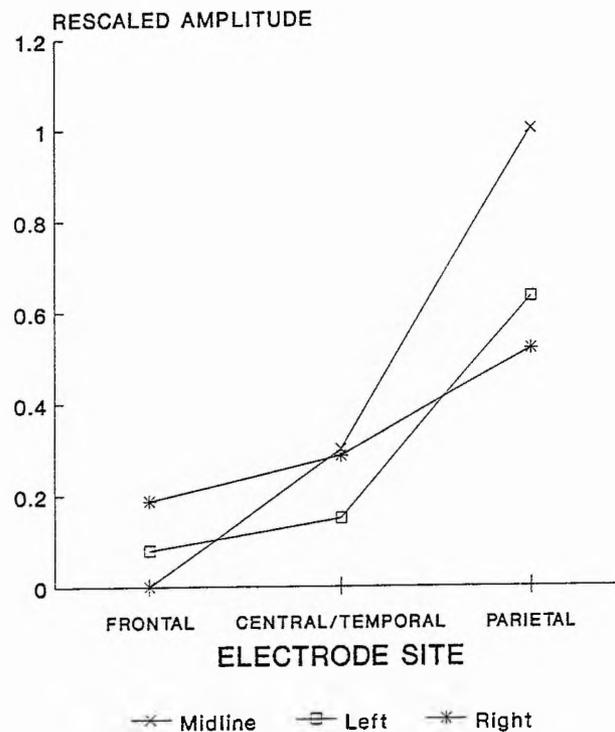


Figure 7.5c

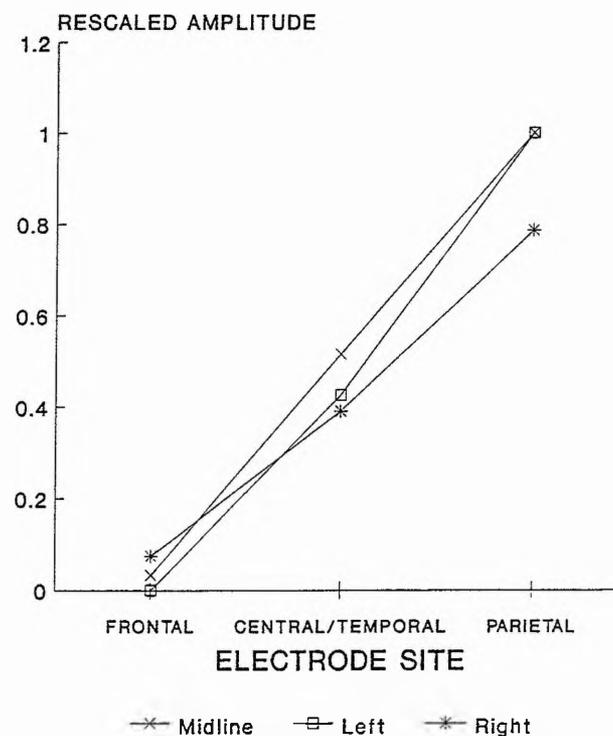


Figure 7.5a, Figure 7.5b and 7.5c Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by frequent (Figure 7.5a), target (Figure 7.5b) and rare nontarget (Figure 7.5c) stimuli within the target homogeneous procedure in Experiment 5.

A four way interaction involving the factors of procedure, condition, chain and site was not obtained. Further ANOVAs were, therefore, carried out to examine the effect of procedure across the scalp for each experimental condition.

Heterogeneous Target Procedure

ANOVA of mean amplitude evoked by the three classes of stimuli revealed a significant interaction involving the factors of condition, chain and site (see Table 7.6.1 of the Appendix). *Post hoc* analysis demonstrated that frequent and rare nontarget stimuli evoked the same mean amplitude at each site along the three chains. Target stimuli evoked greater mean amplitude at central and parietal sites in comparison to the frontal site. Along the lateral chains equal amplitude was evoked at each site.

Homogeneous Target Procedure

ANOVA of mean amplitude evoked by the three classes of stimuli revealed a significant interaction involving the factors of condition, chain and site (see Table 7.6.2 of the Appendix). Similar results were obtained as within the heterogeneous target procedure. Target stimuli evoked greater amplitude at central and parietal sites in comparison to frontal site. In response to frequent and rare nontarget stimuli, amplitude was equally great at each site along all three chains.

Scalp Distribution

Heterogeneous Target

ANOVA of rescaled mean amplitude demonstrated that no interaction involving the factor of condition was found to be significant (see Table 7.6.1 of the Appendix). Figure 7.6 demonstrates the scalp amplitude distribution of the responses evoked by frequent, target and rare nontarget stimuli across the scalp, however, the corresponding interaction involving the factors of Condition X Site did not prove to be statistically significant.

Homogeneous Target

ANOVA of rescaled mean amplitude demonstrated that a significant interaction involving the factors of condition and site was obtained (see Table 7.5b of the Appendix). *Post hoc* analysis demonstrated that frequent and rare nontarget stimuli demonstrated a central/temporal site maximum scalp

Figure 7.6a

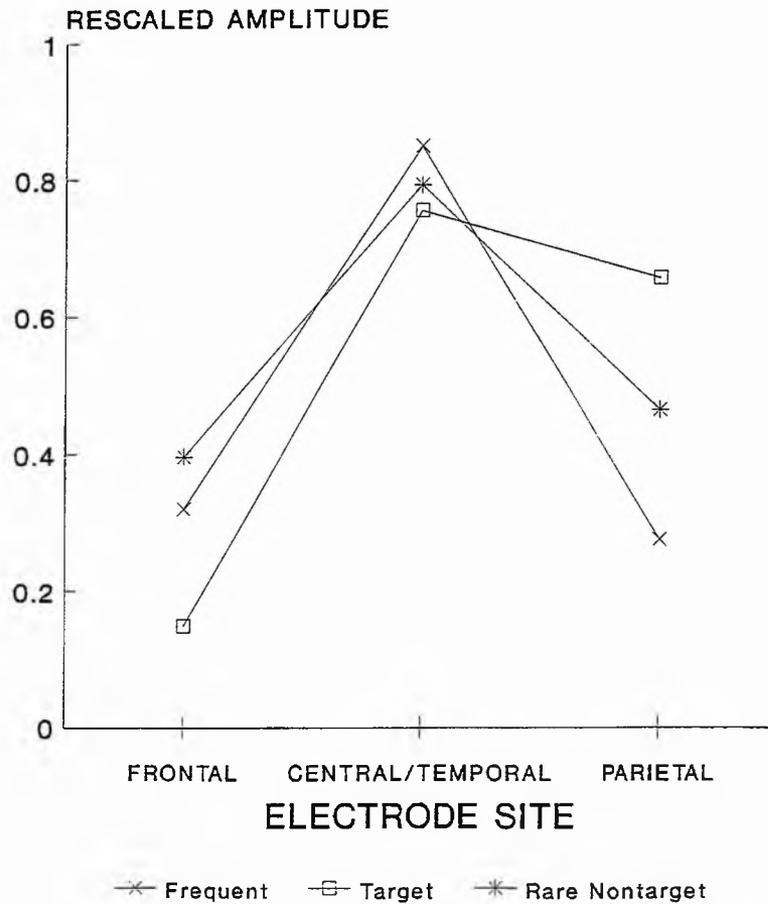


Figure 7.6b

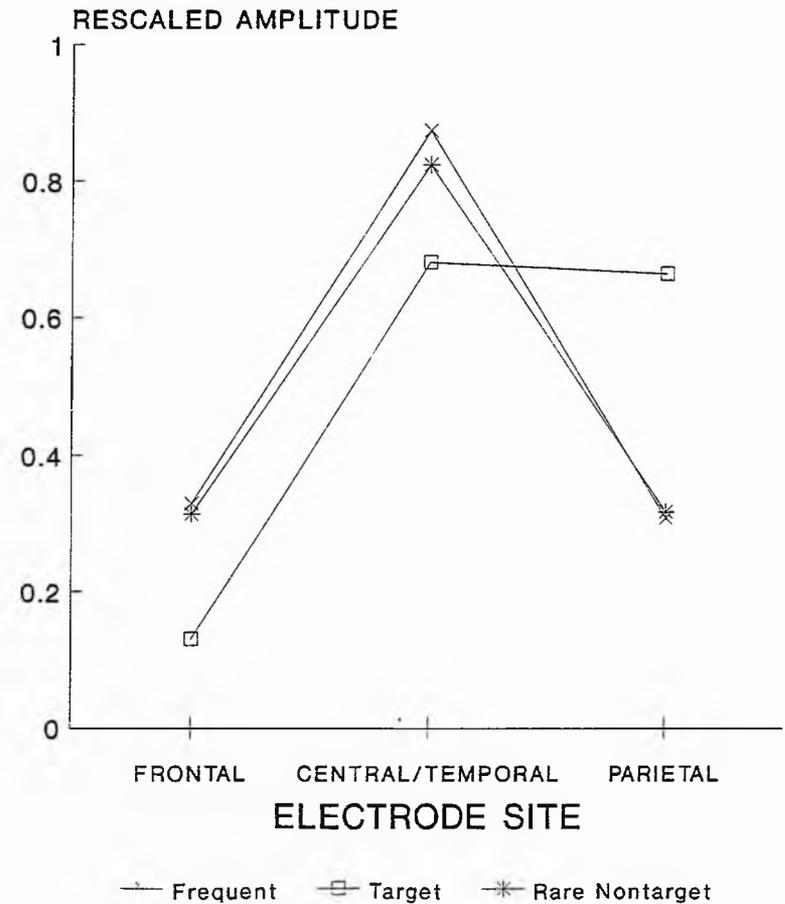


Figure 7.6a and 7.6b Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited within the target heterogeneous (Figure 7.6a) and target homogeneous (Figure 7.6b) procedures within Experiment 5 (collapsed across electrode chains).

amplitude distribution. Target stimuli demonstrated a centro/temporo-parietal scalp amplitude distribution (see Figure 7.7).

150 -350 msec Latency Range

ANOVA of the mean amplitude evoked by the three classes of experimental stimuli within the latency range 150 - 350 msec across experimental procedures demonstrated a significant two way interaction involving the factors of procedure and condition (see Table 7.7 of the Appendix). *Post hoc* analysis demonstrated that within the target heterogeneous procedure target stimuli evoked greater mean amplitude than that evoked by either the frequent or rare nontarget stimuli (see Figure 7.7a). Within the target homogeneous procedure rare nontarget stimuli evoked greater mean amplitude than either frequent or target stimuli. However, target stimuli evoked greater mean amplitude than frequent stimuli (see Figure 7.7b).

7.5 Discussion

The aim of this experiment was to determine whether manipulation of the physical contrast between frequent and target stimuli and frequent and rare nontarget stimuli would alter the mean amplitude and scalp distribution of P300 responses to the three classes of stimuli. A further aim of this experiment was to determine the mean scalp amplitude and the scalp amplitude distribution of the P300 deflection evoked in response to frequent stimuli within a standard three stimulus visual oddball paradigm. The amplitude distribution of the frequent P300 response was not determined in previous experiments (see Chapter 4 and 5) employing frequent stimuli with a probability of occurrence of 70% since the question to be addressed was the relative amplitude distributions of the P300 deflections evoked in response to target and rare nontarget stimuli. Within Chapter 6 the scalp amplitude distribution of the deflection evoked in response to frequent stimuli was determined, however, stimuli were presented with an equal probability of occurrence. Within Chapter 6 all three classes of experimental stimuli evoked P300 deflections with a maximum amplitude distribution across centro-parietal sites.

Within the target homogeneous procedure similar results were obtained as reported in Chapter 4, this was predicted since the same stimuli and experimental procedure were employed. Within the latency range of the P300 deflection target and rare nontarget stimuli both evoked greater amplitude in comparison to that evoked in response to the frequent stimuli. Similarly target

Figure 7.7a

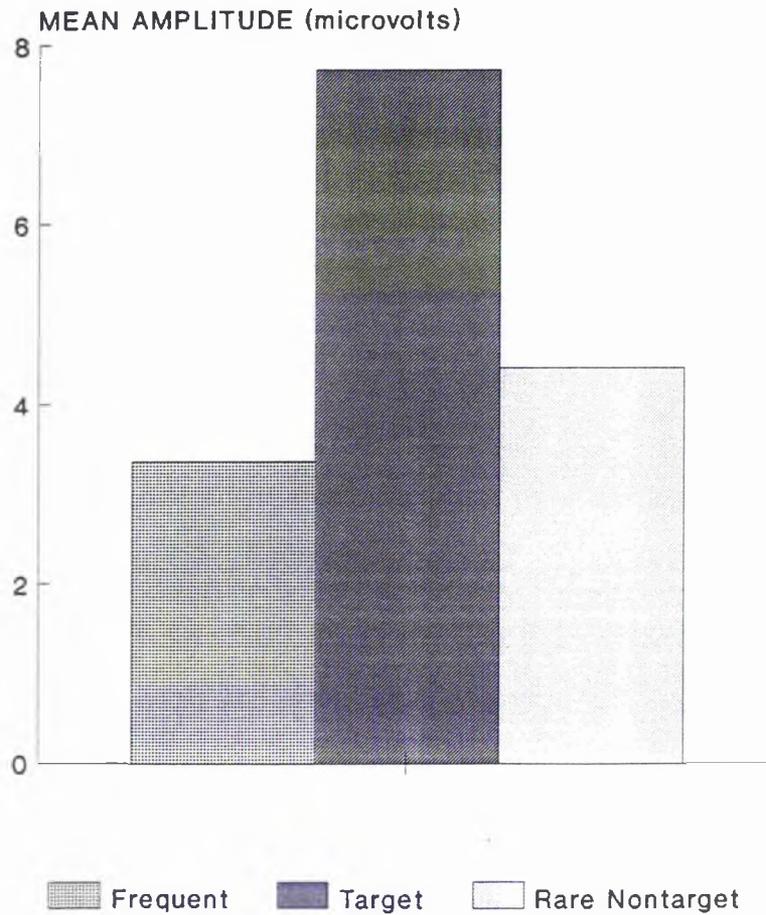


Figure 7.7b

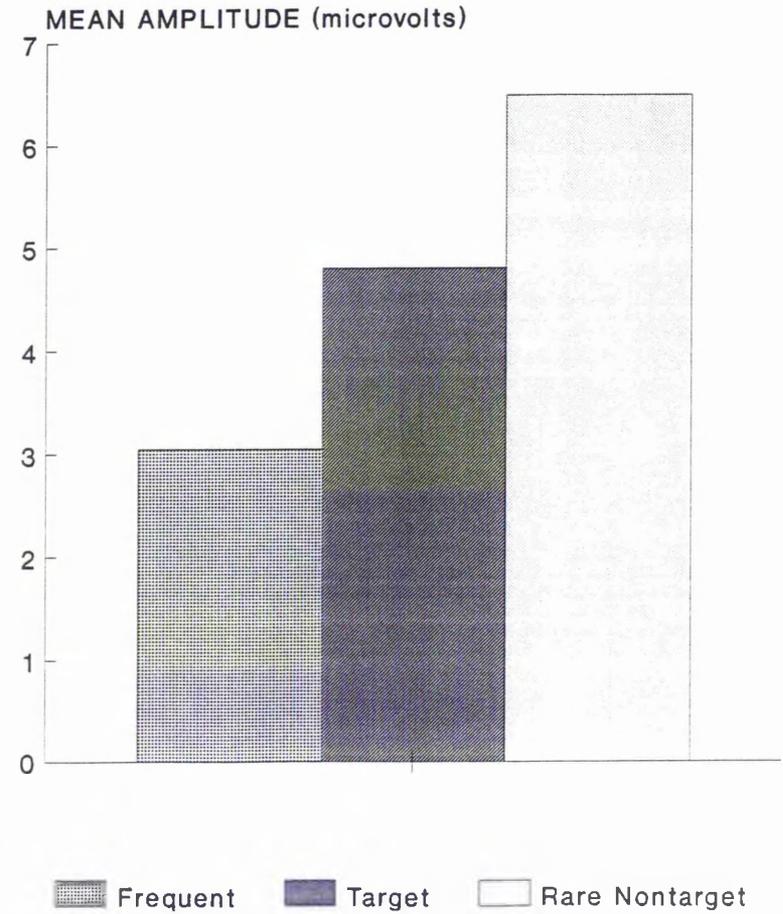


Figure 7.7a and 7.7b Bar diagram illustrating the mean amplitude evoked by frequent, target and rare nontarget stimuli within the heterogeneous (Figure 7.7a) and homogeneous (Figure 7.7b) procedures at lateral parietal sites in Experiment 5.

and rare nontarget P300 responses reported within Chapter 4 demonstrated that both classes of stimuli evoked similar mean amplitudes. Within both experiments subjects appeared to regard target and rare nontarget stimuli as contrasting by a similar amount to the frequent stimuli. As reported previously Courchesne *et al.* (1978) claimed that the greater the contrast between a rare stimulus and the background stimuli the greater the amplitude of the P300 deflection evoked.

As predicted within the target heterogeneous procedure increasing the contrast between the target and frequent stimuli while decreasing the contrast between frequent and rare nontarget stimuli resulted in target stimuli evoking greater mean amplitude in comparison to either the frequent or rare nontarget stimuli. The reduction in contrast between rare nontarget and frequent stimuli resulted in rare nontarget stimuli evoking comparable mean amplitude to that of the frequent stimuli.

Across both experimental procedures the scalp amplitude distribution of the P300 responses elicited in response to the three classes of stimuli demonstrated a centro-parietal amplitude distribution along the midline. Along the lateral chains all three classes of stimuli demonstrated an equipotential amplitude distribution. Results obtained in response to rare stimuli along the midline chain replicated the findings previously reported in Chapter 4 employing similar stimuli within a similar experimental procedure. Reducing the dissimilarity between the frequent and rare nontarget stimuli reduced the mean amplitude evoked in response to rare nontarget stimuli to comparable levels to that evoked in response to frequent stimuli. However, the scalp amplitude distribution remained the same as when the contrast between the two classes of stimuli was greater.

Such a result indicates that while the output of underlying neural generators may be altered by the relative characteristics of the stimuli (*i.e.* the stimulus complexity of the stimuli; see section 1.5.1.2) the underlying combination of generators responsible for the activity that may be recorded from the scalp as the P300 remains the same. The results demonstrated that target stimuli evoked a response with a consistently greater mean amplitude in comparison to that evoked in response to frequent stimuli regardless of their stimulus characteristics (target stimuli complexity being subjectively greater within the target heterogeneous procedure in comparison to the target homogeneous procedure). The mean amplitude of rare nontarget stimuli, however, was significantly greater within the procedure in which such stimuli demonstrated greater stimulus complexity in comparison to frequent stimuli.

Regardless, however, of the relative amount of amplitude evoked both classes of rare stimuli evoked P300 deflections with consistent scalp amplitude distributions across procedures. Both evoked deflections with a centro-parietal maximum amplitude distribution. Similarly, frequent stimuli demonstrated a positive deflection within the latency range of the P300 deflection. Across both procedures frequent stimuli evoked deflections with a maximum amplitude distribution across centro-parietal sites along the midline chain. Such an amplitude distribution demonstrates the activity of a similar combination of neural generators as the combination of generators responsible for the generation of the deflection evoked in response to rare stimuli.

Within the N200 latency range it was demonstrated that stimuli with the greater contrast with the frequent stimuli demonstrated a greater anterior maximum scalp amplitude distribution. Within the target heterogeneous procedure the target stimuli demonstrated a greater contrast with the frequent than that of the rare nontarget stimuli. Rare nontarget and frequent stimuli both demonstrated an equipotential amplitude distribution across the scalp. Target stimuli demonstrated a centro-frontal amplitude distribution along the midline. Such a negative component occurring within the latency range of the N200 deflection may correspond to an N2b component. Such a component corresponds to a frontally distributed deflection elicited to an allocation of attention to the eliciting stimulus.

Within the target homogeneous procedure rare nontarget stimuli demonstrated a greater contrast with frequent stimuli. Both target and frequent stimuli demonstrated an equipotential scalp amplitude distribution. Rare nontarget stimuli demonstrated a frontal site maximum amplitude distribution along all three chains. Such a negative component occurring within the latency range of the N200 deflection may correspond to an N2a (MMN) component. Such a component with a frontal site amplitude distribution may correspond to a subject's responsiveness to low probability "deviant" stimuli even when the subject is not attending to the stimulus sequence.

Such a dissociation of responses within the N200 latency range demonstrates that the N200 deflection observed within active oddball tasks may be formed by a composite of MMN (N2a) and N2b components. However, the above results would seem to suggest that an N200 deflection may be elicited simply by the physical deviance of the class of stimuli regardless of whether the stimuli are regarded as either a target or rare nontarget. Such an elicitation of an N200 deflection in response to the physical deviance of a class of stimuli may correspond to the MMN reported within the auditory modality. A similar

finding of what may appear to be a composite N2b/N2a(MMN) deflection within the visual modality has been described by Alho *et al.* (1992) and Woods *et al.* (1992).

Alho *et al.* (1992) employed a balanced, intermodal experimental design to evaluate the possibility that infrequent changes in visual input might elicit a visual counterpart to the auditory MMN. It was demonstrated that visual deviants (easy visual discrimination) elicited so-called deviance-related negativities (DRN) during both visual and auditory attention. Alho *et al.* (1992; see also Woods *et al.* 1992) claimed that the early component of the visual DRN shared characteristics with the auditory MMN. Difference waves (deviant minus standard) in both the auditory and visual conditions revealed a broad negativity over occipital and inferior temporal regions of the hemisphere contralateral to the stimulated visual field. The visual MMN/N2b demonstrated a right hemisphere amplitude predominance that has also been reported for the auditory MMN (Paavilainen *et al.* 1991). Like the auditory MMN the visual MMN/N2b was not affected by the processing load during attention to the other modality. However, as pointed out by Alho *et al.* (1992) the early part of the visual MMN/N2b differed from the auditory MMN in a number of respects. Deviant visual stimuli physically close to the standards failed to evoke an MMN/N2b at all, this was not found to be the case in the auditory modality (Sams *et al.* 1985). From the results it appears that the visual MMN/N2b may be sensitive to changes in only certain stimulus features whereas the auditory MMN is elicited by a large variety of physical changes (Näätänen 1990). Finally the visual MMN/N2b resembled the occipital negativity that is seen to occur following visual targets presented also. These three points leave open the question as to whether the visual MMN/N2b was related to processing of stimulus change or whether it simply reflected a less refractory sensory response to infrequent visual stimuli.

Both Alho *et al.* (1990) and Naatanan *et al.* (1982) have demonstrated that the N2b component may be elicited by both target and nontarget deviant stimuli in one-channel situations. Within the auditory modality the N2b and P3a components are said to form an N2b-P3a wave complex (Naatanan 1990; Squires *et al.* 1977). Although, as pointed out in section 1.5.4.1, the N2b may be elicited without a P3a component and a P3a without an N2b component.

Experimental procedure and condition both failed to affect the scalp amplitude distribution of the N100 responses across the scalp. It would, therefore, appear that regardless of the physical characteristics of the three

classes of stimuli a similar combination of neural generators is responsible for the generation of the N100 component.

A similar finding was demonstrated within the 500 - 850 msec latency range. Within the target homogeneous procedure a condition by site interaction was obtained. Analysis of this interaction demonstrated that target stimuli demonstrated a centro/temporo-parietal scalp amplitude distribution. Both frequent and rare nontarget stimuli demonstrated a central/temporal maximum scalp distribution. Although a significant interaction involving the factor of condition was not obtained within the target heterogeneous procedure as may be seen in Figure 7.4a the findings are qualitatively similar to those demonstrated in Figure 7.4b which illustrate the distribution of responses within the target homogeneous procedure. Target stimuli appeared to demonstrate a more centro/temporo-parietal distribution in comparison to the more central/temporal distribution demonstrated in response to frequent and rare nontarget stimuli. The results demonstrated within the target homogeneous procedure support the view that positive posterior slow wave activity may reflect the additional processing required in response to certain types of task demand. Target stimuli demonstrated a more posterior maximum amplitude distribution in comparison to that demonstrated in response to frequent and rare nontarget stimuli. Alteration of the contrast between rare nontarget and target stimuli with that of frequent stimuli failed to significantly alter the distribution of responses within the mean latency range 500 - 850 msec. Such a result indicates that activity within this latency range demonstrates task relevance characteristics in contrast to stimulus characteristics.

As previously reported (see Chapters 3, 4, 5 and 6) Wijers *et al.* (1989a; 1989b) have claimed that ERPs evoked by attended stimuli demonstrated a prolonged negative shift compared to ERPs to unattended stimuli if the two classes (to be attended - target stimuli; not to be attended - rare nontarget stimuli) may be discriminated on the basis of simple physical stimulus attributes or selection cues. Within previous experiments employing visual stimuli a heterogeneous set of rare nontarget stimuli have been discriminated from target stimuli on the basis of contour. This physical characteristic has, therefore, been postulated to act as a selection cue. Within the present experiment within the target homogeneous procedure a heterogeneous set of rare nontarget stimuli may be discriminated from target stimuli on the basis of contour characteristics. As in previously reported experiments (see Chapters 3, 4, 5 and 6) target stimuli deflections demonstrated a prolonged negative shift at

lateral parietal sites within a latency range of 150 - 350 msec in comparison to rare nontarget stimuli deflections.

However, in the target heterogeneous procedure rare nontarget stimuli consisted of a homogeneous set of stimuli while target stimuli were drawn from a set of heterogeneous stimuli. Here target stimuli may be distinguished from rare nontarget stimuli on the basis of their contour characteristics. Subsequently within this procedure the rare nontarget deflections evoked demonstrated a prolonged negative shift in comparison to the deflection evoked in response to target stimuli. Such a difference between procedures demonstrates that it is the physical characteristics rather than the task characteristics which appears to be acting as a selection cue. However, an alternative explanation may also account for the greater amplitude evoked in response to the rare target stimuli in comparison to that evoked in response to rare nontarget stimuli. As illustrated in Figure 7.1a the ascending portion of the P300 deflection is relatively steep in comparison to the corresponding limb of the P300 evoked within the target homogeneous procedure (see Figure 7.1b). The difference in mean amplitude exhibited at lateral parietal sites within the target homogeneous waveform may therefore reflect increased target amplitude rather than a negative shift of the rare nontarget deflection.

Altering the contrast between the rare stimuli and the frequent stimuli simply altered the evoked mean amplitude of the rare stimuli as predicted by Courchesne *et al.* (1978). As stated previously the contrast between rare stimuli and the ongoing background sequence of frequent stimuli appears to simply alter the strength of output but not the combination of underlying neural generators.

Summary

Reducing the contrast between rare nontarget and frequent stimuli reduced the mean P300 amplitude evoked by rare nontarget stimuli to comparable levels to that evoked by frequent stimuli.

Reducing the contrast between rare nontarget and frequent stimuli failed to alter the scalp amplitude distribution of the P300 rare nontarget response.

Across both experimental procedures target and rare nontarget P300 responses demonstrated a maximum scalp amplitude distribution at centro-parietal sites along the midline chain. Similarly frequent stimuli evoked a P300 deflection with a centro-parietal amplitude distribution along the midline. All three classes of stimuli evoked an equipotential amplitude distribution along the lateral chains.

Chapter 8

Experiment 6: Investigation of the Effect of Advancing Age upon the Scalp Amplitude Distribution of Visually and Auditorially Evoked P300 Potentials

8.1 Introduction

Johnson (1989a) claims that there is a growing body of evidence that argues against the concept of a single modality independent neural generator responsible for the elicitation of the P300 complex. If the P300 ERP is modality independent it is possible that this would be manifested by differences in the rate at which these potentials develop and mature for different modalities.

Johnson (1989b) examined the developmental course of P300 amplitudes and latencies elicited by auditory and visual stimuli in subjects aged between 7 and 20 years. He demonstrated that auditory and visual P300s appeared to develop at different rates and that such changes as a function of age were not the result of latency changes in any of the measurable components that preceded the P300. In contrast to the smaller and more gradual changes in the latency of visual P300s, auditory P300 latencies underwent much larger and more abrupt changes. For instance, whereas auditory P300 latencies were larger than visual P300 latencies in the youngest children, this relation was reversed in the older children.

Goodin *et al.* (1978) initially reported that the latency of the P300 wave to detected targets within the auditory modality was significantly increased in elderly in comparison to young subjects. This finding of latency prolongation has consistently been reported (for a review see Bashore 1990; Bashore *et al.* 1989) particularly in two tone tasks (for example Barrett *et al.* 1987; Brown *et al.* 1983; Picton *et al.* 1984; Polich *et al.* 1985; Syndulko *et al.* 1982). An increase in P300 latency with age has also been observed in visual and somatosensory oddball tasks (Barrett *et al.* 1987; Beck *et al.* 1980; Mullis *et al.* 1985; Pfefferbaum *et al.* 1984; Yamaguchi and Knight 1991c). There is disagreement concerning the function relating age to P3 latency. Most reports have described a linear increase of P3 latency with age across the adult life span with slopes ranging from 0.91 msec to 1.85 msec per year (for instance see Barrett *et al.* 1987; Goodin *et al.* 1978; Picton *et al.* 1984).

However, a nonlinear (accelerating) relationship between P300 latency and age has been reported by Brown *et al.* (1983) and Beck *et al.* (1980). Beck *et al.* reported that the slope of the P300 latency/age regression doubled after the age of 63 (from a slope of 0.8msec/year between 28 to 63 to one of 1.6msec/year between 63 and 79). The effects of aging on the latencies of the N100 and N200 components of the ERP elicited by target tones has also been investigated in oddball tasks. The N100 seems to remain relatively invariant in latency across the life span (Brown *et al.* 1983; Picton *et al.* 1984; Barrett *et al.* 1987). The N200, however, increases although to a lesser degree than does the P300 (Barrett *et al.* 1987; Goodin *et al.* 1978).

P300 amplitude is also reported to decrease with advancing age (Goodin *et al.* 1978; Brown *et al.* 1983). The amplitude reduction in P300 with age has also been reported to be associated with a shift in the scalp distribution of the P300 component. The P300 component is reported to be reduced at parietal scalp and increased at frontal scalp, effectively producing a flatter amplitude distribution across the scalp with advancing age (Picton *et al.* 1984; Friedman *et al.* 1989; Strayer *et al.* 1987; for reviews see Ford and Pfefferbaum 1980; 1985; Polich and Starr 1984). Friedman *et al.* (1993) claim that "in addition to the increment in P300 latency with advancing age, the difference in scalp distribution between young and elderly subjects is one of the most robust age-related findings in the ERP literature" (pp. 393).

Friedman *et al.* (1993) employed a young, a middle aged and an elderly group of subjects within an auditory three tone oddball task, rare nontarget stimuli consisted of 48 unique nontonal novel sounds. It was reported that there was a propensity in all age groups (somewhat more marked in the two older groups) for the rare nontarget P300 response to show a greater spread of amplitude and current source density over the scalp of the left hemisphere compared with that of the target.

Despite the large number of studies that have examined the effects of aging on the ERP as pointed out by Friedman *et al.* (1993) few studies have examined the major ERP components of both frequent and target tones. The majority have only reported effects on the N200 and P300 deflections in response to auditory target stimuli. However, there are notable exceptions for instance Friedman *et al.* (1993) and Barrett *et al.* (1987) who both examined the effect of advancing age upon the N100, N200 and P300 deflections. Similarly the majority of studies examining the effect of advancing age have employed auditory stimuli within two tone oddball paradigms.

This experiment aimed to examine the effect of age upon the latency, amplitude and scalp distribution of the target and rare nontarget P300 responses within the visual and auditory modalities employing three stimulus oddball paradigms. If the P300 response is modality dependent it is feasible P300 responses within each modality may alter with advancing age differently. As reported above both the latency and amplitude of P300 responses change with age, the question to be examined here is whether the combination of underlying generators changes differentially within each sensory modality with age. It was predicted that within the young subjects the results obtained would replicate those previously reported in chapter 3 and 4 (employing auditory and visual stimuli respectively). A dissociation of scalp amplitude distribution between modalities with increased age would suggest a different generator configuration between modalities.

An age-extremes design was employed for the reasons outlined by Pfefferbaum *et al.* (1979). The study of extreme age groups is both efficient and sensitive to small effects that may be evident in an older population of subjects. It enables strict inclusion criteria to be enforced in order to reduce the confounding effect of CNS pathology which increases with advancing age. For these reasons a group of healthy and well educated elderly subjects was selected and compared to a similar group of young subjects.

8.2 Method

Subjects

The two groups that participated in the study were 16 healthy elderly subjects (mean age 64 years, range 57-74, twelve female) recruited from a university sponsored 'keep-fit' exercise class. The young group of subjects were 16 healthy students (mean age 20 years, range 18-24, eleven female). No subject had previously participated in an ERP experiment.

EEG Recording

Electroencephalographic (EEG) and electro-oculogram (EOG) activity were recorded from the scalp montage described in section 2.5 using a proprietary electrode cap with tin electrodes.

Procedure

Each subject performed an auditory and a visual procedure (alternated between subjects). The auditory and visual procedures employed will be discussed in sections 8a.2.4 and 8b.2.4 respectively.

8.3 Data Analysis

Latency Data

See section 2.6.2 for a description of the peak latencies measured. Latency values for each component were determined for both auditory and visual procedures within both groups of subjects separately. Such ANOVAs took the form of Subject X Condition X Site.

Amplitude Data

See section 2.6.3 for a description of the ANOVAs performed on amplitude data. The ANOVAs took the form of Group X Subject X Condition X Chain X Site. In the case of the P300 and N200 components between group analyses were carried out upon target and rare nontarget responses. Such ANOVAs took the form of Group X Subject X Chain X Site.

Scalp Distribution

To examine the scalp distribution of experimental conditions between groups between group analyses were carried out. Such analyses took the form of Group X Subject X Chain X Site. To examine the scalp distribution of experimental conditions between condition analyses were carried out within groups. Such ANOVAs took the form of Subject X Condition X Chain X Site.

Single Trial Analysis

To examine whether the amplitude of responses evoked by target and rare nontarget stimuli altered during the initial presentation of stimuli single trial analysis, as described in section 2.7, was carried out. Such analyses were performed upon data from both auditory and visual modalities within both groups of subjects.

Within the young group of subjects single trial analysis was performed upon data from 13 subjects since two subjects demonstrated significant eye blink artifact upon a significant proportion of the first 10 presentations of the stimuli. It did not prove possible to recall the raw EEG data from the back-up media for the final young subject. Single trial analysis was carried out upon 12

subjects within the elderly group of subjects since four subjects demonstrated significant eye blink artifact upon a significant proportion of the first 10 presentations of the stimuli.

Presentation of Results

To aid clarity of presentation all results pertaining to auditory stimuli will be presented beginning with the prefix '8a'. All results pertaining to visual stimuli will be presented as beginning with the prefix '8b'. This numbering scheme will be employed throughout text, tables and graphs.

8a Auditory Modality

8a.2 Method

Stimuli

The auditory stimuli described in section 3.4 were employed here.

Procedure

The procedure described in section 3.4 was employed here.

8a.3 Data Analysis

In three subjects (1 young and 2 elderly) N200 deflections could not be identified. ANOVA of unequal groups was carried out upon these data using groups of 15 young and 14 elderly subjects.

8a.4 Results

Behavioural Data

Mean reaction times to correctly detected targets (young = 463 msec with a standard deviation across subjects of 99 msec; elderly 474 msec with a standard deviation across subjects of 126 msec) failed to demonstrate a significant age related difference ($t(15) = 0.28$ $p = 0.78$). Target detection was near ceiling for both age groups (young 98.2%; elderly 98.7%). The false alarm rate was very low (young 0.3%; elderly 0.16%) neither the false alarm or hit rate between the age groups proved to be significant.

ERP Data

Grand average waveforms (see Figure 8a.1a and 8a.1b) for both groups of subjects were produced.

	Young Group	Elderly Group
Frequent	163 (117-160)	181 (119-204)
Target	37 (28-44)	40 (27-45)
Rare Nontarget	38 (29-45)	40 (29-45)

As may be observed, in Figure 8a.1a, the young group of subjects demonstrated a negative deflection of the waveform at approximately 100 msec post stimulus, the N100. This negative deflection was greatest at frontal and central/temporal electrode sites. A second negative deflection evoked in response to rare stimuli with a latency of approximately 200 msec was evident at frontal sites. Following the resolution of the N200 deflection rare stimuli evoked a positive deflection at approximately 300 msec. Rare stimuli demonstrated a negativity at frontal sites and a positivity at parietal sites following the resolution of the P300 deflection.

The elderly group of subjects demonstrated a similar ERP waveform (see Figure 8a.1b). The N100 deflection was greatest at frontal and central/temporal electrode sites. Rare stimuli evoked an N200 deflection followed by a P300 deflection. Both target and rare nontarget stimuli deflections in the P300 latency range appeared to be more equally distributed along the electrode sites than was evident in the young group of subjects. Rare nontarget stimuli demonstrated an asymmetry across the lateral chains of electrodes, reduced amplitude was evoked along the right chain of electrodes than along the left chain. Both the responses to frequent and target stimuli were symmetrically distributed across the lateral chains of electrodes. Following the resolution of the P300 deflection the rare stimuli demonstrated a negativity at frontal sites and a positivity at parietal sites.

Table 8a.13.1 and 8a.13.2 of the Appendix show the mean amplitude and mean rescaled amplitude elicited by auditory experimental stimuli within the

Figure 8a.1a

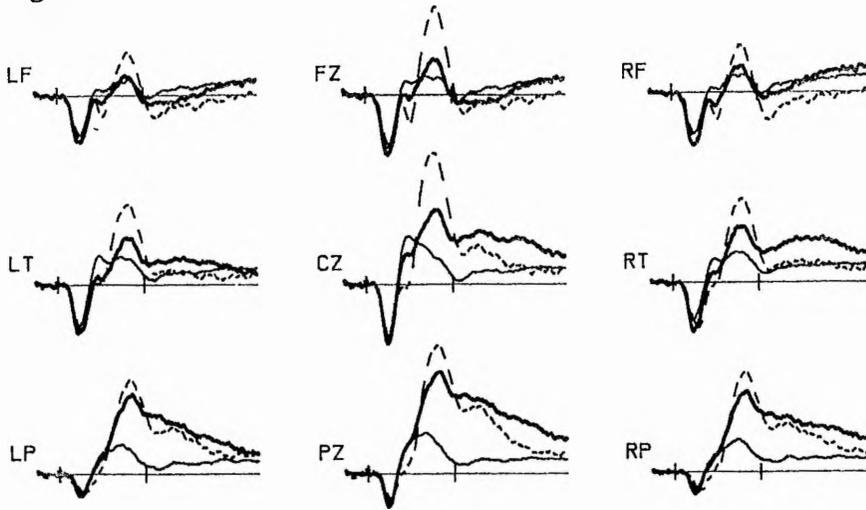


Figure 8a.1b

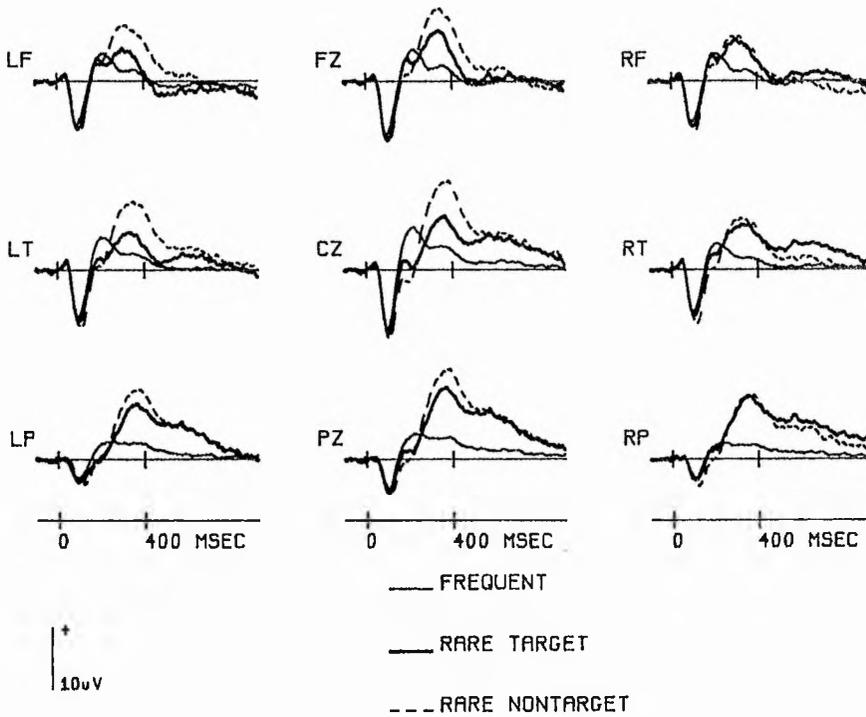


Figure 8a.1a and 8a.1b Waveforms, averaged across 16 subjects, for each condition within the young (Figure 8a.1a) and elderly (Figure 8a.1b) subject groups employing auditory stimuli in Experiment 6.

latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain within the young group of subjects. Table 8a.13.3 and 8a.13.4 similarly show the mean amplitude and mean rescaled amplitude within the elderly group.

P300

Target Deflections ANOVA of the latency of the target P300 deflection between the two groups was significant (see Table 8a.1 of the Appendix). The young group of subjects demonstrated a significantly earlier response than the elderly group (322 msec v 357 msec - see Table 8a.2 of the Appendix).

The mean amplitude evoked in response to target stimuli was compared by means of ANOVA across groups. Such an analysis failed to yield a significant group main effect. A significant three way interaction involving the factors of group, chain and site was obtained (see Table 8a.3). *Post hoc* analysis revealed that the young group of subjects demonstrated a P300 deflection with greatest amplitude at parietal sites along all three chains. The elderly group of subjects demonstrated a P300 deflection with equipotential mean amplitude along the midline and left chains. Along the right chain the parietal site demonstrated greater amplitude in comparison to the frontal site.

Rare Nontarget Deflections ANOVA of the latency of the rare nontarget P300 deflection was significant (see Table 8a.1 of the Appendix). The young group of subjects demonstrated a significantly earlier response than the elderly group of subjects (312 msec v 357 msec - see Table 8a.2 of the Appendix).

The mean amplitude evoked in response to rare nontarget stimuli was also compared across groups by means of ANOVA. A main effect of group was obtained (see Table 8a.4). Less mean amplitude was evoked within the elderly group in comparison to the young group (15.7 microvolts vs 11.4 microvolts amplitude, collapsed across the scalp sites - see Table 8a.13.1 and 8a.13.3 of the Appendix).

A significant three way interaction involving the factors of group, chain and site was obtained. *Post hoc* analysis demonstrated that within the young group of subjects greater mean amplitude was evoked at centro/temporo-parietal sites in comparison to the frontal sites along all three chains of electrodes. Within the elderly group of subjects equipotential amplitude was evoked at each site

Table 8a.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by auditory target stimuli between the young and elderly groups of subjects within the auditory modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	0.571	0.454	232.708
Chain CH	1.6,47.9	22.388	0.000*	14.707
Site ST	1.3,39.5	54.292	0.000*	22.838
Interactions				
GP X CH	1.6,47.9	0.939	0.377	14.707
GP X ST	1.3,39.5	12.697	0.000*	22.838
CH X ST	2.9,86.0	0.391	0.750	2.512
GP X CH X ST	2.9,86.0	3.381	0.024*	2.512
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.034	0.855	2.981
Chain CH	1.5,43.6	14.705	0.000*	0.229
Site ST	1.3,38.9	29.368	0.000*	0.333
Interactions				
GP X CH	1.5,43.6	0.985	0.355	0.229
GP X ST	1.3,38.9	0.983	0.347	0.328
CH X ST	3.2,96.7	0.091	0.971	0.003
GP X CH X ST	3.2,96.7	2.523	0.058	0.031

Table 8a.4 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by auditory rare nontarget stimuli between the young and elderly groups of subjects within the auditory modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	6.580	0.016*	201.158
Chain CH	1.6,48.6	68.206	0.000*	15.336
Site ST	1.3,37.8	15.570	0.000*	19.990
Interactions				
GP X CH	1.6,48.6	7.333	0.003*	15.336
GP X ST	1.3,37.8	8.360	0.004*	19.990
CH X ST	3.1,92.8	5.512	0.001*	2.672
GP X CH X ST	3.1,92.8	2.656	0.050*	2.677
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.033	0.857	0.050
Chain CH	1.5,45.9	62.528	0.000*	0.123
Site ST	1.3,39.3	34.656	0.000*	0.173
Interactions				
GP X CH	1.5,45.9	2.949	0.076	0.123
GP X ST	1.3,39.3	0.837	0.393	0.173
CH X ST	3.1,92.8	4.657	0.004*	0.025
GP X CH X ST	3.1,92.8	2.218	0.090	0.025

* denotes a p value statistically significant at the 0.05% level or greater.

along both the midline and left chains. Along the right chain the parietal site evoked greater mean amplitude in comparison to the frontal site.

Scalp Distribution

Target Deflections ANOVA of rescaled amplitude between subject groups demonstrated a main effect of chain and one of site (see Table 8a.3). *Post hoc* analysis of the chain main effect showed that the midline chain demonstrated a greater amplitude distribution than either of the lateral chains. Analysis of the site main effect demonstrated that the parietal sites demonstrated a maximal scalp amplitude distribution. No interaction involving the factor of group was found to be significant.

Rare Nontarget Deflections ANOVA of rescaled amplitude evoked between subject groups demonstrated a two way interaction involving the factors of chain and site (see Table 8a.4). *Post hoc* analysis demonstrated that along both the midline and left chains a centro/temporal-parietal maximum amplitude distribution was obtained. Along the right chain a parietal site maximum amplitude distribution was obtained. No interaction involving the factor of group was found to be significant.

No interaction involving the factor of age group was found to be significant within either of the ANOVA examining the scalp distribution of responses evoked by target or rare nontarget stimuli. It was, therefore, not possible to determine the scalp distribution of target or rare nontarget P300 responses within the groups of subjects. Separate ANOVAs were, therefore, carried out upon target and rare nontarget responses within the two groups in order to determine their scalp distributions.

Young Group ANOVA of the mean latency of the target and rare nontarget P300 deflections failed to demonstrate a significant main effect of either condition or site (see Table 8a.1 of the Appendix).

ANOVA of rescaled amplitude evoked in response to target and rare nontarget stimuli demonstrated a significant three way interaction involving the factors of condition, chain and site (see Table 8a.5). *Post hoc* analysis demonstrated that the target response revealed a parietal site maximum amplitude distribution along all three chains (see Figure 8a.2a). In contrast the rare nontarget response demonstrated a more anterior distribution being

Table 8a.5 ANOVA summary table for analysis of P300 rescaled amplitude elicited by auditory target and rare nontarget stimuli within the young and elderly groups of subjects.

Young Group				
	df	F	p	mse
Main Effects				
Condition CC	1,15	0.186	0.671	0.772
Chain CH	1.7,25.9	43.451	0.000*	0.099
Site ST	1.2,17.9	73.775	0.000*	0.137
Interactions				
CC X CH	1.5,23	13.740	0.000*	0.029
CC X ST	1.4,21.4	7.285	0.008*	0.044
CH X ST	2.4,35.8	2.837	0.063	0.021
CC X CH X ST	2.8,42.5	9.719	0.000*	0.004
Elderly Group				
	df	F	p	mse
Main Effects				
Condition CC	1,15	0.048	0.829	1.690
Chain CH	1.6,23.3	14.750	0.000*	0.392
Site ST	1.3,19.5	8.223	0.006*	0.660
Interactions				
CC X CH	1.3,19.2	6.294	0.016*	0.184
CC X ST	1.4,20.3	2.120	0.157	0.170
CH X ST	3,44.4	1.278	0.295	0.070
CC X CH X ST	3.1,45.9	3.885	0.014	0.017

Table 8a.6 ANOVA summary table for analysis of P300 rescaled amplitude elicited by auditory target and rare nontarget stimuli between the young and elderly groups of subjects between lateral groups of electrodes.

Target Stimuli				
	df	F	p	mse
Main Effects				
Group GP	1,30	0.000	0.987	1.578
Chain CH	1,30	2.523	0.123	0.320
Site ST	1.3,39.8	31.431	0.000*	0.213
Interactions				
GP X CH	1,30	0.875	0.355	0.320
GP X ST	1.3,39.8	0.293	0.655	0.213
CH X ST	1.8,55.1	0.042	0.949	0.042
GP X CH X ST	1.8,55.1	0.331	0.700	0.042
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Group GP	1,30	0.027	0.871	0.020
Chain CH	1,30	2.853	0.102	0.109
Site ST	1.2,36.1	38.071	0.000*	0.111
Interactions				
GP X CH	1,30	6.630	0.015*	0.109
GP X ST	1.2,36.1	0.930	0.356	0.111
CH X ST	1.7,49.9	3.284	0.044*	0.030
GP X CH X ST	1.7,49.9	3.131	0.061	0.030

* denotes a p value statistically significant at the 0.05% level or greater.

Figure 8a.2a

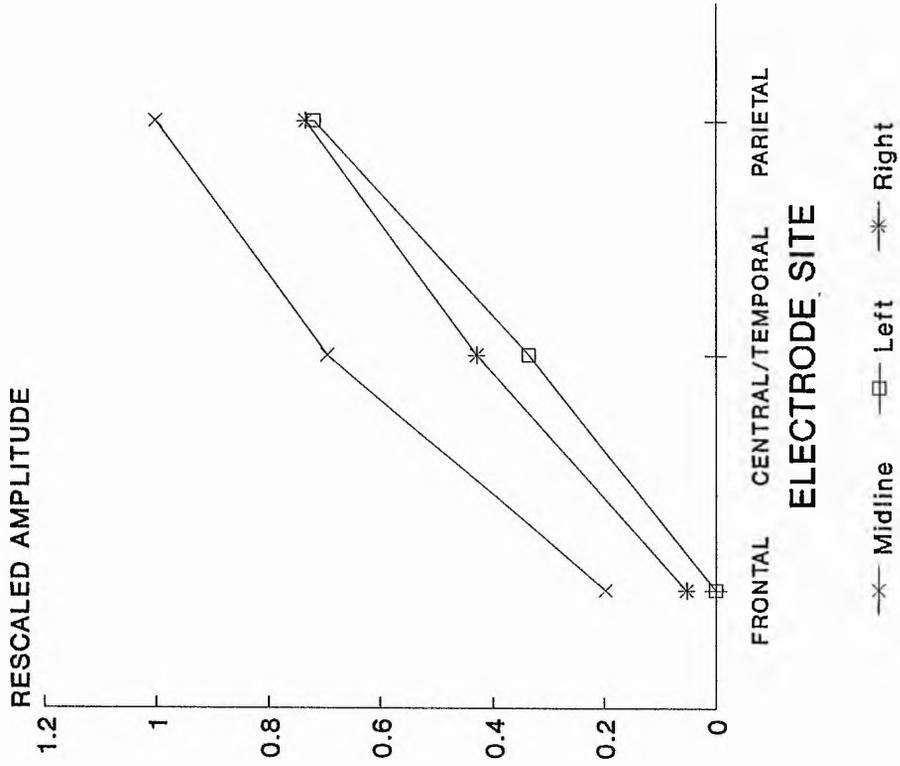


Figure 8a.2b

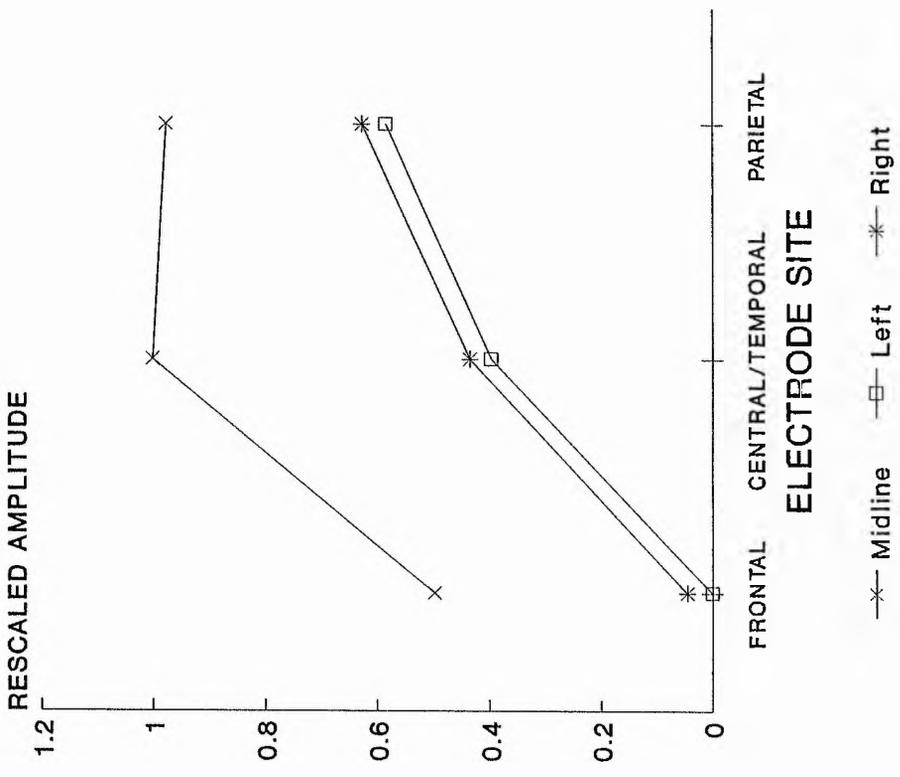


Figure 8a.2a and 8a.2b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8a.2a) and rare nontarget (Figure 8a.2b) stimuli within the young group of subjects in Experiment 6.

maximally evoked at centro/temporo-parietal sites (see Figure 8a.2b). Greater amplitude was evoked along the midline chain in comparison to the lateral chains for both responses.

Elderly Group ANOVA of the mean latency of the target and rare nontarget P300 deflections did not demonstrate significant main effects of either condition or site (see Table 8a.1 of the Appendix).

ANOVA of the rescaled mean amplitudes produced a significant three way interaction involving the factors of condition, chain and site (see Table 8a.5). Both target and rare nontarget responses demonstrated an equipotential amplitude distribution across the scalp (see Figure 8a.3a and 8a.3b).

Scalp Distribution Between Lateral Chains

An ANOVA was conducted on rescaled amplitude data from the lateral chains between groups in order to examine the observed reduction in the elderly group's waveform in response to rare nontarget stimuli (see Figure 8a.1b). Such an analysis was carried out since previous researchers (Woods 1992; Friedman *et al.* 1993) have reported an asymmetric hemisphere distribution in response to rare nontarget stimuli within elderly subjects in comparison to that obtained within young subjects.

A significant two way interaction involving the factors of age group and chain was obtained in response to rare nontarget stimuli (see Table 8a.6). *Post hoc* analysis demonstrated that within the young group equipotential amplitude was obtained across the lateral chains. However, within the elderly group rescaled amplitude was maximally distributed along the left chain.

A similar comparison was carried out between groups in response to target stimuli (see Table 8a.6). No interaction involving the factor of group was found to be significant. Rescaled amplitude was distributed equipotentially between chains in both groups of subjects.

Reports from the neuropsychological literature support the view that frontal lobe function within the elderly may be reduced in comparison to that of younger subjects (for example Craik *et al.* 1990; Albert *et al.* 1990; Haaland *et al.* 1987). Such studies have typically failed to dissociate the functioning of the right and left frontal lobes. Further analysis was, therefore, carried out to examine the symmetry of rescaled amplitude at each site (frontal, temporal and

Figure 8a.3a

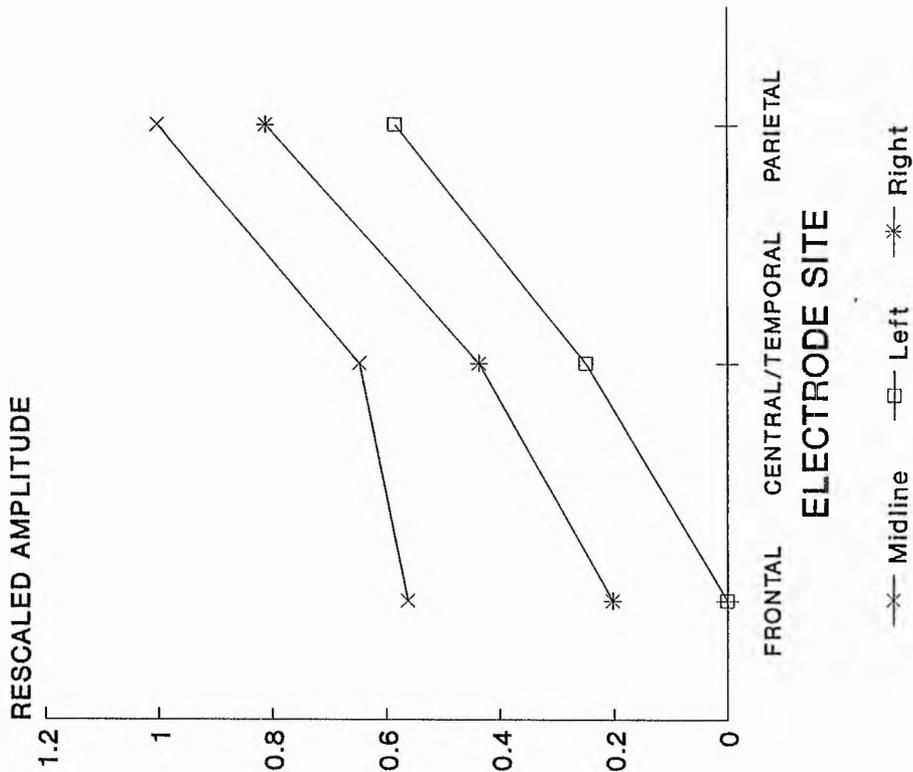


Figure 8a.3b

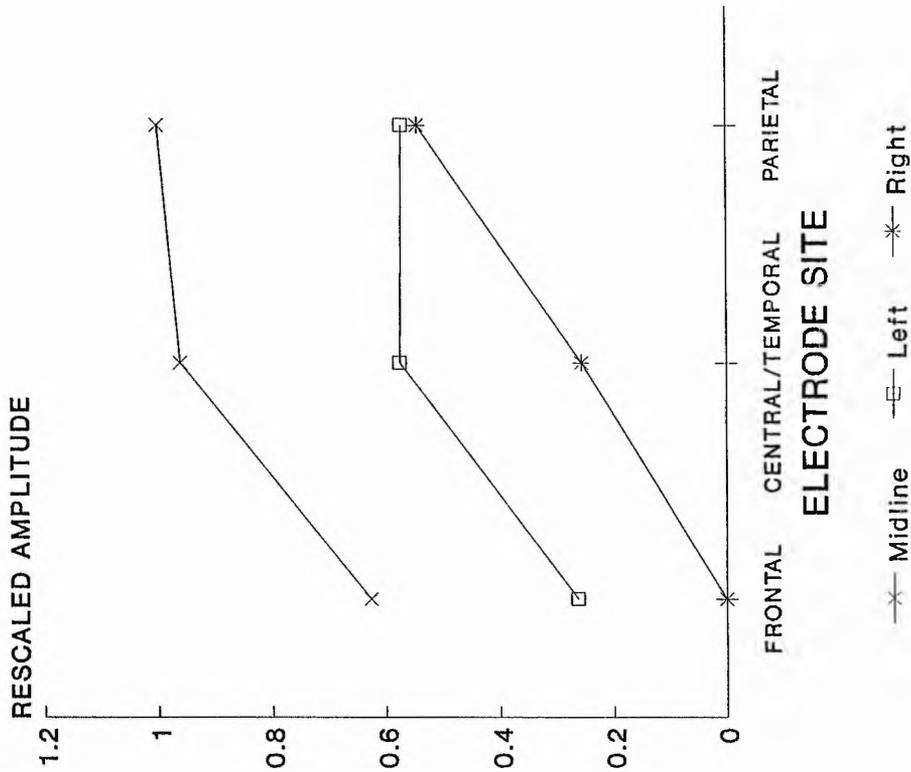


Figure 8a.3a and 8a.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8a.3a) and rare nontarget (Figure 8a.3b) stimuli within the elderly group of subjects in Experiment 6.

parietal) along the lateral chains. Such analysis was carried out to determine whether the reduced amplitude obtained over the right lateral chain in comparison to the left was consistent along the three sites, or demonstrated a more pronounced anterior or posterior reduction.

Rare Nontarget Stimuli

Frontal Site A significant two way interaction involving the factors of group and chain was obtained (see Table 8a.7). *Post hoc* analysis demonstrated that within the young group equipotential amplitude was obtained between the sites. Within the elderly group the left site demonstrated significantly greater amplitude in comparison to that obtained at the right site (see Figure 8a.4a).

Temporal Site A significant two way interaction involving the factors of group and chain was obtained (see Table 8a.7). *Post hoc* analysis demonstrated that within the young group of subjects an equipotential amplitude distribution was obtained across the sites. Within the elderly group the left site demonstrated a greater amplitude distribution in comparison to that demonstrated at the right site (see Figure 8a.4b).

Parietal Site No significant main effect or interaction was obtained for the amplitude evoked between the groups across the parietal sites (see Table 8a.7 and Figure 8a.4c).

Target Stimuli

No significant main effect or interaction was obtained between the groups at frontal, temporal or parietal sites along the lateral chains in response to target stimuli (see Table 8a.7 and Figure 8a.5a, 8a.5b and 8a.5c).

Single Trial Analysis

Single trial analysis was carried out upon the amplitude of the first ten epochs elicited in response to both target and rare nontarget stimuli within both age groups.

Table 8a.7 ANOVA summary table for analysis of P300 rescaled amplitude elicited by auditory target and rare nontarget stimuli at frontal, temporal and parietal sites across the lateral chains of electrodes.

Rare Nontarget Stimuli				
	df	F	p	mse
Frontal Site				
Main Effects				
Group Gp	1,30	0.554	0.460	0.190
Chain Ch	1,30	9.138	0.005*	0.021
Interactions				
GP X CH	1,30	18.160	0.000*	0.021
Temporal Site				
Main Effects				
Group Gp	1,30	0.000	0.998	0.310
Chain Ch	1,30	4.069	0.053	0.077
Interactions				
GP X CH	1,30	6.591	0.016*	0.077
Parietal Site				
Main Effects				
Group Gp	1,30	0.108	0.744	0.036
Chain Ch	1,30	0.014	0.906	0.001
Interactions				
GP X CH	1,30	0.292	0.591	0.070
Target Stimuli				
	df	F	p	mse
Frontal Site				
Main Effects				
Group Gp	1,30	0.129	0.720	0.090
Chain Ch	1,30	2.535	0.122	0.102
Interactions				
GP X CH	1,30	0.887	0.351	0.102
Temporal Site				
Main Effects				
Group Gp	1,30	0.042	0.839	0.560
Chain Ch	1,30	2.767	0.107	0.115
Interactions				
GP X CH	1,30	0.315	0.577	0.115
Parietal Site				
Main Effects				
Group Gp	1,30	0.017	0.898	0.750
Chain Ch	1,30	1.253	0.273	0.187
Interactions				
GP X CH	1,30	0.971	0.330	0.187

* denotes a p value statistically significant at the 0.05% level or greater.

Figure 8a.4a

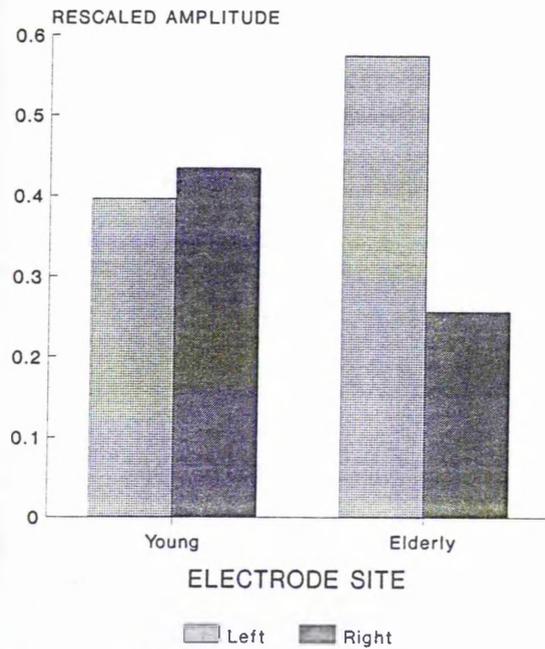


Figure 8a.4b

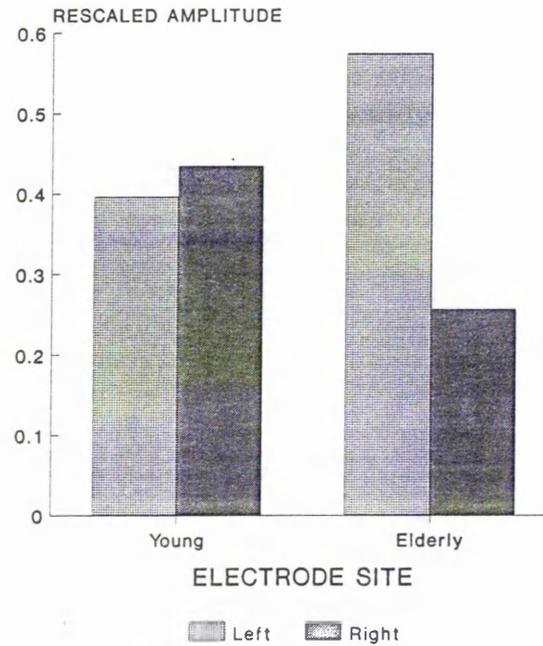


Figure 8a.4c

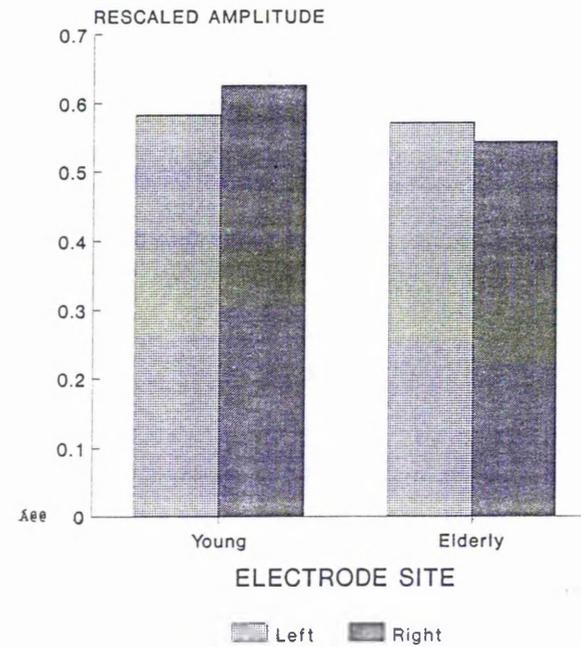


Figure 8a.4a, 8a.4b and 8a.4c Bar diagrams illustrating the amplitude distribution evoked by auditory rare nontarget stimuli at frontal (Figure 8a.4a), temporal (Figure 8a.4b) and parietal (Figure 8a.4c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8a.5a

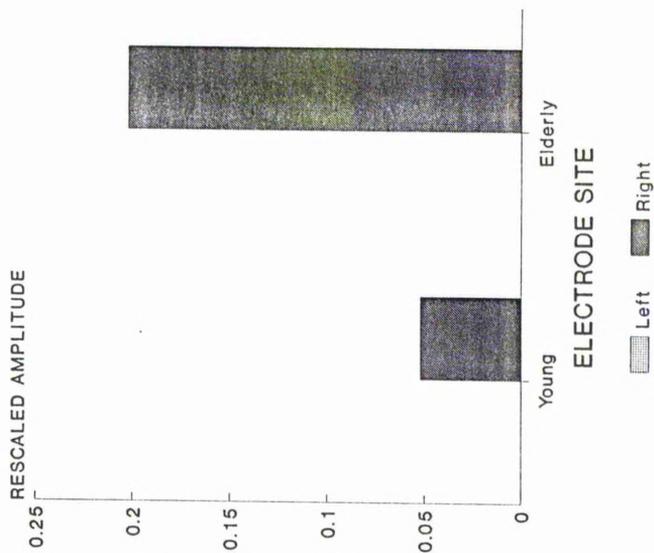


Figure 8a.5b

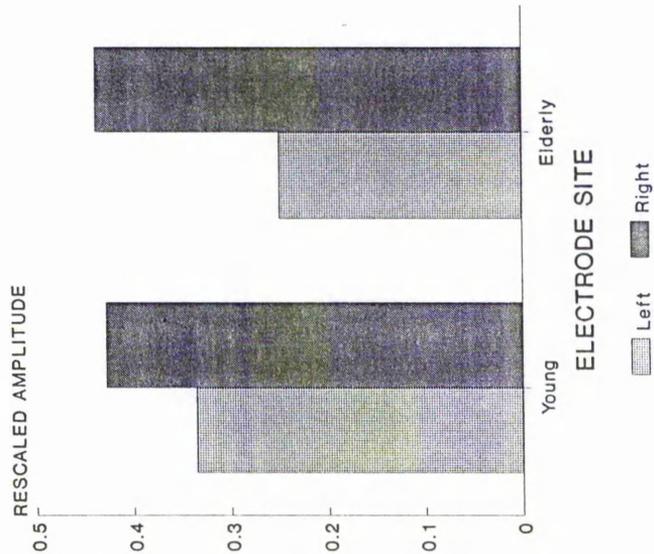


Figure 8a.5c

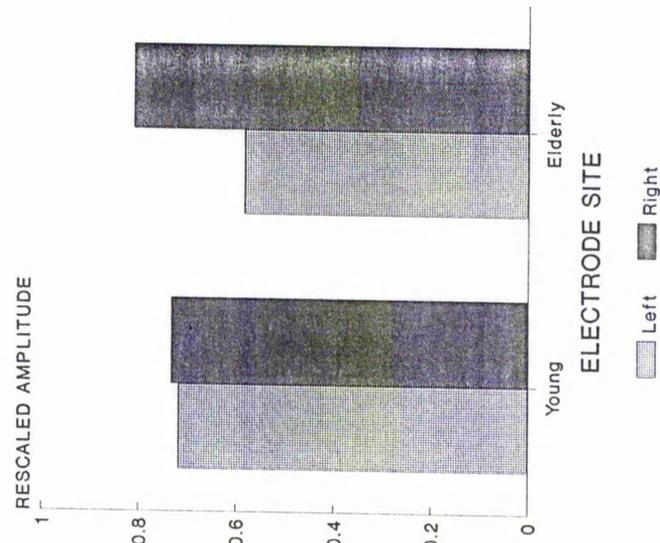


Figure 8a.5a, 8a.5b and 8a.5c Bar diagrams illustrating the amplitude distribution evoked by auditory target stimuli at frontal (Figure 8a.5a), temporal (Figure 8a.5b) and parietal (Figure 8a.5c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Elderly Group

Target Stimuli ANOVA of amplitude evoked in response to target stimuli within the elderly group of subjects failed to reveal a significant main effect or interaction (see Table 8a.8).

Rare Nontarget Stimuli ANOVA of amplitude evoked in response to rare nontarget stimuli within the elderly group of subjects failed to reveal a significant main effect or interaction (see Table 8a.8).

Young Group

Target Stimuli No main effect of trial was obtained (see Table 8a.9). However, a main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked in response to target stimuli across sites, collapsed across trials was significantly greater at Pz in comparison to that evoked at the Cz and Fz electrode sites. Similarly greater amplitude was evoked at Cz in comparison to that evoked at the Fz site. An interaction involving the factors of site and trial was not obtained.

Rare Nontarget Stimuli. No main effect of trial was obtained (see Table 8a.9). However, a main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked in response to rare nontarget stimuli across sites, collapsed across trials, was significantly greater at Cz and Pz sites in comparison to that evoked at Fz. An interaction involving the factors of site and trial was not obtained.

N100

ANOVA of the latencies evoked by frequent, target and rare nontarget stimuli along the midline failed to demonstrate a significant main effect of age group (see Table 8a.1 of the Appendix). A significant interaction involving the factors of group and site was obtained. *Post hoc* analysis demonstrated that within the young group of subjects the latencies (collapsed across experimental conditions) were significantly earlier at central and parietal sites in comparison to the frontal site. Within the elderly group of subjects no significant difference was obtained between the latencies obtained along the three midline sites.

Table 8a.8 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of auditory target and rare nontarget stimuli within the elderly subjects.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	3.8,42	1.489	0.225	373.416
Site ST	1.7,18.3	2.385	0.127	118.998
Interactions				
TR X ST	6.1,66.7	0.930	0.478	34.963
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	4.3,47.3	1.851	0.131	177.188
Site ST	1.5,16.1	0.660	0.510	71.452
Interactions				
TR X ST	4.5,49.8	1.077	0.383	40.308

Table 8.9 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of auditory target and rare nontarget stimuli within the young subjects.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	5.9,71.2	0.757	0.603	395.544
Site ST	1.5,17.9	35.049	0.000*	110.383
Interactions				
TR X ST	5.8,70.1	1.077	0.385	44.499
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	5.1,61.7	1.736	0.138	373.558
Site ST	1.4,16.7	23.612	0.000*	174.629
Interactions				
TR X ST	4.7,56.8	0.554	0.725	42.099

* denotes a p value statistically significant at the 0.05% level or greater.

ANOVA of mean amplitude evoked by the three classes of stimuli between the two groups of subjects failed to produce a significant interaction involving the factor of group. A significant two way interaction involving the factors of condition and site was obtained (see Table 8a.10 of the Appendix). *Post hoc* analysis demonstrated that the greatest deflection was at centro/temporo-parietal sites in comparison to the parietal sites in response to all three experimental conditions.

Scalp Distribution

ANOVA of rescaled mean amplitude elicited by the three classes of experimental stimuli between the two groups of subjects failed to produce a significant interaction involving the factor of group. A significant two way interaction involving the factors of chain and site was obtained (see Table 8a.10 of the Appendix). *Post hoc* analysis demonstrated that along all three chains a centro/temporo-frontal maximum scalp amplitude distribution was obtained (see Figure 8a.6).

N200

Target Deflections ANOVA of the latencies of the response to target stimuli between the age groups was significant (see Table 8a.1 of the Appendix). Examination of the means demonstrated that the young group demonstrated an earlier response than the elderly group (215.2 msec v 239.7 msec).

ANOVA of the mean amplitude of the target N200 deflections between groups produced a three way interaction involving the factors of group, chain and site (see Table 8a.11.1 of the Appendix). *Post hoc* analysis demonstrated that within the young group of subjects greater mean amplitude was obtained at the frontal site in comparison to the central and parietal sites along the midline. Along the left chain temporal and frontal sites demonstrated greater mean amplitude than the parietal site. Along the right chain greater amplitude was obtained at the frontal site.

Within the elderly group of subjects mean amplitude was equally great at each site along each chain of electrodes.

Rare Nontarget Deflections No significant difference between the latency of the responses to rare nontarget stimuli was produced between the two age groups (see Table 8a.1 of the Appendix).

Figure 8a.6

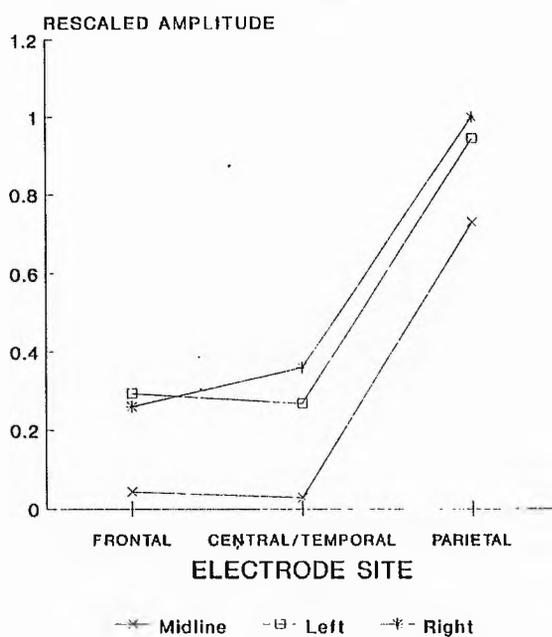


Figure 8a.6 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by auditory stimuli within Experiment 6 (collapsed across subject group and experimental condition).

ANOVA of the mean amplitude of the rare nontarget N200 deflection between groups produced a three way interaction involving the factors of group, chain and site (see Table 8a.11.2 of the Appendix). *Post hoc* analysis demonstrated that within the young group of subjects greatest mean amplitude was obtained at frontal sites along all three chains. Within the elderly group of subjects the central site demonstrated greater mean amplitude than either the frontal or parietal sites along the midline chain. Along the left chain the temporal and parietal sites demonstrated greater mean amplitude in comparison to the frontal site. Along the right chain mean amplitude was equally great at each site.

Scalp Distribution

Target Deflections ANOVA of mean rescaled amplitude of the target N200 deflection between groups produced a three way interaction involving the factors of group, chain and site (see Table 8a.11.1 of the Appendix). Within the young group along both the midline and right chains mean amplitude was distributed maximally at frontal sites. Along the left chain mean rescaled amplitude was maximally distributed along temporo-frontal sites (see Figure 8a.7a).

Within the elderly group along the midline chain mean rescaled amplitude was maximally distributed at the central site. Along the lateral chains amplitude was distributed equipotentially along the sites (see Figure 8a.7b).

Rare Nontarget Deflections ANOVA of the mean rescaled amplitude of the rare nontarget N200 deflections between groups produced a three way interaction involving the factors of group, chain and site (see Table 8a.11.2 of the Appendix). Within the young group of subjects amplitude was distributed maximally at frontal sites along all three chains (see Figure 8a.8a).

Within the elderly group of subjects along the midline chain the central site demonstrated greater mean amplitude distribution in comparison to either the frontal or parietal sites. Along the lateral chains frontal sites demonstrated greater maximal scalp amplitude distribution in comparison to either the parietal or temporal sites (see Figure 8a.8b).

Figure 8a.7a

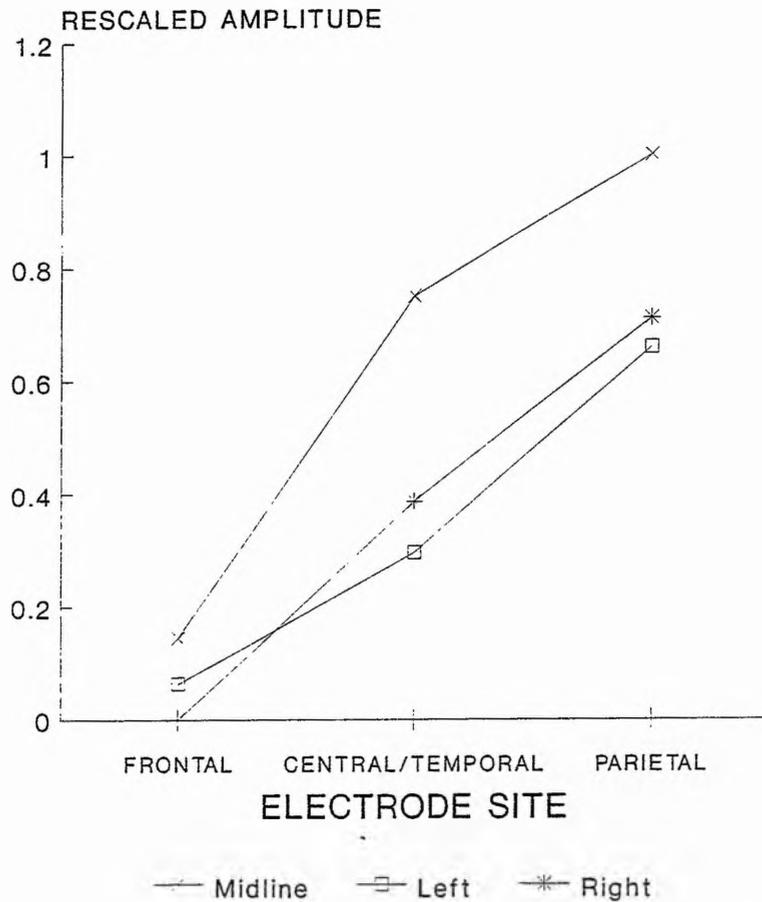


Figure 8a.7b

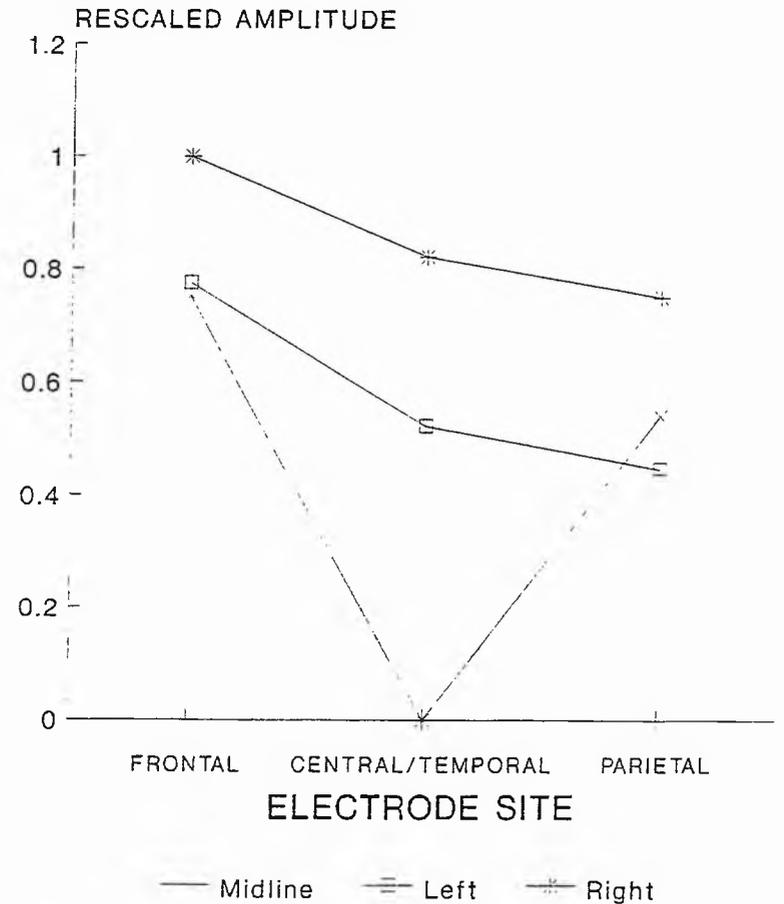


Figure 8a.7a and 8a.7b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory target stimuli within the young (Figure 8a.7a) and elderly (Figure 8a.7b) groups of subjects within Experiment 6.

Figure 8a.8a

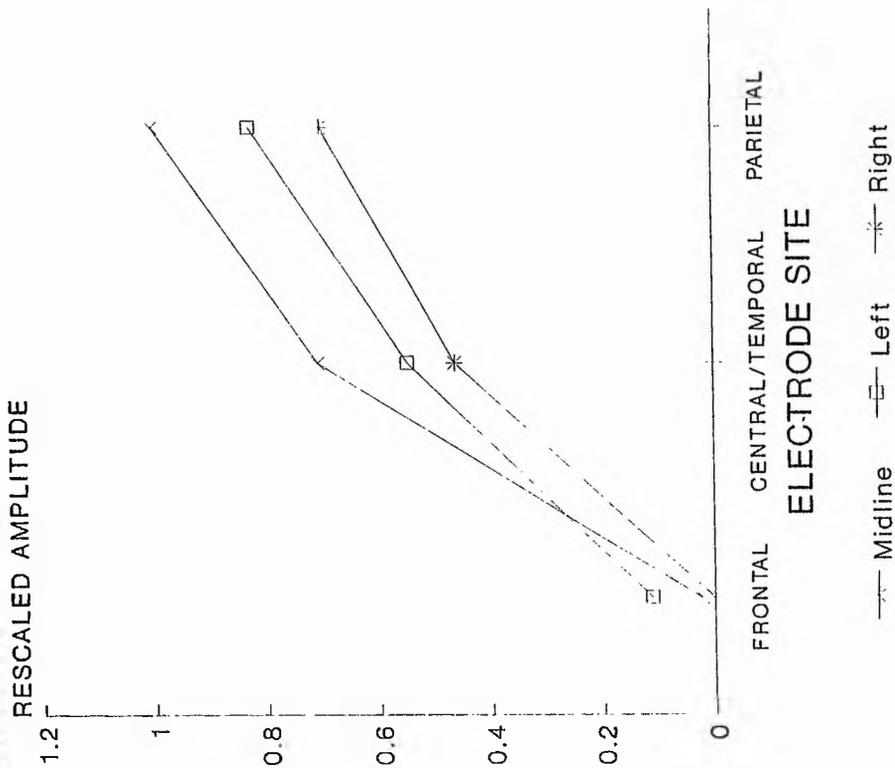


Figure 8a.8b

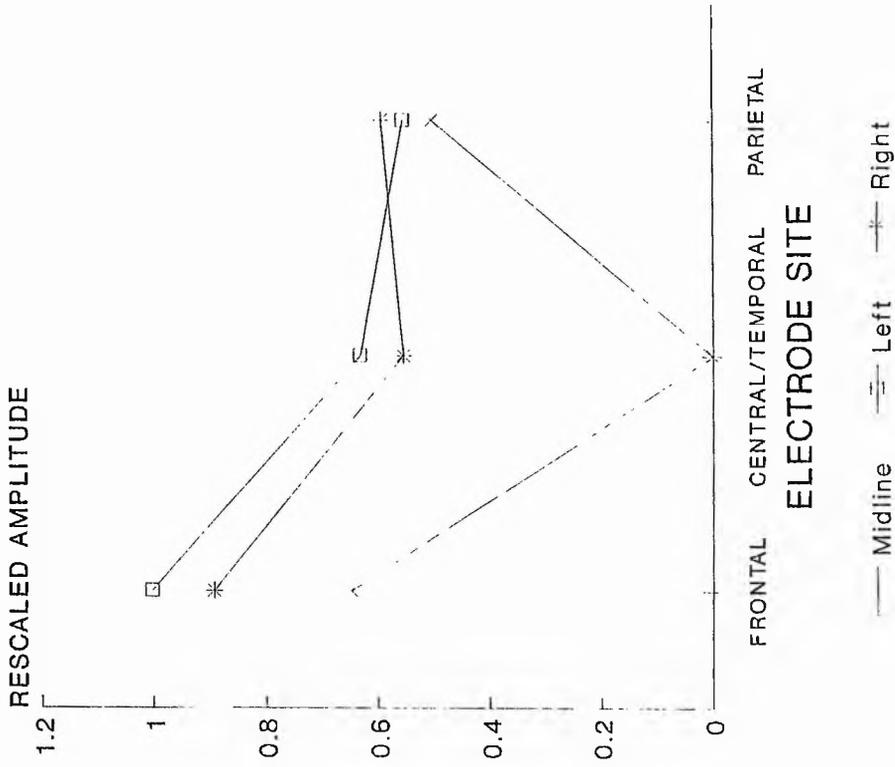


Figure 8a.8a and 8a.8b Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N200 deflection elicited by auditory rare nontarget stimuli within the young (Figure 8a.8a) and elderly (Figure 8a.8b) groups of subjects within Experiment 6.

500 - 850 Latency Range

ANOVA of the mean amplitude evoked within the latency range 500 - 850 msec produced a significant four way interaction involving the factors of group, condition, chain and site (see Table 8a.12 of the Appendix). *Post hoc* analysis demonstrated that within the young group of subjects frequent stimuli evoked a response with equal mean amplitude at each site along all three chains. Target stimuli evoked greater amplitude at central/temporal and parietal sites in comparison to frontal sites along all three chains. In response to rare nontarget stimuli greater mean amplitude was evoked at central and parietal sites in comparison to the frontal site along the midline chain. Along the lateral chains the parietal sites demonstrated greater mean amplitude than the frontal site.

Within the elderly group frequent stimuli evoked a response with equal mean amplitude at each site along all three chains. Target stimuli evoked greater mean amplitude at temporal and parietal sites in comparison to the frontal site along the midline chain. Along the left chain amplitude was equally great at each site. Along the right chain the parietal site demonstrated greater mean amplitude than the frontal site. Rare nontarget stimuli evoked greater mean amplitude at central and parietal sites in comparison to the frontal site along the midline chain. Along the lateral chains the parietal sites demonstrated greater mean amplitude than the frontal sites.

Scalp Distribution

Mean amplitude in the 500 - 850 msec latency range were rescaled and subjected to ANOVA to search for possible differences in scalp distribution between the groups (see Table 8a.12 of the Appendix). No effect involving the factor of group was found to be significant. A two way interaction involving the factors of chain and site was found to be significant. *Post hoc* analysis demonstrated that along all three chains a centro/temporo-parietal scalp amplitude distribution was obtained (see Figure 8a.9).

8a.5 Discussion

As predicted topographical differences between target and rare nontarget P300 deflections within the young group of subjects replicated previous reports of the dissociation of the responses on the basis of scalp amplitude distribution (see Chapter 3). Target stimuli evoked a response with a parietal site maximum

Figure 8a.9

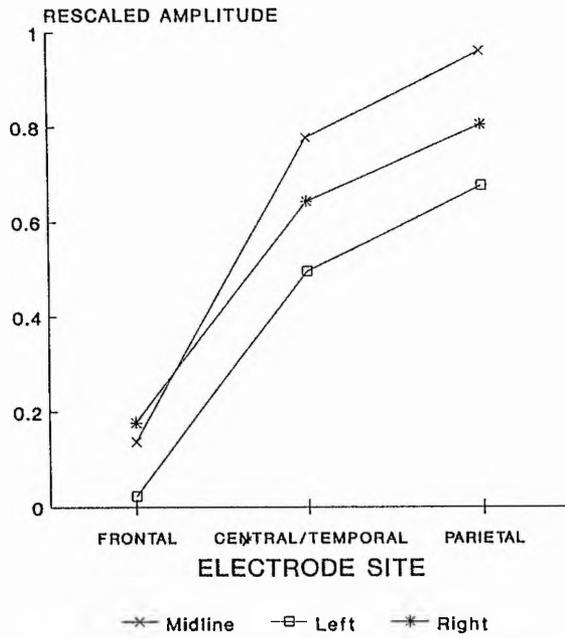


Figure 8a.9 Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 - 850 msec elicited by auditory stimuli within Experiment 6 (collapsed across experimental conditions).

amplitude distribution. Rare nontarget stimuli evoked a response with a centroparietal site maximum amplitude distribution. However, in contrast to findings reported in Chapter 3 the latency of the rare nontarget P300 deflection did not prove to be significantly shorter than the latency of the target P300 deflection.

Such a dissociation on the basis of scalp distribution was not obtained within the elderly subjects. Both target and rare nontarget deflections demonstrated an equipotential scalp amplitude distribution. This failure to dissociate the two responses would appear to be largely due to the more equipotential distribution of evoked amplitude between Fz and Pz. Similar reports of this change in P300 amplitude have been made by Pfefferbaum *et al.* (1984) and Smith *et al.* (1980). Iragui *et al.* (1993) reported a gradual decrease of P300 amplitude with advancing age at central and parietal sites along with a trend for an increase at frontal sites.

Single trial analysis demonstrated that the flat amplitude distribution obtained within the elderly subjects was consistent across trials and was not the result of a more positive response initially that habituated over trial presentations to a more equipotential distribution across sites. Similar analysis demonstrated that the young subjects responses remained consistent across trial presentations.

Advancing age also had a significant effect upon the scalp amplitude distribution of the N200 component. Within the young group of subjects both target and rare nontarget responses demonstrated a maximum scalp amplitude distribution at anterior scalp sites. However, within the elderly group of subjects N200 responses to both target and rare nontarget stimuli were maximally distributed at central sites along the midline. Iragui *et al.* (1993) reported similar findings of a significant increase of target N200 at central and parietal sites. However, others have failed to observe N200 amplitude changes (Barrett *et al.* 1987; Brown *et al.* 1983; Smith *et al.* 1980).

Within the young subjects the midline chain of electrodes demonstrated a significantly greater P300 amplitude distribution in comparison to that demonstrated along the lateral chains. The amplitude along the lateral chains was distributed symmetrically. Similarly within the elderly group the midline chain demonstrated significantly greater amplitude distribution than the lateral chains. However, in response to rare nontarget stimuli amplitude was distributed maximally over the left chain in comparison to that evoked over the right chain. This hemispheric asymmetry of the rare nontarget P300 response was evident at both frontal and temporal sites, at parietal sites a symmetrical amplitude distribution was observed across the chains (see Figure 8a.3b and 8a.4b). The response to target stimuli was symmetrical across the hemispheres

(see Figure 8a.3a and 8a.5b). The response to target (see Figure 8a.3a and 8a.5a) and rare nontarget (see Figure 8a.3b and 8a.4a) stimuli within the young subjects was symmetrical across the lateral chains of electrodes. The flat amplitude distribution of the P300 response together with the asymmetric distribution of the rare nontarget P300 amplitude across the lateral chains will be discussed in greater detail in the general discussion below.

Experimental condition failed to affect the mean amplitude evoked within the N100 latency range. As discussed in section 3.7.1 such a result is not consistent with the attentional trace theory proposed by Näätänen (1982; 1990; 1992). Näätänen and Picton (1987) proposed that stimuli presented frequently would demonstrate less mean amplitude since the generating neurons were believed to become refractory upon repeated presentation of the same stimulus (see section 3.7.1 for a fuller discussion of this point). Advancing age failed to alter the scalp amplitude distribution of the N100 deflection in comparison to that observed within the young group of subjects.

Although there was a tendency for reaction times (with increased standard deviations) to be longer in the elderly group there was no significant increase in RTs with advancing age. Similar findings are reported by Iragui *et al.* (1993) and Picton *et al.* (1984) who employed two tone oddball tasks as well as Pfefferbaum *et al.* (1984) and Ford and Pfefferbaum (1985) who employed three tone oddball tasks.

However, advancing age had comparable effects on both target and rare nontarget P300 latencies. Target P300 latency increased by 0.8 msec/year (collapsed across the three midline sites), this value is just below the range of values reported for target P300 latency prolongation (rate of delay ranging from 0.9 to 1.8 msec/year) reported by Polich (1991). Similarly target N200 latency increased by 0.54 msec/year (collapsed across the midline sites). Rare nontarget P300 latency increased by 1.02 msec/year. As described by Barrett *et al.* (1987) "the slope of the relationship between P3 latency and age has varied from one report to the next although direct comparisons are made difficult by the use of different experimental paradigms..... and different methods of measurement" (pp. 410). Such inconsistencies between experimental studies makes it difficult to develop a precise relationship between P300 latency and age. However, a general relationship of increased age and increased P300 latency appears to be supported within the present results involving auditory data.

8b Visual Modality

8b.2 Method

Stimuli

The visual "triangle" procedure described in section 4.2 was employed here.

Procedure

The procedure described in section 4.2 was employed here.

8b.3 Data Analysis

See section 8.3 for a description of the data analyses performed.

8b.4 Results

Behavioural Data

Mean reaction time to correctly detected targets (young 469 msec with a standard deviation across subjects of 72msec; elderly 496 msec with a standard deviation across subjects of 112msec) failed to demonstrate a significant age related difference ($t(15) = -0.68$ $p = 0.51$). Target detection was near ceiling for both age groups (young 99.1%; elderly 98.2%). The false alarm rate was also very low (young 1.1%; elderly 0.79%). Neither the false alarm rate or hit rate between groups proved to be significant.

ERP Data

Grand average waveforms (see Figure 8b.1a and 8b.1b) were produced for both groups of subjects.

	Young Group	Elderly Group
Frequent	183 (124-208)	158 (107-203)
Target	38 (20-45)	34 (25-45)
Rare	39 (28-45)	32 (25-42)
Nontarget		

As may be observed in Figure 8b.1a and 8b.1b the young and elderly groups of subjects demonstrated similar ERP waveforms. All three stimulus types evoked a negative deflection at approximately 100 msec (N100). Following the resolution of the N100 deflection a second negative deflection was observed at anterior scalp sites particularly in response to rare nontarget stimuli.

A large positive deflection of the waveform (P300) was observed in response to target and rare nontarget stimuli. This deflection was observed to be maximal at posterior scalp sites. Frequent stimuli also evoked a P300 type of deflection which was most evident at posterior scalp. Within the elderly subjects rare nontarget stimuli appeared to evoke an asymmetric amplitude distribution across the lateral chains, however, this asymmetry appears to be less pronounced than that observed within the auditory modality. Along the right chain reduced amplitude was evident in comparison to that observed along the left chain. The symmetry was not evident for the deflections evoked by frequent or target stimuli. Within the young group deflections evoked in response to all three classes of stimuli appeared to be symmetrical across the lateral chains.

The P300 deflection was followed by a period of sustained positivity at posterior scalp sites, this positivity was evident but less marked at anterior sites.

Following the resolution of the N100 deflection and the peak of the P300 deflection rare nontarget stimuli demonstrated a period of sustained positivity in comparison to both frequent and target stimuli at parietal sites.

Table 8b.14.1 and 8b.14.2 of the Appendix show the mean amplitude and mean rescaled amplitude elicited by visual experimental stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500 - 850 msec for each site, of each electrode chain within the young group of subjects. Mean amplitude evoked by the three classes of stimuli at lateral parietal sites within a 150 - 350 msec latency range are also shown. Table 8b.14.3 and 8b.14.4 similarly show the mean amplitude and mean rescaled amplitude within the elderly group.

8b.43 P300

Target Deflections ANOVA of the latency of the target P300 deflection along the midline chain between subject groups produced significant effects of

Figure 8b.1a

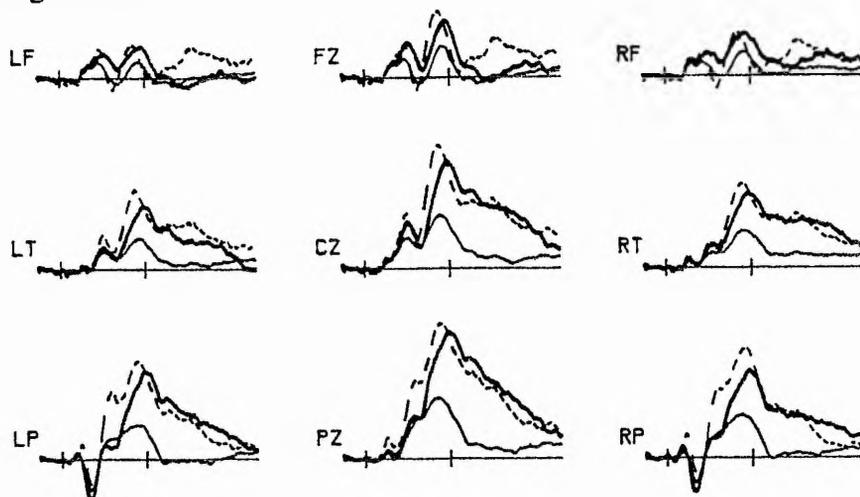


Figure 8b.1b

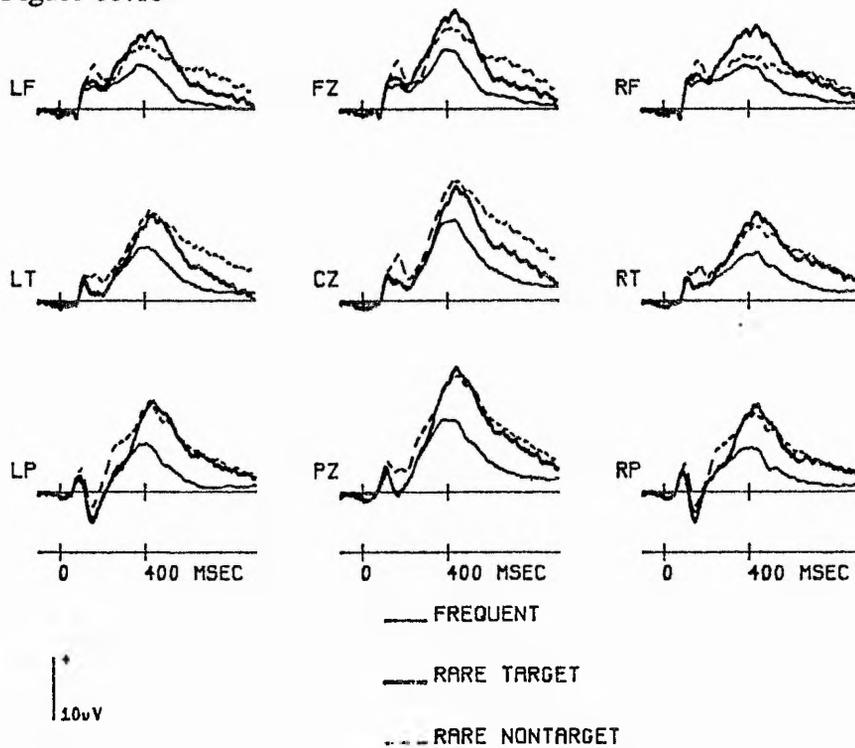


Figure 8b.1a and 8b.1b Waveforms, averaged across 16 subjects, for each condition within the young (Figure 8a.1a) and elderly (Figure 8a.1b) subject groups employing visual stimuli in Experiment 6.

group and site (see Table 8b.1 of the Appendix). *Post hoc* analysis of the group effect demonstrated that the young group evoked a significantly earlier response than the elderly group of subjects (379 msec v 420 msec). Analysis of the site effect demonstrated that across groups an earlier response was elicited at the Cz and Pz electrodes than at the Fz electrode (see Table 8b.2 of the Appendix).

ANOVA of the target P300 mean amplitude failed to yield a significant group main effect (see Table 8b.3). *Post hoc* analysis of the two way interaction involving the factors of group and site revealed that the young subject group demonstrated the greatest mean amplitude at parietal sites. The elderly group of subjects evoked equipotential amplitude in response to target stimuli across the scalp sites.

Rare Nontarget Deflections ANOVA of the latency of the rare nontarget P300 deflection along the midline between groups produced effects of group and site (see Table 8b.1 of the Appendix). Analysis of the group effect demonstrated that the young group demonstrated a significantly earlier deflection than the elderly group (347.5 msec v 417.5 msec). Analysis of the site effect demonstrated that across groups the Cz and Pz electrodes evoked an earlier response than the Fz electrode (see Table 8b.2 of the Appendix).

ANOVA of rare nontarget P300 mean amplitude failed to yield a significant group main effect (see Table 8b.4). *Post hoc* analysis of the two way interaction involving the factors of age group and electrode chain demonstrated that within the young group the midline chain demonstrated greater P300 mean amplitude than the lateral chains. However, the right chain demonstrated greater mean amplitude than the left. Within the elderly group the midline demonstrated greater mean P300 amplitude than the lateral chains. However, the left chain demonstrated greater mean amplitude than the right.

Analysis of the two way interaction involving the factors of subject group and site revealed that the young group demonstrated the greatest mean amplitude at parietal sites. Within the elderly group a greater mean amplitude was evoked at parietal sites in comparison to frontal and central/temporal sites.

Table 8b.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by target stimuli between the young and elderly groups of subjects within the visual modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	2.324	0.138	293.168
Chain CH	1.8,53.3	43.722	0.000*	15.740
Site ST	1.2,36.6	21.541	0.000*	39.647
Interactions				
GP X CH	1.8,53.3	0.985	0.369	15.740
GP X ST	1.2,36.6	7.425	0.007*	39.647
CH X ST	3.2,97.3	11.788	0.000*	3.154
GP X CH X ST	3.2,97.3	0.761	0.526	3.154
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.253	0.617	4.353
Chain CH	1.9,57.2	33.458	0.000*	0.187
Site ST	1.3,38.4	12.023	0.001*	0.448
Interactions				
GP X CH	1.9,57.2	1.865	0.166	0.187
GP X ST	1.3,38.4	1.078	0.324	0.448
CH X ST	3.2,97	10.410	0.000*	0.032
GP X CH X ST	3.2,97	1.007	0.398	0.032

Table 8b.3 ANOVA summary table for analysis of P300 amplitude and rescaled amplitude elicited by rare nontarget stimuli between the young and elderly groups of subjects within the visual modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	0.582	0.450	187.761
Chain CH	2,59.6	70.262	0.000*	12.725
Site ST	1.1,33.4	45.146	0.000*	38.336
Interactions				
GP X CH	2,59.6	5.761	0.005*	12.725
GP X ST	1.1,33.4	9.990	0.003*	38.336
CH X ST	3.2,96.7	5.444	0.001*	3.149
GP X CH X ST	3.2,96.7	0.139	0.945	3.149
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.040	0.842	1.119
Chain CH	2,58.5	76.997	0.000*	0.067
Site ST	1.1,34.2	39.942	0.000*	0.193
Interactions				
GP X CH	2,58.5	11.462	0.000*	0.067
GP X ST	1.1,34.2	2.720	0.104	0.193
CH X ST	3.2,95.6	5.418	0.001*	0.018
GP X CH X ST	3.2,95.6	0.339	0.808	0.018

* denotes a p value statistically significant at the 0.05% level or greater.

Scalp Distribution

Target Deflections ANOVA of rescaled amplitude evoked by target stimuli between subject groups demonstrated a significant two way interaction involving the factors of chain and site (see Table 8b.3). *Post hoc* analysis demonstrated that along the midline chain a parietal site maximum amplitude distribution was obtained. Along the left chain a centro-parietal distribution was obtained. Along the right chain the parietal site demonstrated greater amplitude distribution than the frontal site.

Rare Nontarget Deflections ANOVA of rescaled amplitude evoked by rare nontarget stimuli between groups demonstrated a significant two way interaction involving the factors of group and chain (see Table 8b.4). *Post hoc* analysis demonstrated that within the young group the midline chain demonstrated significantly greater distribution of amplitude than either of the lateral chains. Amplitude between the lateral chains was distributed equipotentially. Within the elderly group the midline chain evoked greater amplitude distribution than either of the lateral chains. However, the left chain demonstrated significantly greater amplitude distribution than the right chain.

As within the auditory modality three way interactions involving the factors of group, chain and site were not produced by ANOVA of rescaled amplitude evoked by target or rare nontarget stimuli. In order to determine the scalp distribution of the responses evoked by target and rare nontarget stimuli across the scalp individual ANOVAs were performed upon target and rare nontarget responses within the two groups separately.

Young Subjects ANOVA of the latency of the target and rare nontarget P300 deflections along the midline demonstrated a significant effect of condition (see Table 8b.1 of the Appendix). *Post hoc* analysis demonstrated that the rare nontarget stimuli evoked a significantly earlier peak deflection than the target stimuli (347.5 msec v 379.9 msec - see Table 8b.2 of the Appendix).

The scalp distribution of the amplitude evoked by the target and rare nontarget stimuli were contrasted by ANOVA of their rescaled mean amplitudes (see Table 8b.5).

Post hoc analysis of the three way interaction involving the factors of condition, chain and site (see Table 8b.5) demonstrated that rare nontarget

Table 8b.5 ANOVA summary table for analysis of P300 rescaled amplitude elicited by visual target and rare nontarget stimuli within the young and elderly groups of subjects.

Young Group	df	F	p	mse
Main Effects				
Condition CC	1,15	0.783	0.388	0.348
Chain CH	1.6,24.6	36.840	0.000*	0.091
Site ST	1.1,16.1	38.029	0.000*	0.268
Interactions				
CC X CH	1.8,26.4	0.756	0.462	0.020
CC X ST	1.2,18.2	0.708	0.436	0.060
CH X ST	2.6,38.7	4.928	0.008*	0.021
CC X CH X ST	3.3,49.1	5.679	0.002*	0.006
Elderly Group				
Main Effects				
Condition CC	1,15	0.601	0.448	3.056
Chain CH	2.0,29.9	33.065	0.000*	0.267
Site ST	1.3,18.9	5.148	0.029*	0.693
Interactions				
CC X CH	1.8,27.2	2.200	0.134	0.127
CC X ST	1.5,22.0	1.278	0.289	0.256
CH X ST	3.0,45.4	4.282	0.009*	0.054
CC X CH X ST	3.1,46.9	5.280	0.003*	0.019

Table 8b.6 ANOVA summary table for analysis of P300 rescaled amplitude elicited by visual target and rare nontarget stimuli between the young and elderly groups of subjects between lateral groups of electrodes.

Target Stimuli	df	F	p	mse
Main Effects				
Group GP	1,30	0.795	0.377	2.233
Chain CH	1,30	0.427	0.517	0.208
Site ST	1.2,37.4	7.466	0.006*	0.278
Interactions				
GP X CH	1,30	0.082	0.776	0.208
GP X ST	1.2,37.4	1.586	0.220	0.278
CH X ST	1.6,48.3	1.780	0.186	0.033
GP X CH X ST	1.6,48.3	0.048	0.923	0.033
Rare Nontarget Stimuli				
Main Effects				
Group GP	1,30	0.646	0.426	0.623
Chain CH	1,30	2.080	0.160	0.057
Site ST	1.1,33.3	34.451	0.000*	0.127
Interactions				
GP X CH	1,30	15.687	0.000*	0.057
GP X ST	1.1,33.3	3.160	0.081	0.127
CH X ST	1.9,55.8	1.545	0.224	0.016
GP X CH X ST	1.9,55.8	0.268	0.749	0.016

* denotes a p value statistically significant at the 0.05% level or greater.

stimuli evoked a response with a centro/temporo-parietal maximum amplitude distribution along all three chains (see Figure 8b.2a). Target stimuli evoked a centro-parietal maximum amplitude distribution along the midline chain. Along the lateral chains greater amplitude was distributed at parietal sites in comparison to that at frontal sites (see Figure 8b.2a).

Elderly Subjects ANOVA of the latency of target and rare nontarget P300 deflections along the midline failed to demonstrate a condition main effect (see table 8b.1 of the Appendix). Electrode site produced a significant main effect. *Post hoc* analysis demonstrated that the latency of the responses produced a significantly earlier response at the Cz electrode than at either Fz or Pz (see Table 8b.2 of the Appendix).

A three way interaction involving the factors of condition, chain and site was obtained (see Table 8b.2c). Target and rare nontarget stimuli evoked P300 deflections with an equipotential scalp amplitude distribution along all three chains (see Figure 8b.3a and 8b.3b).

Comparison of Rescaled Amplitude Between Lateral Chains

As within the auditory modality an ANOVA was conducted upon rescaled amplitude from the lateral chains between groups in order to examine the observed reduction in the elderly group's ERP evoked in response to rare nontarget stimuli.

A significant two way interaction involving the factors of group and chain was obtained (see Table 8b.6). *Post hoc* analysis demonstrated that young subjects demonstrated an equipotential amplitude distribution across the lateral chains. However, within the elderly group rescaled amplitude was maximally distributed along the left chain.

A similar comparison was carried out between groups in response to target stimuli (see Table 8b.6). No interaction involving the factor of group was found to be significant. Rescaled amplitude was distributed equipotentially between chains within both groups of subjects.

As described in relation to auditory data to further examine the asymmetry between the sites of the lateral chains further ANOVAs were conducted that examined the amplitude distribution between groups at frontal, temporal and parietal sites along the lateral chains in response to both target and rare nontarget stimuli.

Figure 8b.2a

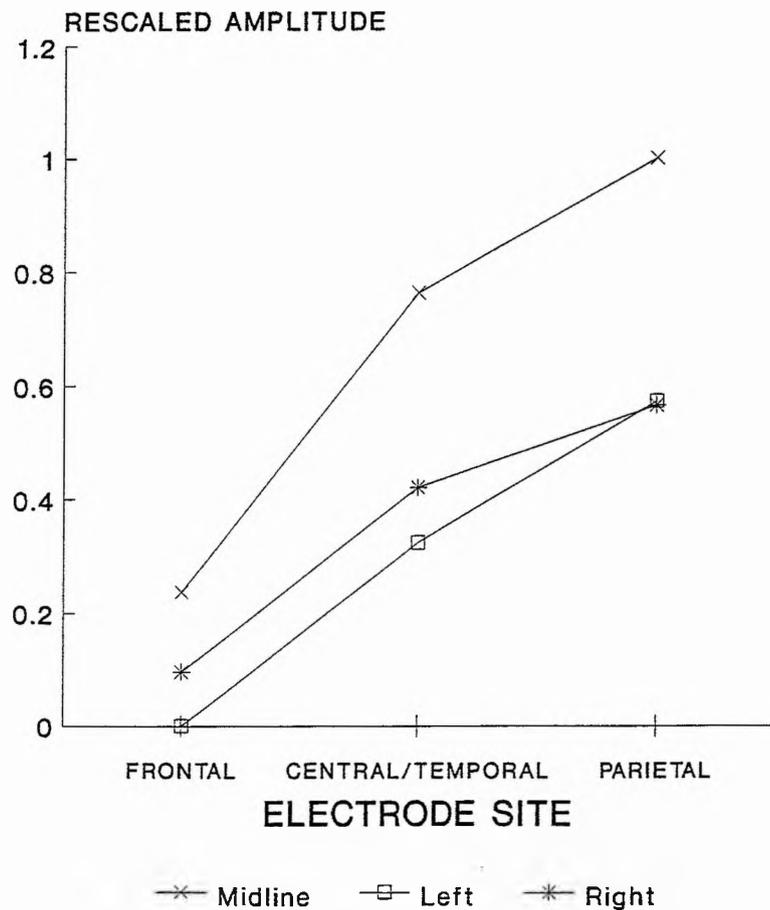


Figure 8b.2b

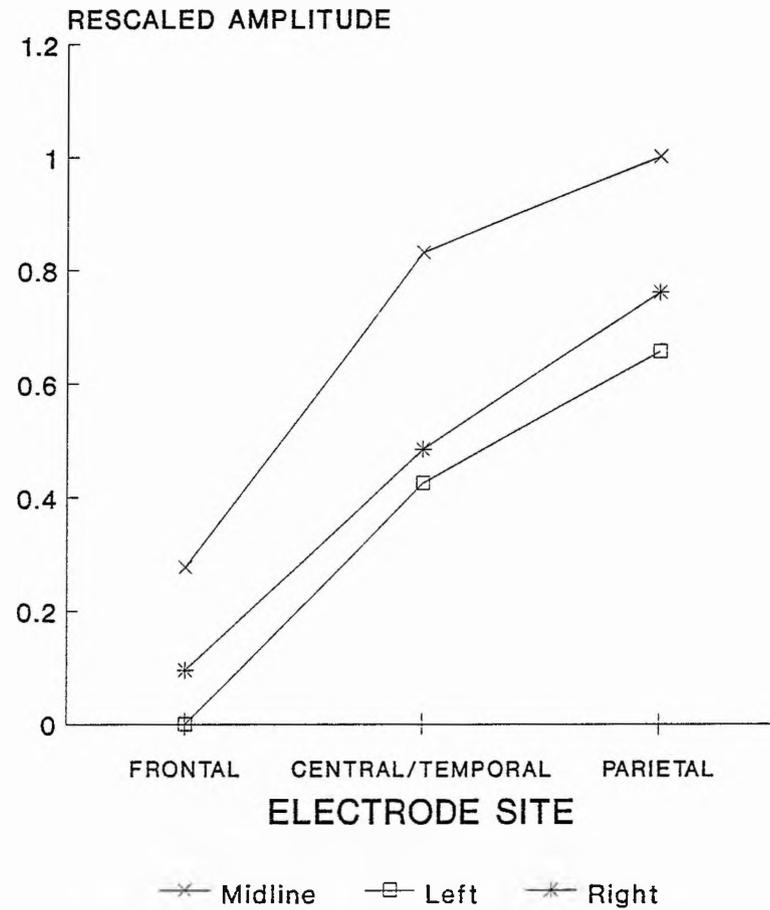


Figure 8b.2a and 8b.2b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8b.2a) and rare nontarget (Figure 8b.2b) stimuli within the young group of subjects in Experiment 6.

Figure 8b.3a

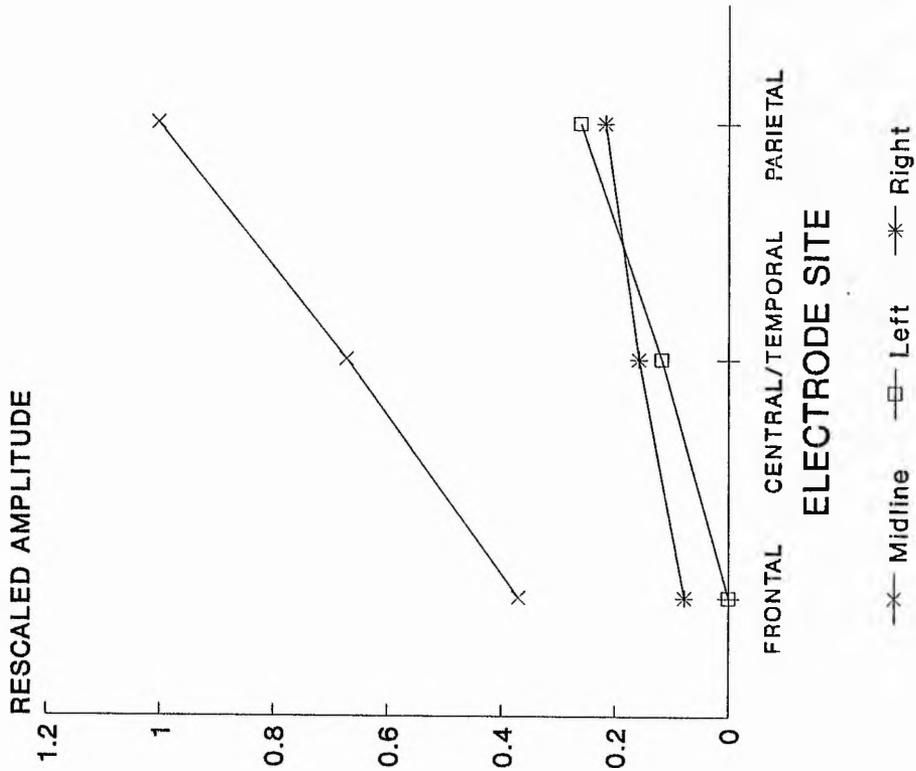


Figure 8b.3b

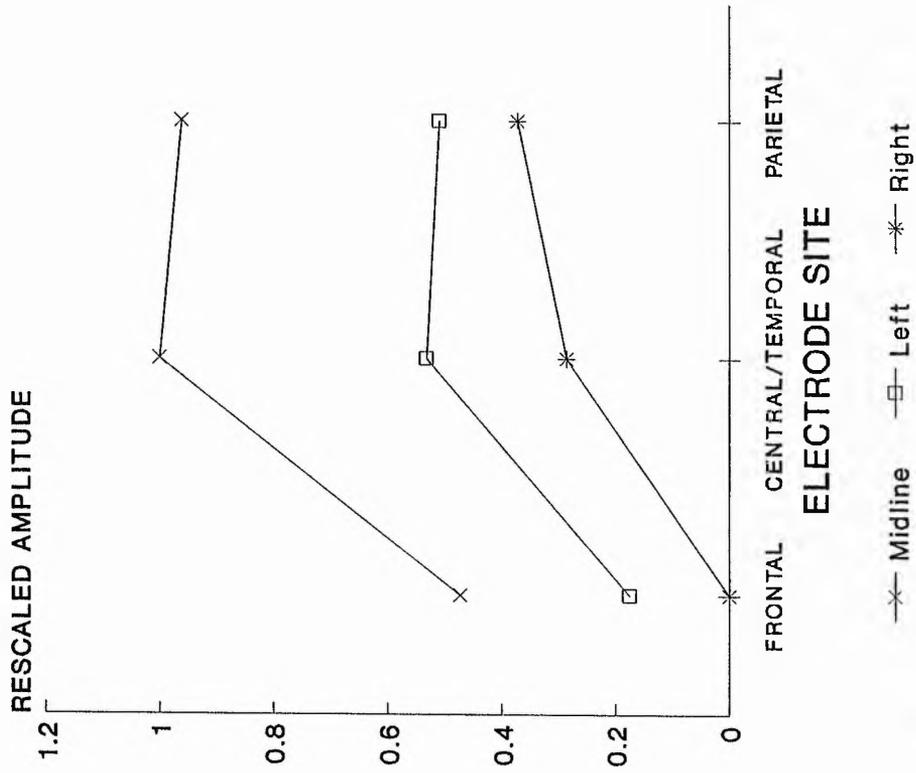


Figure 8b.3a and 8b.3b Graph illustrating the distribution, across electrode chain, of rescaled amplitude of the P300 deflection elicited by target (Figure 8b.3a) and rare nontarget (Figure 8b.3b) stimuli within the elderly group of subjects in Experiment 6.

Rare Nontarget Stimuli

Frontal Site A significant two way interaction involving the factor of group and chain was obtained (see Table 8b.7). *Post hoc* analysis demonstrated that within the young group the right frontal site demonstrated greater amplitude distribution in comparison to that obtained at the left frontal site. Within the elderly group the opposite effect was obtained, the left frontal site demonstrated greater amplitude distribution in comparison to that observed at the right frontal site (see Figure 8b.4a).

Temporal Site A significant two way interaction involving the factors of group and chain was obtained (see Table 8b.7). *Post hoc* analysis demonstrated an equipotential amplitude distribution across the temporal sites within the young group of subjects. Within the elderly group the left temporal site demonstrated greater amplitude distribution in comparison to the right temporal site (see Figure 8b.4b).

Parietal Site A significant two way interaction involving the factors of group and chain was obtained (see Table 8b.7). *Post hoc* analysis demonstrated that within the young group of subjects the right site demonstrated greater amplitude distribution in comparison to the left site. Within the elderly group the left site demonstrated greater amplitude distribution in comparison to the right parietal site (see Figure 8b.4c).

Target Stimuli

No significant main effect or interaction was obtained at the frontal, temporal or parietal site along the lateral chains in response to target stimuli (see Table 8b.7 and Figure 8b.5a, 8b.5b and 8b.5c).

Single Trial Analysis

Single trial analysis was carried out upon the amplitude of the responses evoked by the first ten presentations of the rare stimuli within both groups of subjects.

Table 8b.7 ANOVA summary table for analysis of P300 rescaled amplitude elicited by visual target and rare nontarget stimuli at frontal, temporal and parietal sites across the lateral chains of electrodes.

Rare Nontarget Stimuli				
	df	F	p	mse
Frontal Site				
Main Effects				
Group Gp	1,30	0.055	0.816	0.451
Chain Ch	1,30	1.379	0.250	0.018
Interactions				
GP X CH	1,30	16.490	0.000*	0.018
Temporal Site				
Main Effects				
Group Gp	1,30	0.133	0.717	0.261
Chain Ch	1,30	3.970	0.056	0.035
Interactions				
GP X CH	1,30	10.801	0.003*	0.035
Parietal Site				
Main Effects				
Group Gp	1,30	6.983	0.013*	0.164
Chain Ch	1,30	0.130	0.720	0.036
Interactions				
GP X CH	1,30	6.509	0.016*	0.036
Target Stimuli				
Frontal Site				
Main Effects				
Group Gp	1,30	0.002	0.961	0.506
Chain Ch	1,30	1.372	0.252	0.089
Interactions				
GP X CH	1,30	0.014	0.906	0.089
Temporal Site				
Main Effects				
Group Gp	1,30	0.870	0.356	1.025
Chain Ch	1,30	0.725	0.399	0.102
Interactions				
GP X CH	1,30	0.130	0.719	0.102
Parietal Site				
Main Effects				
Group Gp	1,30	1.403	0.246	1.258
Chain Ch	1,30	0.135	0.715	0.083
Interactions				
GP X CH	1,30	0.068	0.796	0.083

* denotes a p value statistically significant at the 0.05% level or greater.

Figure 8b.4a

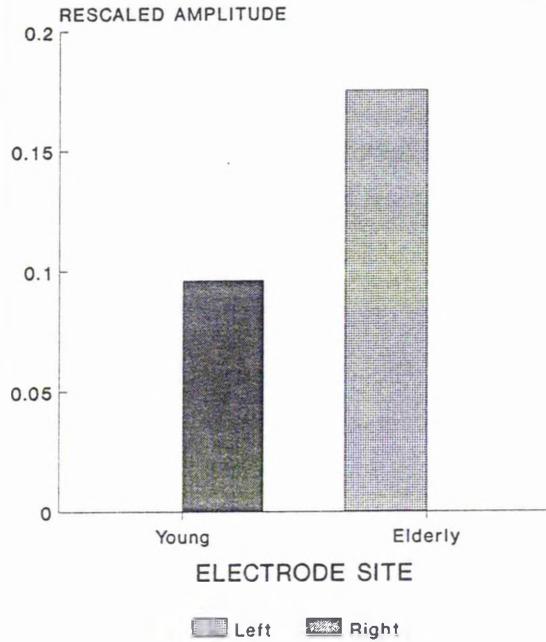


Figure 8b.4b

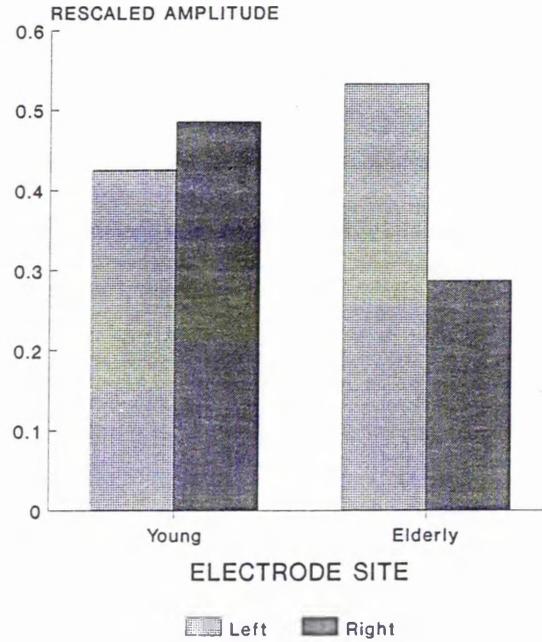


Figure 8b.4c

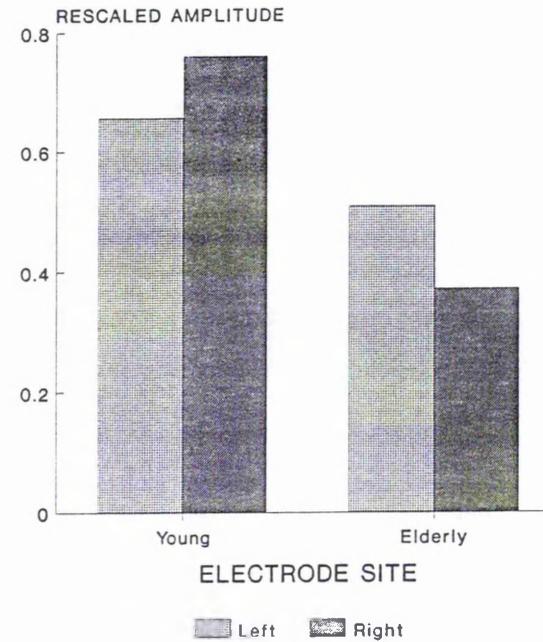


Figure 8b.4a, 8b.4b and 8b.4c Bar diagrams illustrating the amplitude distribution evoked by visual rare nontarget stimuli at frontal (Figure 8b.4a), temporal (Figure 8b.4b) and parietal (Figure 8b.4c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Figure 8b.5a

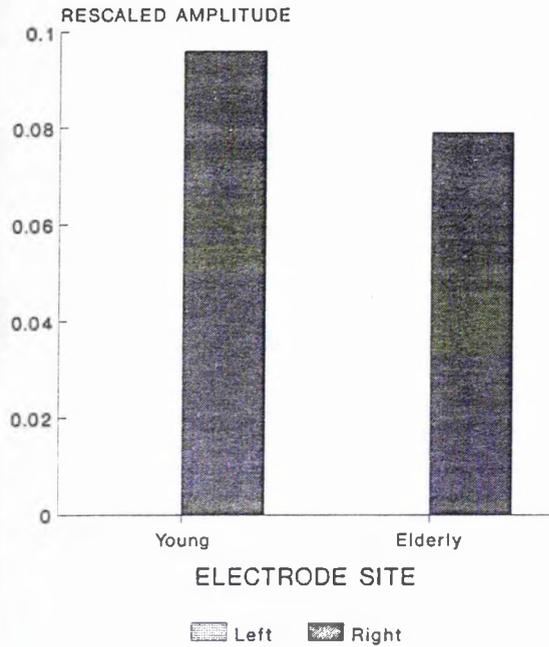


Figure 8b.5b

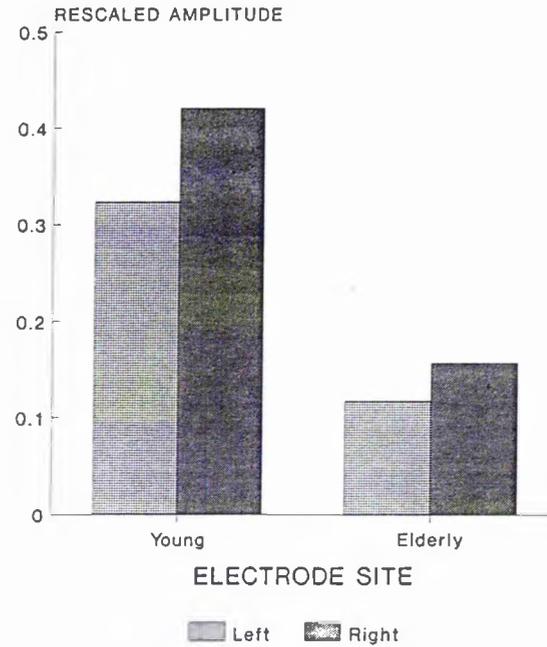


Figure 8b.5c

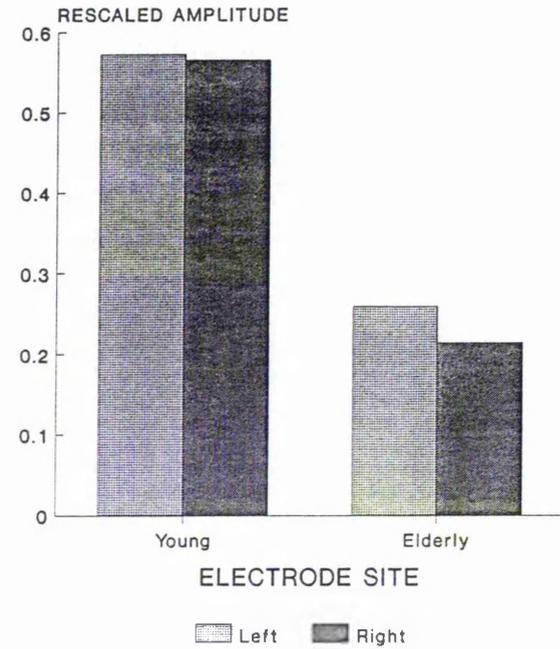


Figure 8b.5a, 8b.5b and 8b.5c Bar diagrams illustrating the P300 amplitude distribution evoked by visual target stimuli at frontal (Figure 8b.5a), temporal (Figure 8b.5b) and parietal (Figure 8b.5c) sites along the lateral chains of electrodes by the young and elderly groups of subjects.

Elderly Group

Target Stimuli ANOVA of amplitude evoked in response to target stimuli within the elderly group of subjects failed to reveal a significant main effect or interaction (see Table 8b.8)

Rare Nontarget Stimuli ANOVA of amplitude evoked in response to rare nontarget stimuli within the elderly group of subjects failed to reveal a significant main effect or interaction (see Table 8b.8).

Young Group

Target Stimuli No main effect of trial was obtained (see Table 8b.9). A main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked in response to target stimuli across sites, collapsed across trials, was significantly greater at both Cz and Pz electrode sites in comparison to that evoked at the Fz site. An interaction between the factors of trial and site did not prove to be significant.

Rare Nontarget Stimuli No main effect of trial was obtained (see Table 8b.9). A main effect of site was obtained. *Post hoc* analysis demonstrated that amplitude evoked in response to rare nontarget stimuli across sites, collapsed across trials, was significantly greater at both the Cz and Pz electrodes sites in comparison to that evoked at the Fz site. An interaction between the factors of trial and site did not prove to be significant.

N100

ANOVA of the latencies of the three classes of experimental stimuli along the midline between groups failed to produce significant effects for either age group or experimental condition (see Table 8b.1 of the Appendix).

ANOVA of the mean amplitude evoked by the three classes of stimuli revealed a significant three way interaction involving the factors of group, chain and site (see Table 8b.10 of the Appendix). *Post hoc* analysis demonstrated that within the young group of subjects greater mean amplitude was evoked at parietal sites in comparison to the frontal sites along the lateral chains of electrodes. Along the midline chain mean amplitude was equally

Table 8b.8 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of visual target and rare nontarget stimuli within the elderly subjects.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	3.7,40.2	0.593	0.653	345.918
Site ST	1.8,19.3	0.179	0.809	71.125
Interactions				
TR X ST	6.1,66.7	1.055	0.400	22.355
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	3.6,39.9	0.610	0.641	489.533
Site ST	1.2,12.7	1.368	0.271	145.546
Interactions				
TR X ST	6.3,69.3	1.186	0.325	32.273

Table 8b.9 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of visual target and rare nontarget stimuli within the young subjects.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	5.2,63	1.873	0.109	264.528
Site ST	1.4,16.3	31.741	0.000*	147.647
Interactions				
TR X ST	6.2,74.5	1.200	0.316	33.851
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	4.5,54.3	0.662	0.638	412.247
Site ST	1.5,17.8	20.705	0.000*	188.108
Interactions				
TR X ST	6.5,77.7	1.443	0.206	53.705

* denotes a p value statistically significant at the 0.05% level or greater.

great at each site. Within the elderly group the parietal sites demonstrated greater mean amplitude in comparison to both the frontal and central/temporal sites.

Scalp Distribution

ANOVA of the rescaled mean amplitude failed to produce significant interactions involving the factor of age group (see Table 8b.10 of the Appendix). A significant two way interaction involving the factors of chain and site was obtained. *Post hoc* analysis demonstrated that, collapsed across both experimental condition and group, a parietal site maximum amplitude distribution was obtained along both the lateral chains. Along the midline chain an equipotential amplitude distribution was obtained (see Figure 8b.3a).

N200

Target Deflections ANOVA of the latency of the response to target stimuli measured along the midline demonstrated a significant effect for age group (see Table 8b.1 of the Appendix). This was due to the elderly group's response being evoked earlier than that of the young group's (226 msec v 266 msec). A significant interaction involving the factors of group and site was obtained. *Post hoc* analysis demonstrated that at the Pz electrode latency was earlier than at the Fz or Cz electrodes across both groups of subjects (see Table 8b.2 of the Appendix).

ANOVA of the mean amplitude of the target N200 deflection between groups produced a two way interaction involving the factors of group and site (see Table 8b.11.1 of the Appendix). *Post hoc* analysis demonstrated that within the young group mean amplitude, collapsed across chains, was greater at frontal and central/temporal sites in comparison to parietal sites. Within the elderly group amplitude was equally large at each site.

Rare Nontarget Deflection ANOVA of the latency of the response evoked in response to rare nontarget stimuli measured along the midline failed to demonstrate any significant main effect or interaction (see Table 8b.1 of the Appendix). ANOVA of the mean amplitude of the rare nontarget deflection between groups produced a two way interaction involving the factors of group and site (see Table 8b.11.2 of the Appendix). *Post hoc* analysis demonstrated that within the young group mean amplitude, collapsed across electrode chains,

Figure 8b.6

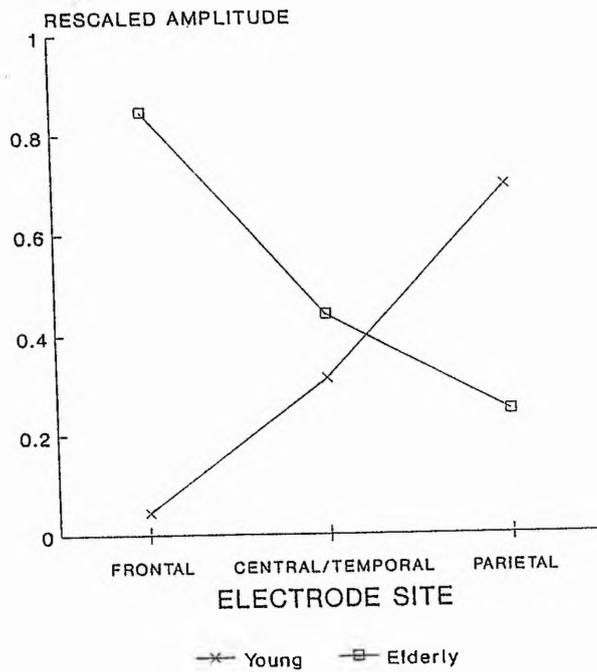


Figure 8b.6 Graph illustrating the distribution, across electrode site, of rescaled amplitude of the N100 deflection elicited by visual stimuli within Experiment 6 (collapsed across experimental condition and subject group).

was largest at frontal sites. Within the elderly group amplitude was equally large at each site.

Scalp Distribution

Target Deflections ANOVA of the mean rescaled amplitude of the target N200 deflection produced a two way interaction involving the factors of group and site (see Table 8b.11.1 of the Appendix). *Post hoc* analysis demonstrated that within the young group greater mean amplitude was distributed at the frontal sites in comparison to the parietal sites. Within the elderly group greater mean amplitude was distributed at the parietal sites in comparison to the frontal sites (see Figure 8b.7).

Rare Nontarget Deflections ANOVA of the mean rescaled amplitude of the rare nontarget deflection between groups produced a three way interaction involving the factors of group, chain and site (see Table 8b.11.2 of the Appendix). *Post hoc* analysis demonstrated that within the young group greater mean amplitude was distributed at the frontal sites in comparison to the parietal sites (see Figure 8b.8a). Within the elderly group (see Figure 8b.8b) an equipotential amplitude distribution was obtained along all three chains.

500-850 msec Latency Range Mean Amplitude

ANOVA of the mean amplitude evoked in the latency range 500 - 850 msec produced a three way interaction involving the factors of group, condition and site (see Table 8b.12 of the Appendix). *Post hoc* analysis demonstrated that within the young group frequent stimuli evoked a response that was equally large at each site. Target and rare nontarget stimuli both evoked responses that demonstrated greatest amplitude at centro/temporo-parietal sites.

Within the elderly group both frequent and target stimuli evoked responses with equal mean amplitude at each site. Rare nontarget stimuli evoked a response with greater mean amplitude at central-temporal sites in comparison to frontal and parietal sites.

A three way interaction involving the factors of condition, chain and site was also obtained. *Post hoc* analysis demonstrated that frequent stimuli evoked equal amplitude at each site along all three chains. Target stimuli evoked a response with greater amplitude at centro/temporo-parietal sites along both the

Figure 8b.7

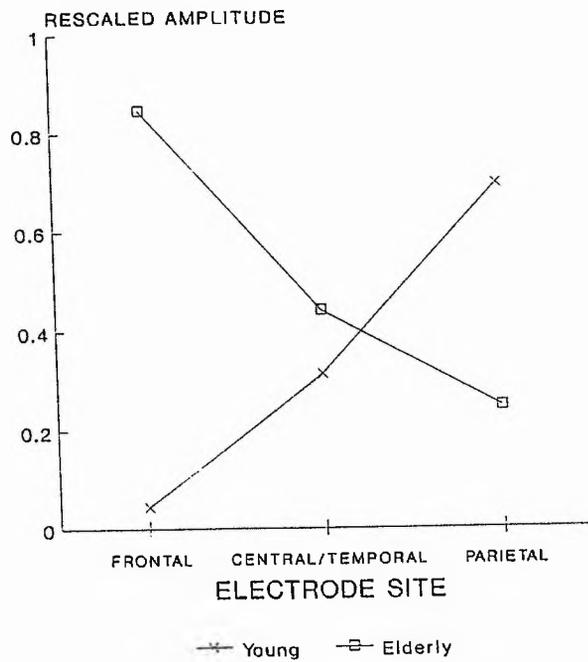


Figure 8b.7 Graph illustrating the distribution of rescaled amplitude of the N200 deflection elicited by target stimuli within the young and elderly groups of subjects within Experiment 6.

midline and left chains. Along the right chain amplitude was equally great at each site. Rare nontarget stimuli evoked a response that was greater at central/parietal sites in comparison to the frontal site along the midline. Along the lateral chains amplitude was equally great at each site.

Scalp Distribution

Mean amplitude in the 500 - 850 latency range was rescaled and subjected to ANOVA to search for possible differences in scalp distribution between the groups. A four way interaction involving the factors of group, condition, chain and site was obtained (see Table 8b.12 of the Appendix). *Post hoc* analysis revealed that within the young group of subjects frequent stimuli demonstrated a centro-parietal distribution along the midline. Along the lateral chains the temporal sites demonstrated greater amplitude distribution in comparison to the frontal sites (see Figure 8b.9a). In response to target stimuli a centro-parietal distribution was obtained along the midline. Along the lateral chains a temporal site maximum amplitude distribution was obtained (see Figure 8b.9b). In response to rare nontarget stimuli a centro-parietal distribution was obtained along the midline. Along the lateral chains an equipotential amplitude distribution was obtained (see Figure 8b.9c).

Within the elderly group all three classes of experimental stimuli demonstrated a centro-parietal distribution along the midline. Along the lateral chains an equipotential amplitude distribution was obtained (see Figure 8b.10a, 8b.10b and 8b.10c).

150 - 350 msec Latency Range at Lateral Parietal Sites

ANOVA of the mean amplitude in the latency range 150 - 350 msec at lateral parietal sites produced a significant two way interaction involving the factors of group and condition (see Table 8b.13 of the Appendix). *Post hoc* analysis demonstrated that within the young group of subjects rare nontarget stimuli evoked greater mean amplitude in comparison to that evoked in response to target and frequent stimuli. However, target stimuli evoked greater mean amplitude in comparison to that evoked by frequent stimuli (see Figure 8b.11a).

Within the elderly group of subjects rare nontarget stimuli evoked greater mean amplitude in comparison to that evoked in response to target and frequent stimuli. Comparable mean amplitude was evoked in response to target and frequent stimuli (see Figure 8b.11b).

Figure 8b.9a

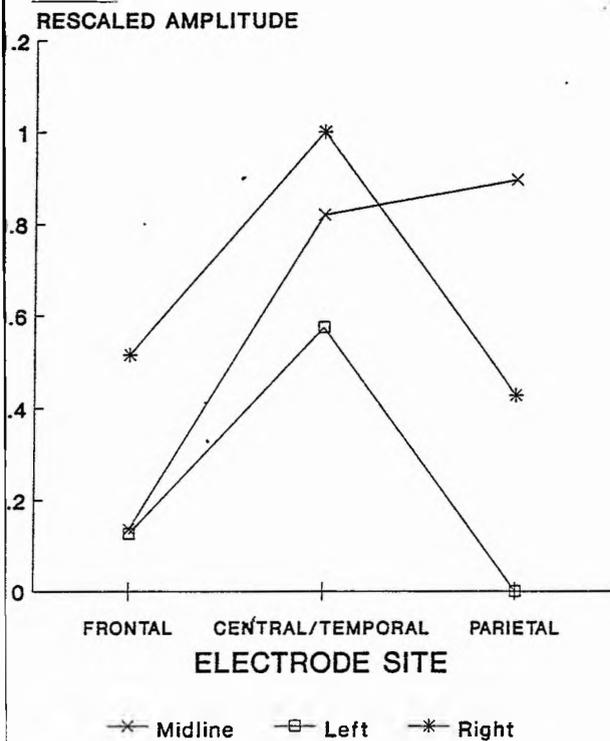


Figure 8b.9b

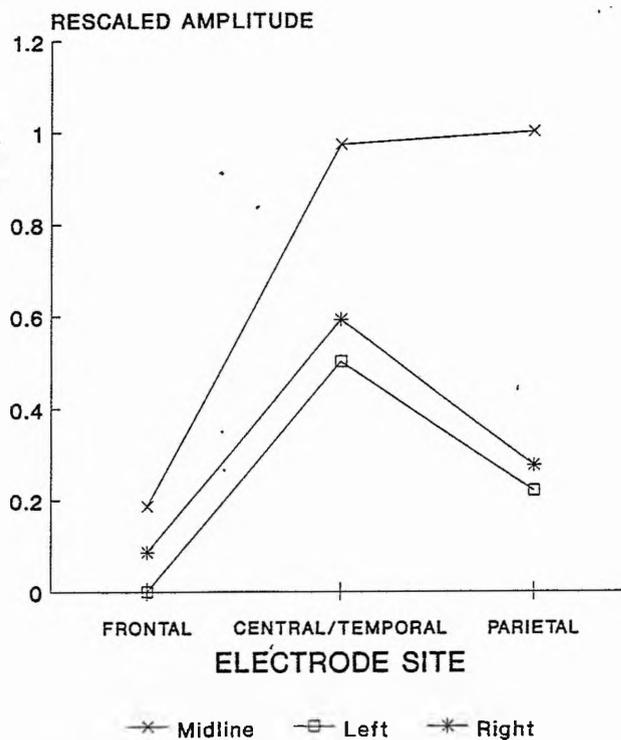


Figure 8b.9c

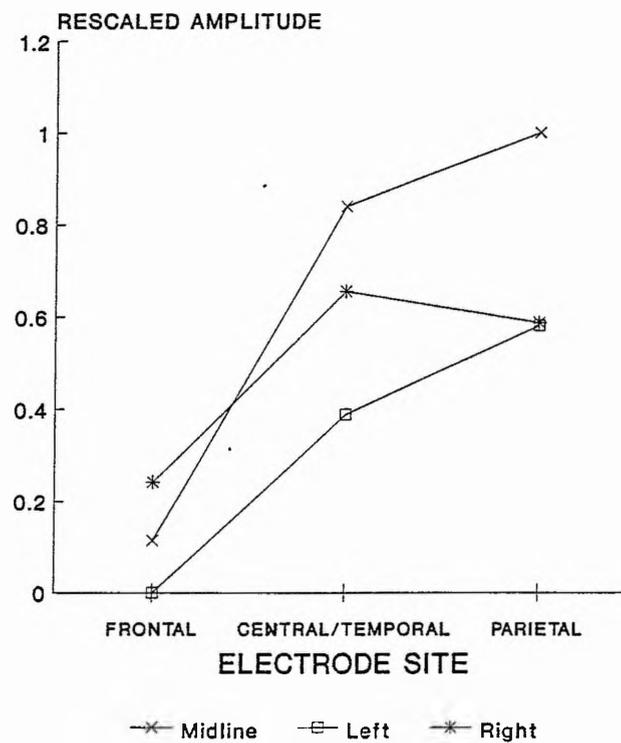


Figure 8b.9a, 8b.9b and 8b.9c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by visual frequent (Figure 8b.9a), target (Figure 8b.9b) and rare nontarget (Figure 8b.9c) stimuli within the young subject group of Experiment 6.

Figure 8b.10a

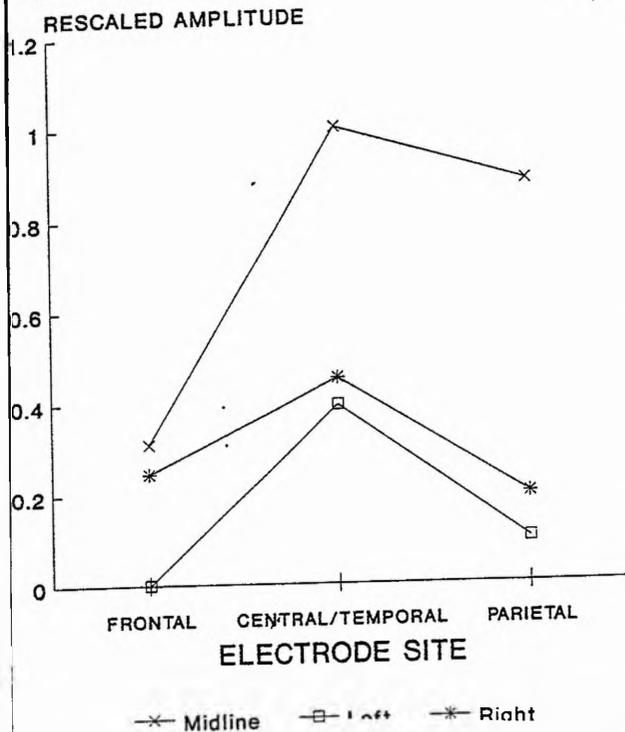


Figure 8b.10b

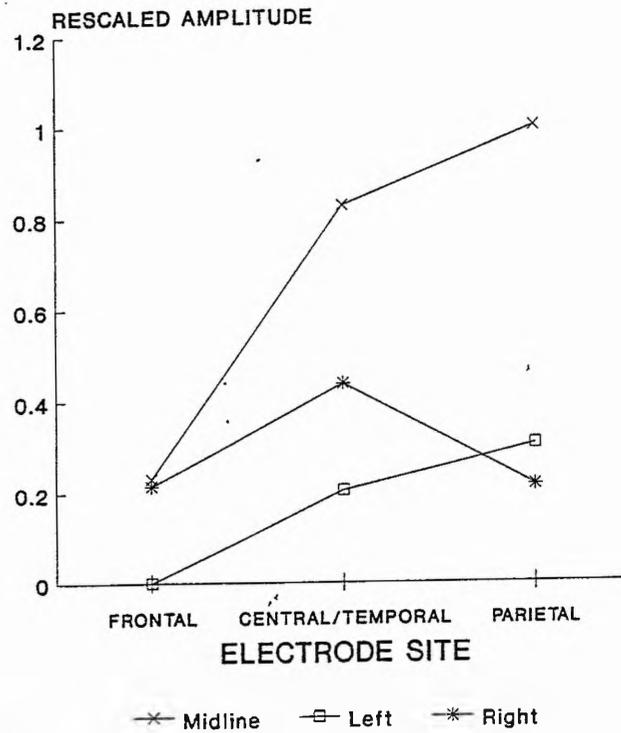


Figure 8b.10c

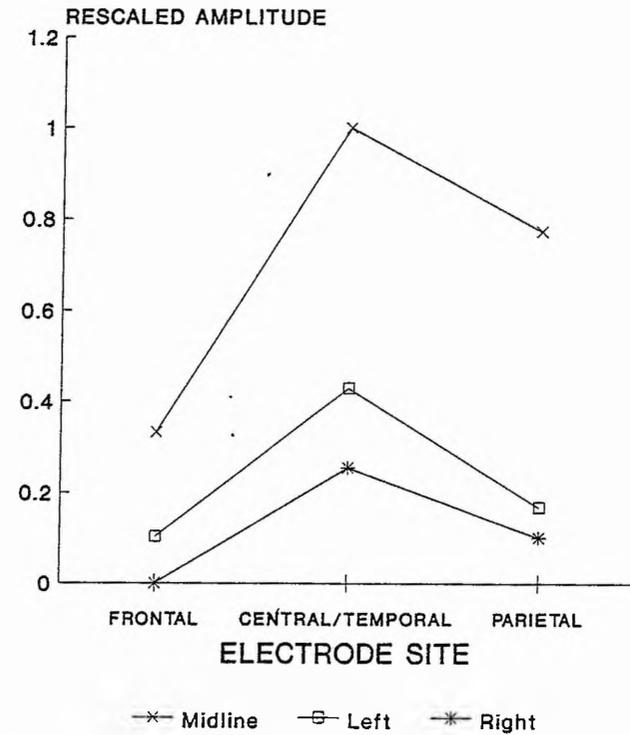


Figure 8b.10a, 8b.10b and 8b.10c Graph illustrating the distribution, across electrode site, of rescaled amplitude within the latency range 500 -850 msec elicited by visual frequent (Figure 8b.10a), target (Figure 8b.10b) and rare nontarget (Figure 8b.10c) stimuli within the elderly subject group of Experiment 6.

Figure 8b.11a

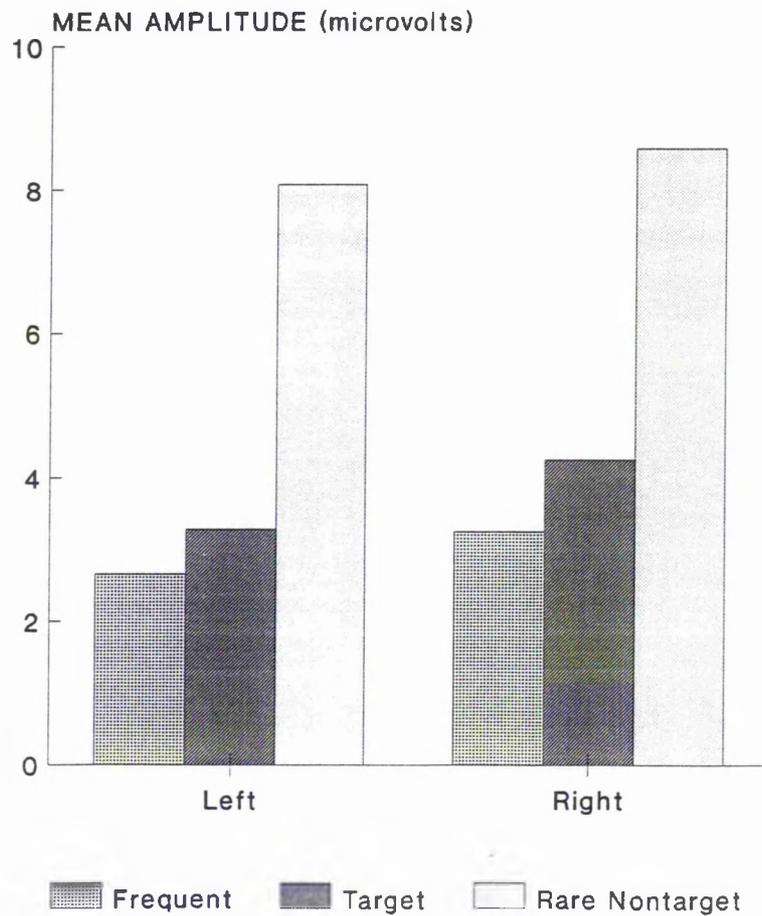


Figure 8b.11b

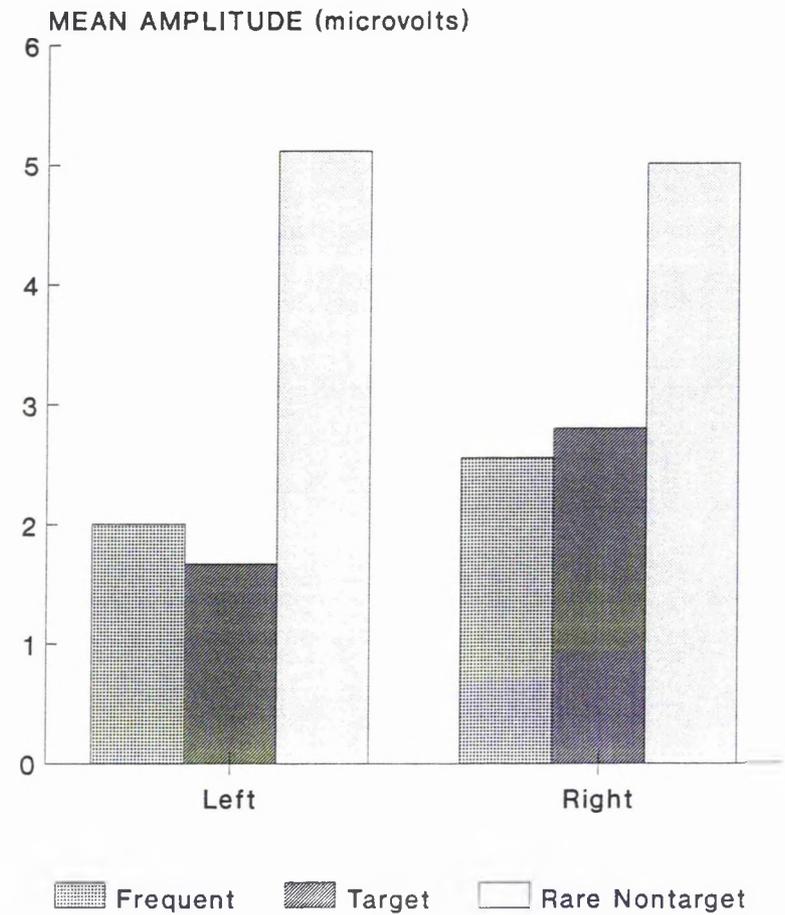


Figure 8b.11a and 8b.11b Bar diagram illustrating the mean amplitude evoked by visual frequent, target and rare nontarget stimuli within the young (Figure 8b.11a) and elderly (Figure 8b.11b) groups of subjects between 150 - 350 msec at lateral parietal sites within Experiment 6.

8b.5 Discussion

As predicted the scalp amplitude distribution of rare stimuli within the young subjects replicated previous findings employing the same experimental stimuli and procedure within a similar group of subjects (see Chapter 4). Rare nontarget stimuli evoked a centro/temporo-parietal amplitude distribution along all three chains. Target stimuli evoked a centro-parietal amplitude distribution along the midline. As previously reported (see section 4.5) the distribution of the target P300 response failed to replicate the parietal maximum amplitude distribution evoked in response to target stimuli reported by Courchesne *et al.* (1975; 1978) and Knight (1991; personal communication).

The elderly group's data demonstrated that both target and rare nontarget P300 responses demonstrated an equipotential amplitude distribution across the scalp. The young subjects demonstrated a symmetrical amplitude distribution across the lateral chains in response to rare stimuli. Similarly in response to target stimuli a symmetrical amplitude distribution was observed across the lateral chains within the elderly group. However, in response to rare nontarget stimuli the left chain evoked a significantly greater amplitude distribution than the right chain. The flat amplitude distribution obtained within the elderly group of subjects together with the asymmetric distribution across the lateral chains in response to rare nontarget stimuli will be discussed in greater detail in the general discussion below.

As reported in connection with auditory stimuli, single trial analysis demonstrated that the flat amplitude distribution obtained within the elderly group was consistent across trials. Such a result demonstrates that the flat distribution obtained across the scalp was not the result of a more positive response initially that habituated over trial presentations to a more equipotential distribution across sites. Similar analysis demonstrated that the young subjects responses remained consistent across trial presentations.

Within the latency range of the N200 deflection a similar dissociation of responses between age groups on the basis of amplitude distribution as that reported in connection with the P300 deflection was obtained. The young group's data demonstrated that the response to rare stimuli was maximally distributed at anterior scalp sites. As previously stated such an N200 deflection is probably a composite of N2b and MMN (N2a) components (see section 1.5.4.1). Within an active oddball paradigm it is difficult to dissociate the target and rare nontarget responses on the basis of scalp amplitude distribution. Within the elderly group an equipotential amplitude distribution was obtained

in response to rare nontarget stimuli. In response to target stimuli the parietal sites demonstrated greater amplitude distribution than the frontal site.

As within the auditory modality there was a tendency for reaction times (and associated standard deviations) to increase in the elderly group of subjects, however, this increase with advancing age was not statistically significant. However, advancing age had comparable effects upon the target and rare nontarget P300 latencies. Target latency increased by 0.9 msec/year (collapsed across the three midline sites). This value is within the range of values reported for target P300 latency prolongation (rate of delay ranging from 0.9 to 1.8 msec/year) reported by Polich (1991). Rare nontarget P300 latency increased by 1.6 msec/year. As discussed in section 8a.5, at present a precise relationship between P300 latency and age does not exist. However, results within the visual modality, as within the auditory modality, support a general relationship between increasing P300 latency and advancing age.

Such a change of scalp amplitude distributions to one more equipotentially distributed across the scalp within elderly subjects in comparison to that observed within young subjects was not obtained within all ERP components. As within the auditory modality advancing age failed to alter the scalp amplitude distribution of the N100 deflection between age groups.

Within the latency range of 500 - 850 msec both groups of subjects demonstrated a centro-parietal amplitude distribution along the midline chain in response to all three classes of experimental stimuli. Such a result demonstrates that the observed equipotential amplitude distribution observed within the latency range of the P300 component within the elderly group of subjects was not evident for all components of the ERP waveform.

Within both elderly and young groups of subjects rare nontarget stimuli demonstrated greater mean amplitude within the 150 - 350 msec latency range in comparison to frequent and target stimuli at lateral parietal sites. Such a result has consistently been reported in the present programme of research (see Chapters 3, 4, 5, 6 and 7). As previously stated such a prolonged negative shift of the target response in comparison to the rare nontarget response is thought to reflect selection negativity (see sections 1.5.4.3 and 9.7).

General Discussion

The behavioural performance within both modalities was not significantly affected by aging. Reaction times, target detection accuracy and false alarm

rates were similar across the young and elderly groups. These results may reflect a ceiling effect due to the simplicity of the target detection task.

It was evident within both modalities that the scalp amplitude distribution became flatter with advancing age in comparison to the larger and more posterior maximum distribution obtained within the young group. Goodin *et al.* (1978) were the first to report that the scalp amplitude distribution of event-related components was found to vary with age yielding a more nearly equipotential distribution for older subjects. This effect of mean P300 amplitude increasing at the frontal site with a reduction at the parietal site has been reported within the auditory (for instance Smith *et al.* 1980) and somatosensory (for instance Yamaguchi and Knight 1991c) modalities (for reviews see Ford and Pfefferbaum 1980; 1985; Polich and Starr 1984). As reported by Friedman *et al.* (1993) such a change in the scalp amplitude distribution in elderly subjects to a flatter distribution in comparison to that obtained from young subjects is consistently reported.

Similar scalp distributional changes were observed across groups within the N200 latency range. Within the visual modality young subjects demonstrated a frontal site maximum amplitude distribution in response to both target and rare nontarget stimuli in comparison to the equipotential amplitude distribution demonstrated within the elderly group of subjects in response to rare nontarget stimuli. Target stimuli demonstrated a posterior maximum amplitude distribution. Similarly, within the auditory modality the young subjects demonstrated a frontal site maximum amplitude distribution in response to rare stimuli in comparison to the elderly subjects more central site maximum amplitude distribution.

The negative deflections evoked in response to frequent, target and rare nontarget stimuli within the N100 latency range failed to demonstrate a change in scalp amplitude distribution with advancing age. A similar lack of significant differences between young and elderly subjects has been reported by Ford and Pfefferbaum (1991) and Friedman *et al.* (1993) for the N100 deflection. No attenuation of the amplitude of the N100 deflection elicited by the three classes of stimuli within either the auditory or visual modalities was obtained. A modality specific N100 scalp amplitude distribution was obtained. The visual modality demonstrated a more posterior amplitude distribution in comparison to the anterior amplitude distribution obtained in response to auditory stimuli. The relatively invariant nature of the N100 argues against the possibility that age related changes in late latency ERP components were the

result of conduction changes associated with differences in skull or scalp thickness with age.

Both Ford and Pfefferbaum (1991) and Friedman *et al.* (1993) have reported age-related changes in the rare nontarget P300 component within the auditory modality. Such changes in the scalp distribution of this component were confined to the frontal electrode sites where, compared with their oldest subjects, the young subjects showed smaller normalised amplitudes. Such results, it is suggested by Friedman *et al.* (1993), suggest the possibility of age-related changes in a function that is presumed to involve the frontal lobes. Wood and McCarthy (1985) have reported that intracranially recorded ERP data suggested the presence of a frontal lobe contribution to the scalp recorded P300 elicited during a modified oddball experiment.

Across both modalities the response to rare nontarget stimuli within the elderly group demonstrated a reduced P300 amplitude distribution along the right chain of electrodes in comparison to the amplitude distributed along the left chain. This observed reduction was most evident at frontal and temporal sites in comparison to that observed at parietal sites within the auditory modality. Within the visual modality each site along the right hemisphere demonstrated a significantly reduced amplitude distribution in comparison to that obtained along the left hemisphere.

The asymmetry of the rare nontarget P300 response in elderly subjects may reflect the asymmetric activation of a neural circuit or neural circuits involved specifically in the processing of deviant intrusive stimuli. Such a hypothesis would suggest that such circuits are involved in the involuntary redirection of attention, a function that the frontal lobes are known to be involved in (Luria 1973).

On the basis of the results of the present experiment such results may be extended to include the visual modality, although as described a change in amplitude was also observed at posterior sites in response to visual rare nontarget stimuli. Within both modalities it is evident that the right chain (hemisphere) demonstrated a greater reduction of amplitude in comparison to that observed along the left chain (hemisphere).

Similarly Woods (1992) has reported a change in the inter-hemispheric distribution of the mismatch negativity (MMN) with age. In a middle-aged (mean age 43.2 years) group, the MMN demonstrated a right hemisphere predominance similar to that previously reported in younger subjects (Paavilainen *et al.* 1991). In an elderly (mean age 66.7 years) group the MMN amplitude was larger over the left hemisphere. Woods (1992) argued that such

results suggest that the cerebral mechanisms that are involved in the automatic detection of stimulus change show an age-related reduction in the right hemisphere.

As previously stated reports from the neuropsychological literature support the view that frontal lobe function in the elderly may be reduced in comparison to that of younger subjects (for example Craik *et al.* 1990; Albert and Wolfe 1990; Haaland *et al.* 1987). However, such studies have typically failed to dissociate the functioning of the right and left frontal lobes. Similarly neuropathological studies (for example Kemper 1984) and cerebral blood flow studies (Shaw *et al.* 1984) have suggested that age-related changes, for instance cell loss, are most marked in the frontal lobes relative to other areas of the brain. However, again such studies fail to dissociate the relative decline of function or physical states between the frontal lobes. Such studies while demonstrating the age related changes that may occur, fail to account for the posterior as well as the anterior reduction of amplitude obtained along the right chain in response to visual stimuli that was observed within the elderly group.

Within the auditory modality Knight (1984) has examined the novelty, rare nontarget P300 in patients with unilateral lesions of the dorsolateral prefrontal cortex. He reported that unexpected rare nontarget stimuli elicited a frontally distributed P300 component in controls but a parietally distributed P300 in the patients with frontal lobe lesions. Knight (1990) has suggested that the dorsolateral prefrontal area is either required for the modulation of the novelty P300 or is a generator of this electrical activity. Similar findings have been reported within the somatosensory modality (Yamaguchi and Knight 1991c).

As pointed out by Friedman *et al.* (1993), because there is no simple isomorphism between scalp-recorded electrical activity and the underlying cortical tissue, reduced amplitude over one hemisphere does not necessarily imply that the generators of the component(s) in question are located within either anterior scalp or the right hemisphere. Therefore, differences in scalp amplitude distribution across the hemispheres in elderly subjects in comparison to the symmetric amplitude distribution obtained within young subjects cannot be concluded to accurately measure differences in hemispheric function between groups. The hypothesis that hemispheric symmetry is altered in the elderly may be further examined by employing analyses such as current source density and spatiotemporal modelling and metabolic techniques.

Advancing age had comparable effects upon both target and rare nontarget P300 latencies across modalities. The rare nontarget latency increase was greater in comparison to the target P300 latency increase. Across modalities a

similar increase was demonstrated for P300 to both target and rare nontarget stimuli. Both Pfefferbaum *et al.* (1984) and Picton *et al.* (1984) compared auditory and visual P300 latency and age both reported the P300 latency/age slope to be steeper for visual in comparison to auditory stimuli. No satisfactory explanation is able to account for the similar increase in latency obtained across modalities within the present experiment. Across both modalities there was no increase in latency of the N100 component. Numerous researchers report that the N100 latency remains invariant across the life span (Barrett *et al.* 1987; Brown *et al.* 1983; Syndulko *et al.* 1982). The results of this experiment suggest that age appears to affect P300 latency across modalities in a similar manner.

Although early investigators suggested a correlation between RT and P300 latency (for example Ritter *et al.* 1972), later studies have demonstrated that the two measures may be dissociated and provide different estimates of mental chronometry (Kutas *et al.* 1977b; Magliero *et al.* 1984). Iragui *et al.* (1993) argues that whereas RT and P300 latency measures are sensitive to changes in stimulus processing demands (*i.e.* encoding, recognition and classification) the timing of P300 is relatively insensitive to demands of the response selection and execution process indexed by the overt behavioural response. Manipulation of stimulus evaluation (varying target discriminability) and response selection (varying stimulus-response compatibility) have therefore demonstrated that P300 latency increases as stimulus discriminability becomes more difficult but is relatively unaffected by stimulus response incompatibility. In contrast RT is significantly affected by both manipulations (Pfefferbaum *et al.* 1983; Pfefferbaum *et al.* 1985; Ragot 1984).

In conclusion the importance of the dissociation of the scalp amplitude distribution evoked in response to target and rare nontarget stimuli across the lateral chains is to be emphasised. It has not proved possible to dissociate the visual rare P300 responses on the basis of amplitude distribution within young subjects. Similarly within elderly subjects it did not prove possible to dissociate the responses on the basis of amplitude distribution along the midline. However, within both visual and auditory modalities it proved possible to dissociate the rare nontarget P300 response from that of the target P300 response on the basis of amplitude symmetry across the lateral chains. Within both modalities less amplitude was distributed along the right chain in comparison to that evoked along the left chain. Within the young group of subjects no such asymmetry was observed within either sensory modality. Such

a result suggests that rare nontarget stimuli may be processed similarly across modalities.

Summary

Across both the auditory and visual modalities results from the young group of subjects replicated previously reported findings (see Chapter 3 and 4 respectively).

Across both modalities the elderly group of subjects demonstrated an equipotential amplitude distribution across the midline chain in response to both target and rare nontarget stimuli.

In response to rare nontarget stimuli across both modalities the elderly group of subjects demonstrated a reduced amplitude distribution across the right chain of electrodes. Such a result suggests that rare nontarget stimuli are processed in a similar manner across sensory modalities.

Advancing age significantly increased the latency of target and rare nontarget P300 responses across both modalities.

Chapter 9

General Discussion

Aim of the Research Programme

The aim of this programme of research was to investigate the feasibility of developing a visual oddball paradigm analogous to previously employed auditory paradigms. Such auditory paradigms have dissociated P300 responses to target and rare nontarget stimuli on the basis of scalp amplitude distribution. Such a visual paradigm would allow the question of the modality specificity of the P300 complex to be examined. It would also allow the modality specificity of the theories pertaining to the functional implications of the P300 complex, in particular the attentional trace theory proposed by Näätänen (1990; 1992), to be examined.

9.1 Auditory Dissociation of the P300 Complex

Previous attempts to dissociate target and rare nontarget P300 responses on the basis of amplitude distribution have largely been confined to studies within the auditory modality. Such studies have typically reported a target P300 deflection with an amplitude distribution maximum over parietal sites in comparison to a rare nontarget P300 response with a more anterior scalp site maximum amplitude distribution (for instance Squires *et al.* 1975; Knight 1984).

Within the present programme it was demonstrated, within two separate experiments, that it was possible to dissociate the auditory P300 responses to target and rare nontarget stimuli on the basis of amplitude distribution. Topographical analysis demonstrated that target stimuli evoked a P300 deflection with a maximum distribution over parietal scalp. This response was believed to correspond to the P3b component of the P300 complex (Squires *et al.* 1975; Knight 1984; Holdstock 1992; Holdstock and Rugg 1993). In comparison, rare nontarget stimuli evoked a response with a centro-parietal maximum distribution, this response was believed to correspond to the P3a component of the P300 complex (Squires *et al.* 1975; Knight 1984; Holdstock and Rugg 1993). As stated previously the "classical" auditory P3a component is reported to have a more anterior distribution than the one reported here (see Squires *et al.* 1975; Knight 1984). However, Holdstock and Rugg (1993) have

reported a P300 component evoked in response to rare nontarget stimuli with a similar centro-parietal amplitude distribution. Such a label for the response does not signify that a pure P3a component as described by Squires *et al.* (1975) was elicited. The possibility exists that the auditory rare nontarget P300 component reported here fails to demonstrate a more anterior distribution due to an overlap of activity from the combination of neural generators responsible for the generation of the target P300 response.

Single trial analysis of the responses elicited by the first ten presentations of both target and rare nontarget stimuli demonstrated that the distribution of amplitude across the scalp remained constant.

Friedman *et al.* (1993) have suggested that current source density maps indicate two general subdivisions of the P300 deflection elicited by auditory target and rare nontarget stimuli. The reference-free current source density foci located within frontal and posterior aspects of the scalp strongly support a subdivision of the P300 (target and rare nontarget) generator into frontal and posterior configurations rather than a single more widespread cortical or deep generator. This interpretation of both frontal and posterior cortical contributions to the scalp recorded P300 within the auditory modality is consistent with reports based upon brain-injured patients (Knight *et al.* 1989), on intracranially recorded ERP data (Wood and McCarthy 1985) and on differential age-related effects on frontally and parietally distributed P300s in aging subjects (Yamaguchi and Knight 1991c).

There are however, two possible explanations for the different scalp distributions of the P3a and P3b components. The deflections may reflect the output of distinct anatomically separate neural generators, as suggested by Friedman *et al.* (1993), one exclusively activated by tones, the other by rare nontarget sounds. Alternatively a combination of output from separate generators may be responsible for the deflections recorded as the P3a and P3b components. Such an explanation may explain the more posterior distribution of the P3a response in comparison to other reports, the contribution of the posterior (target) generator contributing relatively more output to the response elicited by the rare nontarget stimuli.

9.2 Visual Dissociation of the P300 Complex

A smaller number of studies have reported a dissociation of target and rare nontarget P300 responses within the visual modality on the basis of scalp amplitude distribution (Courchesne *et al.* 1975; 1978; Knight 1991; personal

communication). A smaller number still have directly compared the scalp amplitude distributions of auditory and visual target and rare nontarget responses within the same set of subjects (Simson *et al.* 1977; Snyder *et al.* 1980; Picton *et al.* 1984).

Within the present research programme it did not prove possible to dissociate visual target and rare nontarget P300 responses on the basis of amplitude distribution. A visual oddball paradigm employing similar stimuli to a study previously reported to dissociate the target and rare nontarget responses (Courchesne *et al.* 1975; 1978) failed to replicate such a finding. Rare nontarget stimuli elicited a centro/temporo-parietal response along all three chains of electrodes. Target stimuli elicited a similar centro/temporo-parietal response along all three chains. Courchesne *et al.* (1975; 1978) reported a target P300 response with a maximal distribution at parietal sites in comparison to a more anterior P300 deflection evoked in response to rare nontarget stimuli with a maximum distribution over centro-frontal sites.

As reported in section 1.421 and 4.1 Knight (1991; personal communication) reported a visual paradigm that dissociated visual target and rare nontarget P300 deflections on the basis of amplitude distribution. Knight (1991) obtained a centro-parietal distribution in response to target stimuli in comparison to a fronto-central distribution in response to rare nontarget stimuli. However, employing a similar paradigm with similar stimuli to that employed by Knight (1991) both target and rare nontarget P300 deflections demonstrated a centro-parietal amplitude distribution. Such a distribution in response to both target and rare nontarget stimuli was obtained in a standard three stimulus oddball paradigm across three experiments (see Chapters 4, 7 and 8).

As within the auditory modality single trial analysis of the responses elicited by the first ten presentations of both Courchesne *et al.* (1975) and Knight (1991) style target and rare nontarget stimuli demonstrated that the distribution of amplitude across the scalp remained constant.

Visual oddball paradigms employing stimuli adapted from both Courchesne *et al.* (1975) and Knight (1991) demonstrated that the P300 deflections evoked in response to target and rare nontarget stimuli appeared to be generated from the same combination of underlying neural generators since a similar amplitude distribution was obtained. Along the midline chain of electrodes both target and rare nontarget stimuli elicited responses with a centro-parietal distribution.

9.3 Experimental Manipulations within the Visual Modality

Courchesne *et al.* (1978) claimed that the greater the dissimilarity between a presented stimulus and the ongoing background sequence of stimuli the greater would be the mean amplitude of the evoked P300 deflection. Within the auditory modality the mean amplitude of the P300 deflection evoked in response to rare nontarget stimuli was significantly greater than the mean amplitude of the deflection evoked in response to target stimuli. Such a differential in the evoked amplitude of the responses may reflect the greater similarity of the physical characteristics of the stimuli between the frequent and target stimuli in comparison to the greater dissimilarity of the physical characteristics between the frequent and rare nontarget stimuli. Within the visual paradigm employing stimuli adapted from Courchesne *et al.* (1975) the mean amplitude evoked in response to target and rare nontarget stimuli was similar. Such a result indicates that the rare nontarget stimuli failed to be regarded by subjects as demonstrating any greater dissimilarity with the frequent background stimuli than the target stimuli. Stimuli within the visual paradigms employing stimuli adapted from Knight (1991) similarly demonstrated that the mean amplitude evoked in response to target and rare nontarget stimuli were similar. This similarity of mean amplitude evoked in response to target and rare nontarget stimuli was consistent across three experiments (see Chapters 4, 7 and 8).

The results of the visual experiments outlined suggest that a similar combination of underlying neural generators is responsible for the generation of both target and rare nontarget P300 responses. Such a suggestion is supported by the fact that reducing the physical contrast between the rare nontarget and frequent stimuli significantly reduced the amplitude of the P300 deflection evoked in response to rare nontarget stimuli in comparison to that evoked in response to target stimuli. The scalp distribution of the rare nontarget P300 response, however, demonstrated a centro-parietal distribution across experiments regardless of the physical contrast between rare nontarget and frequent stimuli. This effect demonstrates that the output (as indicated by the amplitude of the evoked deflection) of the underlying neural generators may be altered by the physical characteristics of the eliciting stimuli. However, the combination of neural generators responsible for the generation of the target and rare nontarget stimuli remains constant. Frequent stimuli within the standard three stimulus oddball paradigm with a probability of occurrence of 70% similarly evoked a P300 deflection with a centro-parietal amplitude distribution. All three classes of visual stimuli (frequent, target and rare

nontarget) stimuli would, therefore, appear to be generated by the same combination of underlying neural generators.

Decreasing the probability of occurrence of frequent stimuli to comparable levels to those of target and rare nontarget stimuli demonstrated that all three categories of equiprobable (target, simple and complex) stimuli elicited a positive deflection with a centro-parietal amplitude distribution along the midline chain. As described above within the standard three stimuli oddball paradigm the three classes of stimuli evoked similar P300 deflections with maximum amplitude distributions across centro-parietal sites along the midline. As demonstrated in Chapter 6, stimuli with a lower probability of occurrence evoke P300 deflections with greater mean amplitude. It would, therefore, appear that alteration of both the probability of occurrence of classes of stimuli as well as the physical characteristics of stimuli may alter the output of the underlying generators. However, the combination of neural generators responsible for such activity remains constant.

The mean amplitude and scalp amplitude distribution data evoked in response to visual stimuli would appear to be processed in a similar manner by subjects since such results indicate that a similar combination of neural generators produced a similar output in response to both target and rare nontarget stimuli. In contrast, a unique combination of underlying neural generators would appear to be responsible for different amounts of output (as indexed by the mean amplitude recorded) evoked in response to auditory target and rare nontarget stimuli.

However, the visual P300 deflections evoked in response to target and rare nontarget stimuli differed in at least two characteristics. Target stimuli by their very nature are designated as targets and as such subjects are instructed to respond whenever a target stimulus is encountered. Rare nontarget stimuli, however, have no intrinsic task relevance to the subject and yet they still elicited a P300 deflection. Within the visual oddball paradigm employing stimuli used by Knight (1991) rare nontarget stimuli elicited a P300 deflection with a significantly shorter peak latency in comparison to that evoked in response to target stimuli. Such results suggest that visual rare nontarget stimuli appear to automatically capture attention in a manner similar to that outlined for auditory rare nontarget stimuli (Näätänen 1990; 1992). While the elicitation of the auditory rare nontarget response appears to involve a unique combination of generators in comparison to those involved in the elicitation of the target response the elicitation of the visual rare nontarget response appears to depend upon the same combination of generators as is responsible for the

target response. However, it is not possible to categorically claim that the same generator, or combination of generators, is responsible for the generation of target and rare nontarget visual responses. The results of the visual paradigms employed within this programme of research may make such a claim likely. However, such results do not rule out the possibility that other types of visual stimuli or experimental manipulations would possibly access different visual generators or combinations of generators in a task specific (target or nontarget) manner.

9.4 The P300 Complex and Elderly Subjects

Within both auditory and visual modalities an elderly group of subjects demonstrated a P300 deflection distributed equally across the scalp in response to target and rare nontarget stimuli. Such an effect appears to be the result of a relative increase of mean amplitude at frontal sites with a reduction at parietal sites in comparison to young subjects. Such an amplitude distribution failed to dissociate target and rare nontarget stimuli on the basis of amplitude distribution within either modality. The more equipotential amplitude distribution across the scalp in response to rare stimuli within both modalities demonstrates that while the elicitation of the P300 complex may depend upon a modality specific combination of generators aging affects such modality specific generator combinations in a similar fashion.

Single trial analysis of responses evoked by target and rare nontarget stimuli within both the visual and auditory modalities failed to demonstrate a significant trial by site interaction. Such an interaction may have demonstrated an initial dissociation of P300 responses that habituated once averaged over the full run of stimulus presentations. However, no such scalp specific distribution was obtained in response to either class of stimuli within either modality over the initial ten presentations of the stimuli.

Not all the ERP deflections measured (for instance the N100 component) demonstrated distributional changes with advancing age. Similar findings led Friedman *et al.* (1993) to argue against the possibility that age-related changes are due simply to a volume conduction change associated with differences in skull or scalp thickness with age. Similarly Ford and Pfefferbaum (1991) have reported a lack of significant distributional differences between young and elderly subjects for the N100 component.

A dissociation of responses was not obtained across the sites along the electrode chains within either modality. However, a dissociation between P300 responses evoked in response to target and rare nontarget stimuli was obtained

on the basis of an asymmetry of responses across the lateral chains of electrodes. Target stimuli demonstrated an equipotential amplitude distribution along the lateral chains. Rare nontarget stimuli, however, demonstrated a significantly reduced amplitude distribution along the right in comparison to the left chain. Data from the visual modality demonstrated that each site along the right chain of electrodes demonstrated significantly less amplitude in comparison to the corresponding site along the left chain. However, within the auditory modality only the frontal and temporal sites demonstrated significantly less amplitude along the right chain in comparison to the left chain. The parietal lateral sites demonstrated an equipotential amplitude distribution.

Woods (1992) has similarly reported a change in the inter-hemispheric distribution of an endogenous component with advancing age. The MMN component demonstrated a right hemisphere predominance in a middle-aged group of subjects and a younger group of subjects reported by Paavilainen *et al.* (1991), however, within the reported elderly group of subjects a left hemisphere predominance was obtained. No age-related change was reported in exogenous components. Woods argued that the results suggested that cerebral mechanisms involved in the automatic detection of stimulus change demonstrated an age-related reduction in the right hemisphere. He went on to argue that such a reduction in right hemisphere amplitude was consistent with a decline in right hemisphere ability seen in elderly subjects in performance on tests of visuo-spatial and constructional skill.

The result that within the visual modality the P300 responses to target and rare nontarget stimuli may not be dissociable on the basis of scalp amplitude distribution suggest that the P300 responses to target and rare nontarget stimuli may be generated by the same or the same combination of underlying neural generators. However, the reduction over the right hemisphere in response to rare nontarget stimuli suggests that advancing age affects the combination of neural generators in a dissociative manner.

9.5 Modality Specificity of the P300 Complex

Early studies examining the modality specificity of the P300 complex produced contradictory and ambiguous results regarding the influence of modality upon the scalp distribution of the P300 deflection. Simson *et al.* (1977) reported that while the P300 deflection appeared to be modality nonspecific in its scalp distribution the N200 demonstrated a modality specific distribution. Squires *et al.* (1977) reported that rare visual stimuli elicited more

parietal P300 deflections in comparison to that evoked by rare auditory stimuli under certain conditions of a bimodal discrimination task. Snyder *et al.* (1980) examined P300 responses to auditory, visual and somatosensory stimuli presented near threshold. The scalp distribution demonstrated no differences between the three modalities. However, the visual stimuli evoked larger responses to those evoked by auditory and somatosensory stimuli. This result and the fact that visual P300 responses occurred later than responses in the other two modalities led Snyder *et al.* (1980) to suggest that while P300 deflections in all modalities arise from a common neural generating system the visual signals access this system in a "different fashion" from the other modalities.

Johnson (1989a; 1989b) has presented two independent lines of evidence that, he claimed, demonstrated that the generation of the P300 was modality specific. The first examined the topographical profiles comparisons based upon normalised auditory and visual data. Such comparisons revealed significant differences between auditory and visual P300 responses. Visual stimuli demonstrated a more centro-frontal amplitude distribution in comparison to that obtained from auditory stimuli.

The second line of evidence examined the response of temporal lobectomy patients to auditory and visual stimuli (Johnson 1989b). Such a comparison revealed a double dissociation in the auditory and visual P300 activity over frontal scalp. Whereas the left temporal lobectomy patients showed reduced frontal auditory P300 amplitude and normal visual P300 activity at all scalp sites the right temporal lobectomy patients demonstrated normal auditory P300s and reduced frontal visual P300s. Johnson (1989a) claims that neither the topographic data nor the patient data may be explained by the activity of a single modality independent neural generator for the P300.

Woods and Courchesne (1987) compared within and between-modality correlations of auditory and visual P300 amplitude elicited in individual subjects. They reported high positive within-modality correlations but nonsignificant between-modality correlations. Such a result is inconsistent with the activity of a single modality independent P300 generator. Complementary evidence that P300 deflections may be evoked in a modality specific manner is provided by evidence such that in adults different P300 latency/age functions have been found for P300s elicited by auditory and visual stimuli (Pfefferbaum *et al.* 1984; Picton *et al.* 1984). However, as reported no such modality specific differences were obtained for P300 latency/age functions within the present programme of research.

As pointed out by Johnson (1989b) it is apparent that some of these findings may be due to differences in the processing stages that precede the stage at which the P300 is generated. However, such an explanation is unable to explain the Woods and Courchesne (1987) findings. Similarly, within the present results such an explanation fails to account for the dissociation between target and rare nontarget P300 responses obtained within the auditory modality and the failure to obtain such a dissociation within the visual modality. Such results support the view that auditory and visual P300 deflections are elicited by separate neural generators or a different combination of underlying neural generators.

9.6 Functional Models of the P300 Complex

As stated in section 1.6.1 the four models concerned with the functional significance of the P300 each evaluate the evidence pertaining to the P300 from different theoretical standpoints. The attentional trace theory limits itself to a theoretical explanation of the P300 deflection obtained within the auditory modality, this is largely due to the failure to elicit an MMN within the visual modality (however see Johnston *et al.* 1990b below). The triarchic, context updating and context closure models treat the P300 complex as a modality nonspecific phenomenon. Variables affecting the P300 amplitude and/or scalp distribution are regarded as being consistent across both auditory and visual modalities. Each of the three models also deals almost exclusively with the P300 response to target stimuli within active oddball paradigms. However the context updating model (see section 1.5.3) does propose that a rare nontarget (P3a) response may be elicited when a cognitive task is interrupted instead of being brought to its intended closure.

Context Updating and Context Closure Models

As discussed earlier a crucial difference between the triarchic model and the context closure/context updating models is the relationship between subjective probability and task relevance. As described above subjective probability played a part in the elicitation of the P300 deflection within the present Experiments but it was not possible to determine its relationship to task relevance given the experimental design employed. However, the results obtained did permit a comparison of the context closure and context updating models. As pointed out by Verleger (1988), within the context closure model P300 deflections will occur when subjects have managed to integrate a number of items into a meaningful context (*i.e.* by the process of "closure"). One of

the main points concerning the model of context closure is the steady build up of expectancy for the target stimulus. A P300 is elicited when the expected stimulus (the target), which closes the epoch, occurs. Since the process of closing is unable to occur to the first stimulus of a row of stimuli a P300 should not be elicited to such an initial stimuli. As the same stimulus is repeatedly presented and the subject integrates the stimuli into a meaningful context, a larger P300 deflection should occur later in the presented series. It is difficult to see how novel rare nontarget stimuli would elicit a P300 deflection within the context closure model since each presentation of such a stimulus (given a heterogeneous set of novel stimuli) will be unique and hence it would not be possible to integrate such a stimulus into a meaningful context. In comparison the context updating model proposes that initial target stimuli ought to elicit a large P300 deflection since the P300 is regarded as a reflection of the process of updating (*i.e.* such initial stimuli would require updating of the model). Subsequent presentations of the stimulus would reduce the novelty effect of the stimulus and hence elicit smaller or non-existent P300 deflections. Verleger (1988) proposes that novel rare nontarget stimuli would elicit an earlier latency P300 deflection since the novel stimulus interrupts the cognitive task rather than bringing it to its intended closure. Hence novel rare nontarget stimuli would continue to elicit P300 deflections throughout the oddball paradigm. Such a result is difficult to integrate into either of the models.

The results of the visual single trial analysis which examined the amplitude of the first ten presentations of both target and rare nontarget stimuli failed to produce evidence in support of either model. Analysis of the single trial data failed to produce a main effect for trial presentation number from experiments employing either Courchesne *et al.* (1975) or Knight (1991) type stimuli for either target or rare nontarget stimuli. Such a finding indicates that amplitude neither increased nor decreased following the first presentation of the target stimuli. Each presentation of a rare nontarget stimulus evoked a P300 deflection with a consistent amplitude over the first ten presentations. Results of analyses performed upon auditory single trial data similarly failed to demonstrate a significant main effect of trial presentation number.

Attentional Trace Model

As outlined in section 1.542 the mismatch negativity (MMN) component is thought to reflect the detection of a mismatch between a presented stimulus and the hypothesised contents of a sensory memory. As such the generator responsible for the generation of the MMN may be thought to act as a deviance

or novelty detector (Näätänen 1990). The MMN forms a fundamental component of the attentional trace theory proposed by Näätänen (1990; 1992). It is suggested that the MMN and P3a components are related to physical stimulus deviation but not to stimulus significance. Näätänen (1990; 1992) proposed that the P3a may reflect an attentional switch to an environmental change encoded by the cerebral process generating the MMN. The limiting of the attentional trace theory to audition is largely due to the failure to elicit an MMN within the visual modality.

Czigler and Csibra (1990) failed to obtain a visual analogue of the auditory MMN. As described in section 7.5 Alho *et al.* (1992) and Woods *et al.* (1992) reported "deviance-related negativities" with certain characteristics in common with an auditory MMN. However, it was not possible for either study to categorically claim that the deviance-related negativities corresponded to a visual MMN and not simply a composite of the N2b and MMN (N2a) components as well as other possible occipital negativity (see section 1.5.4.3) deflections. The failure to elicit a MMN within the visual modality is suggestive that underlying neural mechanisms automatically process auditory and visual stimuli differentially. Therefore, the possibility arises that later processing of visual and auditory stimuli (as indexed by the P300 deflection) is performed by modality specific generators as well. Such modality specific processing presumably employs a unique combination of underlying neural generators whose outputs are manifested as modality specific amplitude distributions across the scalp.

Within the experiments reported it was not possible to directly measure any possible MMN elicited in response to auditory rare nontarget stimuli or any possible MMN that may have been elicited in response to visual rare nontarget stimuli since the paradigms employed were active oddball tasks. Such tasks require subjects to attend to each sequentially presented stimulus in order to make a discriminative analysis, within such a paradigm the latter part of the MMN may be influenced by the N2b component which is elicited when stimulus deviation is great. It is, therefore, difficult to dissociate the MMN component elicited in response to rare nontarget stimuli and the observed N2b component elicited in response to target stimuli.

However, Johnston *et al.* (1990a; 1990b) questioned Näätänen 's assertion that a process analogous to the MMN does not occur in vision. Johnston *et al.* (1990b) argued that the study of visual attention has concentrated upon what may be called "directed attention". They pointed out that within experimental visual attention experiments subjects are instructed to either look for

prespecified targets (target-detection) or to look at prespecified locations (focused attention). However, attention often is relatively diffuse, or non-directed, initially but is captured suddenly by certain stimuli. Johnston *et al.* (1990b) sought to investigate attention by examining what stimuli happen to "pop out" from a brief non-directed glance at a scene. In particular they examined the possible automatic capture of attention by novel stimuli *i.e.* by stimuli that are unlikely to occur in a particular context.

The general question examined by Johnston *et al.* (1990b) was when subjects have only a glimpse of an array composed of a single unexpected stimulus and several expected stimuli, how likely is the unexpected stimulus to be seen? Johnston *et al.* (1990b) proposed two possibilities. In the first, attention tends to be captured by the unexpected stimulus, making it relatively likely to be seen and yielding what Johnston *et al.* have referred to as "novel popout". The second possibility is that attention tends to be captured by and apportioned among the expected stimuli, making the unexpected stimulus relatively unlikely to be seen and yielding so-called "novel sink-in". Novel popout appears to have a great deal of survival value because it renders organisms sensitive to unexpected intrusions into their familiar surroundings.

Research on the orienting reflex and exploratory behaviour established that unexpected objects elicit arousal and investigatory activity in animals (for example Berlyne 1960; Sokolov 1963). When confronted with two visual patterns, one novel and one familiar, human infants tend to fixate more on the novel pattern (Fantz 1964). Studies of overt and nondirected scanning of naturalistic scenes by adults indicate that unexpected, or incongruent, objects (for example an octopus in a barnyard scene) are looked at longer than are expected, or congruent, objects and perhaps earlier and more frequently (for example Friedman 1979; Loftus and Mackworth 1978). However, the scenes used were visible for at least several seconds. Therefore, it is not clear that the results reflect the immediate and automatic seizure of attention by the novel objects. Rather than having their attention instantly captured by novel objects, subjects may have encountered these objects somewhat late in their initial perusal of the scenes and only then directed their full attention to them.

Johnston *et al.* (1990b) had subjects view a long series of four word arrays. Backward masking was used to limit viewing time for an array to only 200 msec, which prevented any overt scanning of array locations. Shortly after an array was provided the subject was shown one of the four words and asked to indicate the array location the word had occupied. Localisation accuracy was the dependent variable. Some of the words (familiar) appeared in hundreds of

the arrays in the series. Other words (novel) appeared in just one array. The ratio of novel to familiar words (N:F) in an array was the main independent variable. Different ratios were randomly intermixed across the series so that subjects could not anticipate the N:F ratio for any of the arrays. Novel popout effect was observed in 1:3 arrays, *i.e.* when a single word was arrayed with three familiar words localisation accuracy was reliably higher for the novel word than for the familiar word.

Johnston *et al.* (1990b) point out that novel popout is not attributable to figure-ground contrast or stimulus conspicuity because a complementary familiar-popout did not emerge in 3:1 arrays. The effect is also not caused by perceptual satiation, or refractoriness, of familiar words, because localisation accuracy was substantially higher in 0:4 (all-familiar) arrays than in 4:0 (all-novel) arrays. Novel popout is not evident in 3:1 arrays because the three novel words compete for the attention released from the one familiar word.

Johnston *et al.* (1990a) propose novel popout as a visual analog of rapid detection (indicated by MMN) and spontaneous orientation of attention (indicated by P3a) to irregularities in otherwise regular and predictable auditory sequences. They propose that visual popout and auditory deviance detection are based on similar, or even the same, underlying mechanisms. However, no ERP data was collected within this study it is therefore not possible to determine the underlying ERP response to the phenomenon of visual popout. Sereno (1990) similarly suggests that a visual phenomenon analagous to the auditory MMN process with sequential stimuli occurs with parallel (standard and deviant) stimuli. (See also Cammann (1990) and Ciesielski (1990) who have presented preliminary results that may indicate the existence of a visual MMN). However, at the present time there is no direct ERP evidence that such phenomena are analogous to the auditory MMN component (see section 9.7 below on the N200 deflection).

9.7 Other ERP Components Measured

N100 Deflection As previously discussed (see section 3.7.2) Näätänen (1992) has claimed that only visual spatial attention appears to be associated with enhanced components within the latency range of the N100 ERP. He claimed that when relevant and irrelevant stimuli occurred within the same locus attentional selection was predominantly associated with slow negativities. The review of ERP studies pertaining to the N100 ERP by Näätänen and

Picton (1987) dealt almost exclusively with studies carried out within the auditory modality. The modality specificity of the points made by Näätänen and Picton, in particular the scalp distribution and the refractoriness, of the N100 ERP is therefore uncertain at present. In view of this it is difficult to determine the functional significance of the ERP component elicited within the latency range of the N100 component. However, the functional significance of amplitude changes elicited between 150 - 350 msec at lateral parietal sites will be discussed (see below).

N200 Deflection

Stimuli with a greater physical contrast to frequent stimuli demonstrate a more anterior maximum scalp amplitude distribution, such an effect was demonstrated within experiment 5. Regardless of the task demands stimuli with a greater physical contrast to frequent stimuli demonstrate a more anterior scalp amplitude distribution. Both Alho *et al.* (1990) and Näätänen *et al.* (1982) have demonstrated that the N2b component may be elicited by both target and nontarget deviant stimuli in one channel tasks.

As previously described such an elicitation of an N200 deflection in response to the physical deviance of a class of stimuli may correspond to the MMN component reported within the auditory modality. However, as outlined previously due to the nature of the cognitive task employed (oddball paradigm) it was not possible to determine whether the N200 deflection elicited within any particular experiment was predominantly formed from an N2b or MMN(N2a) component or was rather a composite of these two components.

Alho *et al.* (1992) has also demonstrated that visual deviants elicited so-called deviance-related negativities. While such visual MMN/N2b negativities had a number of characteristics in common with an auditory MMN, for instance a right hemisphere amplitude predominance and the fact that the auditory MMN and visual MMN/N2b was not affected by the processing load during attention to the other modality, they did differ in a number of respects. Deviant visual stimuli physically close to the standards failed to evoke a MMN/N2b at all, this was not the case in the auditory modality (Sams *et al.* 1985). Näätänen (1990) claims that the visual MMN/N2b may be sensitive to changes in only certain stimulus features whereas the auditory MMN is elicited by a large variety of physical changes (see section 7.5 for a more extensive discussion).

Slow Wave Deflections

A number of reports have described slowly varying long-duration ERP components whose amplitudes relate directly to task demands. Stuss and Picton (1978) and Kok and de Jong (1980) for instance demonstrated that slow wave activity became more apparent when the task required greater processing on the part of the subject. These so-called "slow waves" may be observed in the epoch following the target related P300 deflection, such an observation suggests that such deflections reflect the further processing involved by increasing task demands. Slow wave activity has been found in a variety of tasks (Ruchkin *et al.* 1988; for a review see Ruchkin and Sutton 1983). The amplitude of slow waves is inversely related to event probability. As demonstrated in Chapter 6, stimuli with the same task demands and stimulus characteristics evoked slow waves with greater amplitude within procedures that had lower event probabilities in comparison to those evoked within procedures which demonstrated equiprobable event probabilities.

Topographical differences suggest that slow wave activity reflects the nature of additional processing in the sense that different tasks may involve different neural generators. Ruchkin *et al.* (1988) suggested that negative slow waves may be associated with scanning and mental imagery while positive slow waves with memory storage, rule learning and perceptual operations. As outlined in section 7.5 target stimuli demonstrated a more positive posterior maximum amplitude distribution in comparison to that demonstrated in response to either frequent or rare nontarget stimuli. Such a result indicates that activity within this latency range demonstrates task relevance characteristics in contrast to stimulus characteristics.

Lateral Parietal Differences between 150 - 350 msec

Within each of the Experiments employing visual stimuli, rare nontarget stimuli demonstrated greater mean amplitude in the 150 - 350 msec latency range in comparison to both target and frequent stimuli at lateral parietal sites. As previously described (see section 3.72) such an observation supports Wijers *et al.* (1989a; 1989b) that ERPs evoked by attended stimuli show a prolonged negative shift compared to ERPs to unattended stimuli if the two classes (attended and unattended) can be discriminated on the basis of simple physical attributes (selection cues).

Similarly Näätänen (1992) argues that when relevant and irrelevant stimuli occur in the same spatial locus (or cannot be discriminated on the basis of the spatial cue) attentional selection is predominantly associated with slow

negativities. According to Harter and Aine (1984) selection negativities are due to the efferent facilitation of neuronal populations that represent the attended stimulus dimension.

Harter and Aine (1984; 1986) claim that there are as many selection negativities as there are functionally distinct neural aggregates involved in the processing of the relevant stimulus. They claim "if the activity of a neurone, with a receptive field organisation that makes it respond selectively to a specific type of stimulation, is considered to be an internal representation of that information then such representations are located throughout the sensory projection system" (pp. 316), and not only in the secondary sensory areas of the cortex. Such a view does not rule out the attentional trace concept proposed by Näätänen (1990; 1992) as far as the attentional trace is an internal representation of a specific feature of the attended stimulus. The neural specificity theory proposes that there can be as many attentional traces as there are functionally distinct neural populations involved in the processing of the attended stimulus.

As demonstrated the difference between target and rare nontarget responses within a latency range of 150 - 350 msec would appear to depend upon the physical deviance of the rare nontarget stimuli in comparison to the target stimuli. Within Chapter 5 it was demonstrated that regardless of the spatial location of the rare nontarget stimuli no difference was obtained in the 150 - 350 msec latency range when the physical characteristics of the three classes of stimuli were similar (all stimuli consisted of single line triangles). However, employing triangles with fragmented contours resulted in an observable difference in mean amplitude at lateral parietal sites between the mean amplitude evoked in response to rare nontarget stimuli and that to target stimuli. Similarly within Chapter 7 the physical characteristics of the rare stimuli rather than their task relevant characteristics (target or nontarget stimuli) appeared to determine the relative mean amplitude evoked by the two classes of stimuli (see section 7.5 for an alternative explanation of the observed difference in mean amplitude evoked within the target heterogeneous procedure).

Harter and Aine (1984) have related such occipital negative waves to the processing negativity components of auditory selective attention experiments. They state that "selection negativity is a measure of the relative increase in the neural response to a stimulus when it does versus when it does not have specified features in common with the relevant stimulus.....It may reflect

enhanced responsiveness to the relevant information and/or suppressed responsiveness to irrelevant information" (pp. 313).

9.8 Conclusion

The results reported here support the view that the underlying neural generators responsible for the generation of the P300 complex are modality specific. The results add to the growing body of evidence which argues against the idea that there is a single, modality independent neural generator for the P300 complex. It was not possible to produce a visual paradigm analogous to the auditory three stimulus oddball paradigm that was able to dissociate the target and rare nontarget P300 responses on the basis of scalp amplitude distribution.

It appears that a similar combination of neural generators is responsible for the P300 deflection elicited in response to target and rare nontarget stimuli within the visual modality. However, factors such as stimulus complexity and task relevance may alter the relative output of such generators in response to each type of stimulus. Across modalities advancing age affected the hemispheric distribution of rare P300 responses in a similar manner. Target stimuli evoked a response that was distributed symmetrically across the lateral chains. However, rare nontarget stimuli evoked a response that demonstrated greater amplitude distribution along the left chain in comparison to the right. Such a result demonstrates that while the generation of the P300 complex may be modality specific, aging affects the neural generators responsible for the P300 response in a similar manner. With advancing age the output from the underlying combination of generators becomes flatter across the scalp within both modalities.

Similarly it did not prove possible to determine the scalp amplitude distribution (and hence possible combination of generators) responsible for the target and rare nontarget responses within the N200 latency range. It is likely a composite N200 deflection (made up of a combination of MMN(N2a) and N2b components) is elicited within active oddball paradigms. However, within latency windows of 500 - 850 msec (so called slow wave activity) and one between 150 - 350 msec at lateral parietal sites (so called occipital or selection negativities) the responses to target and rare nontarget stimuli were dissociable demonstrating that within these portions of the waveform unique combinations of neural generators are responsible for the generation of target and rare nontarget effects.

9.9 Future Developments

The development of passive conditions in visual paradigms would enable the N2b and N2a (MMN) components to be accurately measured and dissociated. Such a paradigm would determine whether an MMN may be elicited within the visual modality.

The rare nontarget P300 hemispheric asymmetry demonstrated within both the auditory and visual paradigms within the elderly group of subjects is of potential significance for the study of age related changes in information processing and its neural basis, and for the localisation of the source(s) of the P3a. Such asymmetries may be usefully examined employing a combination of ERP and imaging techniques (for instance SPECT or functional MRI) as a means of maximising both temporal and spatial resolution.

Future studies are needed to examine the effects of age upon the P300 latency and reaction time across tasks of increasing complexity. Such data would be useful to fractionate the contributions of peripheral and central mechanisms to the slowed processing accompanying aging (Iragui *et al.* 1993).

References

- Adam, N. and Collins, G.I. (1978). Late components of the visual evoked potential to search in short-term memory. *Electroencephalography and Clinical Neurophysiology*, 44, 147-156.
- Albert, M.S., Wolfe, J. and Lafleche, G. (1990). Differences in abstraction ability with age. *Psychology and Aging*, 5, 94 - 100.
- Alho, K., Lavikainen, J., Reinikainen, K., Sams, M. and Näätänen, R. (1990). Event-related brain potentials in selective listening to frequent and rare stimuli. *Psychophysiology*, 27, 73-87.
- Alho, K., Woods, D.L., Algazi, A. and Näätänen, R. (1992). Intermodal selective attention II. Effects of attentional load on processing of auditory and visual stimuli in central space. *Electroencephalography and Clinical Neurophysiology*, 82, 356-368.
- Barrett, G., Neshige, R. and Shibasaki, H. (1987). Human auditory and somatosensory event-related potentials: effects of response condition and age. *Electroencephalography and Clinical Neurophysiology*, 66, 409-419.
- Bashore, T.R. (1990). Age-related changes in mental processing revealed by analyses of event-related potentials. (In) Rohrbaugh, J.W., Parasuraman, R. and Johnson, R. (Eds.), *Event-related brain potentials. Basic issues and applications* (pp. 242-275). New York: Oxford University Press.
- Bashore, T.R., Osman, A. and Heffley, E.F., (1989). Mental slowing in elderly persons: A cognitive psychophysiological analysis. *Psychology and Aging*, 4, 235-244.
- Beck, E.C., Swanson, C. and Dustman, R.E. (1980). Long latency components of the visually evoked potential in man: effects of aging. *Experimental Aging Research*, 6, 523-545.
- Becker, D.E. and Shapiro, D. (1980). Directing attention toward stimuli affects the P300 but not the orienting response. *Psychophysiology*, 17, 385-389.

- Begleiter, H. Porlesz, B. Chou, C.L. and Aunon, J.I. (1983). P3 and stimulus incentive value. *Psychophysiology*, 20, 95-101.
- Berlyne, D.E. (1960). *Conflict, arousal, and curiosity*. New York: McGraw-Hill.
- Bergen, J.R. and Julesz, B. (1983). Parallel versus serial processing in rapid pattern discrimination. *Nature (London)*, 303, 696 - 698.
- Birnbaum, I. M., Taylor, T.H., Johnson, M.K. and Raye, C.L. (1987). Is event frequency encoded automatically? The case of alcohol intoxication. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 13, 251 - 258.
- Brandies, D. and Lehmann, D. (1986). Event-related potentials of the brain and cognitive processes: approaches and applications. *Neuropsychologia*, 24, 151-168.
- Brown, W.S., Marsh, J.T. and LaRue, A. (1983). Exponential electrophysiological aging: P3 latency. *Electroencephalography and Clinical Neurophysiology*, 55, 277-285.
- Cammann, R. (1990). Is there a mismatch negativity (MMN) in the visual modality. *Behavioural and Brain Sciences*, 13, 234-235.
- Campbell, K.B., Courchesne, E., Picton, T.W. and Squires, K.C. (1979). Evoked potential correlates of human information processing. *Biological Psychology*, 8, 45-68.
- Ciesielski, K.T. (1990). Variability, gnostic units and N2. *Behavioural and Brain Sciences*, 13, 236-237.
- Cooper, R., Osselton, J.W. and Shaw, J.C. (1980). *EEG Technology*. Butterworths.
- Courchesne, E. (1977). Event related brain potentials: comparison between children and adults. *Science*, 197, 589-592.
- Courchesne, E. (1978). Changes in P3 waves with event repetition: long-term effects on scalp distribution and amplitude. *Electroencephalography and Clinical Neurophysiology*, 45, 754-766.

- Courchesne, E., Courchesne, R.Y. and Hillyard, S.A. (1978). The effect of stimulus deviation on P3 waves to easily recognized stimuli. *Neuropsychologia*, 16, 189-199.
- Courchesne, E., Hillyard, S.A. and Courchesne, R.Y. (1977). P3 waves to the discrimination of targets in homogenous and heterogenous stimulus sequences. *Psychophysiology*, 14, 590-598.
- Courchesne, E., Hillyard, S.A. and Galambos, R. (1975). Stimulus novelty. Task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, 39, 131-143.
- Cowan, N. (1984). On short and long auditory stores. *Psychological Bulletin*, 96, 341-370.
- Craik, F.I.M., Morris, L.W., Morris, R.G. and Loewen, E.R. (1990). Relations between source amnesia and frontal lobe functioning in older adults. *Psychology and Aging*, 5, 148 - 151.
- Czigler, I. (1990). Is the attentional trace theory modality specific. *Behavioral and Brain Sciences*, 13, 238-239.
- Czigler, I. and Csibra, G. (1990). Event-related potentials in a visual discrimination task: negative waves related to detection and attention. *Psychophysiology*, 27, 669-676
- Czigler, I. and Csibra, G. (1992). Event related potentials and the identification of deviant visual stimuli. *Psychophysiology*, 29, 471-485.
- Dawson, G.D. (1951). A summation technique for detecting small signals in a large irregular background. *Journal of Physiology*, 115, 2P-3P.
- Desmedt, J.E. (1988). Somatosensory evoked potentials. (In) Picton, T.W. (Ed.), *Human event-related potentials. Handbook of electroencephalography and clinical neurophysiology* (Vol. 3, pp. 245-360) Amsterdam: Elsevier.
- Desmedt, J.E. and Debecker, J. (1979). Waveform and neural mechanism of the decision P350 elicited with pre-stimulus CNV or readiness potential in random sequences of near threshold auditory clicks and finger stimuli. *Electroencephalography and Clinical Neurophysiology*, 47, 648-670.

- Donchin, E. (1979). Event related brain potentials: a tool in the study of human information processing. In Begleiter, H. (Ed). *Evoked Brain Potentials and Behaviour*. New York: Plenum Press.
- Donchin, E. (1981). Surprise!.....Surprise? *Psychophysiology*, 18, 493-513.
- Donchin, E. and Coles, M.G.H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, 11, 357-374.
- Donchin, E. and Heffley, E.F. (1978). Multivariate analysis of event related potential data: A tutorial review. (In) Otto, D.A. (Ed.). *sis of event related potential data: A tutorial rsis of event related posis of event related potential data: A tutorial review. (In) Otto, Dsis of event related potential datasis of event related potential data: A tutorial sis of event relatededsis of eventsis of event related potential data: A tutoriasis of event related potential data: A tutorial review. (In) Otto, D.A. (Ed.). Multidisciplinarsis of event relatededsis of eventssis of event related potential data: A tutorial review. (In) Otto, D.A. (Ed.). Multidisciplinary perspectives in event-related ssing. *Biological Psychology*, 14, 1-52.*
- Ericksen, C.W. and Schultz, D.W. (1978). Temporal factors in visual information processing: A tutorial review. (In) Reguin, J. (Ed.). *Attentional Performance vol 7*. Lawrence Erlbaum Associates.
- Fabiani, M., Gratton, G., Karis, D. and Donchin, E. (1987). Definition, identification, and reliability of measurement of the P300 component of the event related brain potential. (In). Ackles, P.K., Jennings, J.R. and Coles, M.G.H. (Eds.). *Advances in Psychophysiology Volume 2*. Greenwich, Connecticut: JAI Press.
- Fantz, R.L. (1964). Visual experience in infants: decreased attention to familiar patterns relative to novel ones. *Science*, 146, 668-670.
- Ford, J.M. and Pfefferbaum, A. (1980). The utility of brain potentials in determining age-related changes in central nervous system and cognitive functioning. (In) Poon, L.W. (Ed.). *Aging in the 1980s* (pp. 115-124). Washington D.C: American Psychological Association.
- Ford, J.M. and Pfefferbaum, A. (1985). Age-related changes in ERPs. (In) Ackles, P.K., J.R. Jennings, J.R. and Coles, M.G.H. (Eds.), *Advances in Psychophysiology* (pp. 301-339). Greenwich, CT: JAI Press.

- Ford, J.M. and Pfefferbaum, A. (1991). Event-related potentials and eye blink responses in automatic and controlled processing; effects of age. *Electroencephalography and Clinical Neurophysiology*, 78, 361-377.
- Ford, J.M., Roth, W.T. and Kopell, B.S. (1976). Auditory evoked potentials to unpredictable shifts in pitch. *Psychophysiology*, 13, 32-39.
- Ford, J.M., Roth, W.T., Mohs, R.C., Hopkins, W.F. and Kopell, B.S. (1979). Event related potentials recorded from young and old adults during a memory retrieval task. *Electroencephalography and Clinical Neurophysiology*, 47, 450-459.
- Friedman, A. (1979). Framing pictures: the role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General*, 108, 316-355.
- Friedman, A., Hakerem, G., Sutton, S. and Fleiss, J.L. (1973). Effect of stimulus uncertainty on the pupillary dilation response and the vertex evoked potential. *Electroencephalography and Clinical Neurophysiology*, 34, 475-484.
- Friedman, D., Putman, L. and Sutton, S. (1989). Event-related potentials in children, young adults and senior citizens: homologous components and scalp distribution changes. *Developmental Neuropsychology*, 5, 33.
- Friedman, D., Simpson, G. and Hamberger, M. (1993). Age-related changes in scalp topography to novel and target stimuli. *Psychophysiology*, 30, 383-396.
- Friedman, D., Vaughan, H.G. and Erlenmeyer-Kimling, L. (1981). Multiple late positive potentials in two visual discrimination tasks. *Psychophysiology*, 18, 635-650.
- Goff, W.R. (1974). Human Average Evoked Potentials: Procedures for Stimulating and Recording. (In) Thompson, R.F. and Patterson, M.M. (Eds.). *Bioelectric Recording Techniques Part B: Electroencephalography and Human Brain Potentials*. New York: Academic Press.

- Goodin, D.S., Squires, K.C., Henderson, B.H. and Starr, A. (1978). Age-related variations in evoked potentials to auditory stimuli in normal human subjects. *Electroencephalography and Clinical Neurophysiology*, 44, 447-458.
- Gomer, F.E., Spicuzza, R.J. and O'Donnell, R.D. (1976). Evoked potential correlates of visual item recognition during memory scanning tasks. *Physiology Psychology*, 4, 61-65.
- Graham, F.K. (1973). Habituation and dishabituation of responses innervated by the autonomic nervous system. (In) Peeke, H.V.S. and Hertz, M.J. (Eds.). *Habituation; Vol I Behavioural Studies*. (pp. 163-218). London: Academic Press.
- Gratton, G., Coles, M.G.H. and Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, 55, 468-484.
- Gulrajani, R.M., Roberge, F.A., and Savard, P. (1984). Moving dipole inverse ECG and EEG solutions. *IEEE Trans Biomed. Eng.* BME-31: 903-910.
- Haaland, K.Y., Vranes, L.F., Goodwin, J.S. and Garry, P.J. (1987). Wisconsin Card Sort Test performance in a healthy elderly population. *Journal of Gerontology*, 42, 345 - 346.
- Haber, R.N. (1983). The impending demise of the icon: A critique of the concept of iconic storage in visual information processing. *Behavioural and Brain Sciences*, 6, 1-54.
- Halliday, A.M. (1982). *Evoked potentials in clinical testing*. London: Churchill Livingstone.
- Hansen, J.C. and Hillyard, S.A. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalography and Clinical Neurophysiology*, 49, 277-290.
- Hansen, J.C. and Hillyard, S.A. (1984). Effects of stimulation rate and attribute cuing on event-related potentials during auditory attention. *Journal of Experimental Psychology: Human Perception and Performance*, 9, 1-19.

- Harter, M.R. and Aine, C.J. (1984). Brain mechanisms of visual selective attention. In: Parasuraman, R. and Davies, D.R. (Eds.), *Varieties of attention* (pp. 293 - 321). London: Academic press.
- Harter, M.R. and Aine, C.J. (1986). Discussion of neural specificity model of selective attention: A response to Hillyard and Mangun and to Näätänen. *Biological Psychology*, 26, 404 - 421.
- Harter, M.R. and Guido, W. (1980). Attention to pattern orientation: Negative cortical potentials, reaction time, and the selection process. *Electroencephalography and Clinical Neurophysiology*, 49, 461-475.
- Harter, M.R. and Previc, M.R. (1978). Size-specific information channels and selective attention: visual evoked potential and behavioural measures. *Electroencephalography and Clinical Neurophysiology*, 45, 628-640.
- Hasher, L. and Zacks, R.T. (1984). Automatic processing of fundamental information: The case of frequency of occurrence. *American Psychologist*, 39, 1372 - 1388.
- Hillyard, S.A., Courchesne, E., Krausz, H.I. and Picton, T.W. (1976). Scalp topography of the P3 wave in different auditory decision tasks. (In) McCallum, W.C. and Knott, J.R. (Eds.). *The Responsive Brain*. Bristol: John Wright and Sons.
- Hillyard, S.A. and Picton, T.W. (1987). Electrophysiology of cognition. In: Plum, F. (Ed). *Handbook of Physiology*. American Physiological Society. Baltimore.
- Hillyard, S.A., Hinh, R.F., Schwent, V.L. and Picton, T.W. (1973). Electrical signs of selective attention in the human brain. *Science*, 182, 177-180.
- Hillyard, S.A. and Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Review of Psychology*, 34, 33-61.
- Hillyard, S.A. and Munte, T.F. (1984). Selective attention to color and location: an analysis with event-related brain potentials. *Perception and Psychophysics*, 36, 185-198.
- Holdstock, J.S. (1992). *The orienting of auditory attention: event related potential investigations*. Unpublished PhD Thesis. St Andrews University Library: St Andrews.

- Holdstock, J.S. and Rugg, M.D. (1993). Dissociation of auditory P300: Differential brain responses to target and rare non-target stimuli. (In) Heinze, H.J., Munte, T.F and Mangun, G.R (Eds). *New Developments in Event-Related Potentials*. Boston: Birkhauser, pp. 71-78.
- Horst, R.L., Johnson, R. and Donchin E. (1980). Event related brain potentials and subjective probability in a learning task. *Memory and Cognition*, 8, 476-488.
- Iragui, V.J., Kutas, M., Mitchiner, M.R. and Hillyard, S.A. (1993). Effects of aging on event-related brain potentials and reaction times in an auditory oddball task. *Psychophysiology*, 30, 10-22.
- Jasper, H.H. (1958). The ten twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, 10, 371-375.
- Johnson, R. Jr. (1986). A triarchic model of P300 amplitude. *Psychophysiology*, 23, 367-384.
- Johnson, R. Jr. (1988). The amplitude of the P300 component of the event-related potential: Review and synthesis. (In) Ackles, P.K. Jennings, J.R. and Coles, M.G.H. (Eds.). *Advances in Psychophysiology* (VolIII, pp. 69-137). Greenwich, CT: Jai Press.
- Johnson, R. Jr. (1989a). Auditory and visual P300s in temporal lobectomy patients; evidence for modality-dependent generators. *Psychophysiology*, 26, 633-650.
- Johnson, R. Jr. (1989b). Developmental evidence for modality-dependent P300 generators: A normative study. *Psychophysiology*, 26, 651-667.
- Johnson, R. Jr. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, 30, 90-97.
- Johnson, R. Jr. and Donchin, E. (1978). On how P300 amplitude varies with the utility of the eliciting stimuli. *Electroencephalography and Clinical Neurophysiology*, 44, 424-437.
- Johnson, R. and Donchin, E. (1980). P300 and stimulus categorisation: Two plus one is not so different from one plus one. *Psychophysiology*, 17, 167-178.

- Johnson, W.A. and Hawley, K.J. (1990a). Novel popout in vision. *Behavioural and Brain Sciences*, 13, 244 - 245.
- Johnson, W.A., Hawley, K.J., Plewe, S.H., Elliot, J.M.G. and DeWitt, M.J. (1990b). Attention capture by novel stimuli. *Journal of Experimental Psychology: General*, 119, 397-411.
- Johnson, R., Pfefferbaum, A. and Kopell, B.S. (1985). P300 and long term memory: latency predicts recognition performance. *Psychophysiology*, 22, 497-507.
- Jonides, J. and Noveh-Benjamin, M. (1987). Estimating frequency of occurrence. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 13, 230 - 240.
- Karlin, L. and Martz, M.J. (1973). Response probability and sensory potentials. (In) Kornblum, S. (Ed.). *Attention and performance IV*. Academic Press.
- Karlin, L., Martz, M.J., Brauth, S. and Mordkoff, A.M. (1971). Auditory evoked potentials, motor potentials and reaction time. *Electroencephalography and Clinical Neurophysiology*, 31, 129-136.
- Karlin, L., Martz, M.J. and Mordkoff, A.M. (1970). Motor performance and sensory-evoked potentials. *Electroencephalography and Clinical Neurophysiology*, 28, 307-313.
- Karis, D., Fabiani, M. and Donchin, E. (1984). "P300" and memory: individual differences in the von Restorff effect. *Cognitive Psychology*, 16, 177-216.
- Kemper, T. (1984). Neuroanatomical and neuropathological changes in normal aging and in dementia. (In) Albert, M.L. (Ed.), *Clinical neurology of aging* (pp. 9-52). New York: Oxford University Press.
- Keselman, H.J. and Rogan, J.C. (1980). Repeated measures F tests and psychophysiological research: controlling the number of false positivies. *Psychophysiology*, 17, 499-503.
- Knight, R.T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology*, 59, 9-20.

- Knight, R.T. (1990). Neural mechanisms of event related potentials: Evidence from human lesion studies. (In) Rohrbaugh, J.W., Johnson, R., and Parasuraman, R. (Eds.) *Event -Related potentials: Issues and Interdisciplinary Vantages*. Oxford Press: New York
- Knight, R.T. (1991). Evoked potential studies of attention capacity in human frontal lobe lesions. (In) Vevin, H.S., Eisenberg, H.M., and Benton, A.L. (Eds.) *Frontal Lobe Function and Dysfunction*. Oxford: Oxford University Press.
- Knight, R.T., Hillyard, S.A., Woods, D.L. and Neville, H.J. (1980). The effects of frontal and temporal-parietal lesions on the auditory evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, 50, 112-124.
- Knight, R.T., Scabini, D., Woods, D.I. and Clayworth, C.C. (1987). Differential effects of parietal and temporo-parietal lesions on human N200 and P300. *Society Neuroscience Abstracts*, 22, 521
- Knight, R.T., Scabini, D., Woods, D.L. and Clayworth, C.C. (1989). Contributions of temporal-parietal junction to the human auditory P3. *Brain Research*, 502, 109-116.
- Kok, A. and Looren de Jong, H. (1980). The effect of repetition of infrequent familiar and unfamiliar visual patterns on components of the event-related brain potential. *Biological Psychology*, 10, 167-188.
- Kutas, M. and Donchin, E. (1977a). The effect of handedness, responding hand and reponse force on the contralateral dominance of the readiness potential. *Progress Clinical Neurophysiology*, 1, 189.
- Kutas, M. and Donchin, E. (1977b). Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science*, 197, 792-795.
- Lindsley, D.B. and Wicke, J.D. (1974). The electroencephalogram: autonomous electrical activity in man and animals. (In) *Bioelectric recording techniques. Part B EEG and Human Brain Potentials*. New York: Academic Press.
- Loveless, N. (1983). The orienting response and evoked potentials in man. (In) Siddle, D. (Ed.). *Orienting and Habituation: Perspectives in Human Research*. (pp.71-107). John Wiley and Sons Limited.

- Luria, A.R. (1973). *The working brain: an introduction to neuropsychology*. New York: Basic.
- Lutxenberger, W., Schandry, R. and Birbaumer, N. (1983). Habituation of the components of the AEP to stimuli of different intensities. (In) Kimmel, H.D., van Olst, E.H. and Orlebeke, J.F. (Eds.) *The Orienting Reflex in Humans*, Erlbaum
- Matsuo, F., Peters, J.F. and Reilly, E.L. (1975). Electrical phenomena associated with movements of the eyelid. *Electroencephalography and Clinical Neurophysiology*, 38, 507 - 511.
- MacLeod, C. and Dunbar, K. (1988). Training and strooplike interference: evidence of a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 14, 126 - 135.
- Magliero, A., Bashore, T.R., Coles, M.G.H. and Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology*, 21, 171-186.
- McCarthy, G. and Donchin, E. (1981). A metric for thought: a comparison of P300 latency and reaction time. *Science*, 211, 77-80.
- McCarthy, G. and Wood, C.C. (1985). Scalp distribution of event related potentials: an ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, 62, 203-208.
- Megela, A.I. and Teyler, T.J. (1979). Habituation and the human evoked potential. *Journal of Comparative and Physiological Psychology*, 93, 1154-1170.
- Mullis, R.J., Holcomb, P.J., Diner, B.C. and Dykman R.A. (1985). The effects of aging on the P3 component of the visual event-related potential. *Electroencephalography and Clinical Neurophysiology*, 62, 141-149.
- Näätänen, R. (1982). Processing negativity: an evoked-potential reflection of selective attention. *Psychological Bulletin*, 92, 605-640.
- Näätänen, R. (1984). In search of a short duration memory trace of a stimulus in human brain. (In) Pulkkinen, L. and Lyytinen, P. (Eds.). *Essays in honour of Marti Takula. Jyväskylä studies in education, psychology and social science*. (pp. 22-36). Helsinki: University of Jyväskylä Press.

- Näätänen, R. (1985). Selective attention and stimulus processing: Reflections in event-related potentials, magnetoencephalogram, and regional cerebral blood flow. (In) Posner M.I. and Marin O.S. (Eds.) *logram, and regional cerebralogram, and regionalallogram, and regional lologram, and regional cerebral blood flow.* (In) Posner M.I. and Marin O.S. (Eds.) *Attention and plogram, anlogram, and regionallogram, and lologram, and regional cerebral blood flow.* (In) Posner M.I. and Marin O.S. (Eds.) *Attention and logram, and regional cerebral blood flow.* (In) Posner M.I. and Marin O.S. *Slogram, and regional cerebral blologram, and lologram, alogram, and logram, and regional cerebralogram, and regional cerebral blood flow.* (In) Posner M.I. *logram, and regional cerebral bK.* (1983). The orienting reflex and the N2 deflection of the event-related potential (ERP). (In) Gaillard A. W. K. and Ritter W. (Eds.). *Tutorials in ERP research: Endogenous components.* North-Holland.
- Näätänen, R. and Michie, P.T. (1979). Early selective attention effects on evoked potential, a critical review and reinterpretation. *Biological Psychology, 8*, 81 - 136.
- Näätänen, R. and Picton, T.W. (1982). N2 and automatic versus controlled processes. (In) McCallum W.C., Zapolli R. and Denoth I. (Eds.), *Electroencephalography and Clinical Neurophysiology, Supplement 30: Cerebral psychophysiology: Studies in event-related potentials* (pp. 64-158). Amsterdam: Elsevier.
- Näätänen, R. and Picton, T.W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*, 375-417.
- Näätänen, R., Gaillard, A.W.K. and Mantysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychologica, 42*, 313-329.
- Näätänen, R., Sams, M.M and Alho, K. (1986). Mismatch negativity: an ERP sign of a cerebral mismatch process. (In) MacCallum, W.C., Zappoli, R. and Denoth, F. (Eds.). *Cerebral psychophysiology studies in event related potentials.* (pp. 174-180). *Supplement 38 to Electroencephalography and Clinical Neurophysiology, 69*, 523-531.

- Neisser, V. (1976). *Cognition and Reality Principles and Implications of Cognitive Psychology*. W.H. Freeman.
- Neville, H.J., Schmidt, A. and Kutas, M. (1983). Altered visual evoked potentials in congenitally deaf adults. *Brain Research*, 266, 127-132.
- Nunez, P.L., and Katznelson, R.D. (1981). *Electric Fields of the Brain: the Neurophysics of the EEG*. Oxford University Press, New York.
- Okita, T., Wijers, A.A., Mulder, G. and Mulder, L.J.M (1985). Memory search and visual spatial attention: An event-related brain potential analysis. *Acta Psychologica*, 60, 263-292.
- O'Toole, D.M. and Iacono, W.G. (1987). An evaluation of different techniques for removing eye-blink artifact from visual evoked response recordings. *Psychophysiology*, 24, 487-497.
- Paul, D.D. and Sutton, S. (1972). Evoked potential correlates of response criterion in auditory signal detection. *Science*, 177, 362-364.
- Paavilainen, P., Alho, K., Reinikainen, K., Sams, M. and Näätänen, R. (1991). Right hemisphere dominance of different mismatch negativities. *Electroencephalography and Clinical Neurophysiology*, 78, 466-479.
- Perry, N.M., Jr. and Copenhaver, R.M. (1965). Differential cortical habituation with stimulation of central and peripheral retina. *Perception and Motor Skills*, 20, 1209-1213.
- Pfefferbaum, A., Ford, J.M., Johnson, R. Jr., Wenegrat, B. and Kopell, B.S. (1983). Manipulation of P3 latency: speed vs. accuracy instructions. *Electroencephalography and Clinical Neurophysiology*, 55, 188 - 197.
- Pfefferbaum, A., Ford, J.M., Roth, W.T., Hopkins, W.F. and Kopell, B.S. (1979). Event related potential changes in healthy aged females. *Electroencephalography and Clinical Neurophysiology*, 46, 81 - 86.
- Pfefferbaum, A., Ford, J.M. and Weller, B.J. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology*, 60, 423-434.

- Pfefferbaum, A. and Ford, J.M. (1988). ERPs to stimuli requiring response production and inhibition: effects of age, probability and visual noise. *Electroencephalography and Clinical Neurophysiology*, 71, 55-63.
- Pfefferbaum, A., Ford J.M., Wenegrat B.G., Roth W.T. and Kopell, B.S. (1984). Clinical application of the P3 component of event-related potentials. I. Normal aging. *Electroencephalography and Clinical Neurophysiology*, 59, 85-103.
- Picton, T.W. (1980). The use of the human event-related potential in psychology. (In) Martin I. and Venables P.H. (Eds.) *Techniques in Psychophysiology*. John Wiley and Sons.
- Picton, T.W, Hillyard, S.A, Krausz, H.I. and Galambos, R. (1974). Human auditory evoked potentials. I. Evaluation of components. *Electroencephalography and Clinical Neurophysiology*, 36, 179-190.
- Picton, T.W. and Stuss D.T. (1980). The component structure of the human event-related potentials. (In). Kornhuber, H.H. and Deecke, L. (Eds.). *Progress in Brain Research* (Volume 54 pp. 17-49). Amsterdam: Elsevier-North Holland.
- Picton, T.W., Stuss, D.T., Champagne S.C. and Nelson, R.F. (1984). The effects of age on human event-related potentials. *Psychophysiology*, 21, 312-325.
- Podlesny, J.A., Dustman, R.E. and Shearer, D.E. (1984). Aging and response-withhold trials: effects on sustained potentials, P3 responses and late activity. *Electroencephalography and Clinical Neurophysiology*, 58, 130-139.
- Polich, J. (1990). P300, probability, and interstimulus interval. *Psychophysiology*, 27, 396-403.
- Polich, J. (1991). P300 in the evaluation of aging and dementia. *Electroencephalography and Clinical Neurophysiology Suppl.* 42, 304-323.
- Polich, J., Howard, L. and Starr, A. (1985). Effects of age on the P300 component of the event-related potential from auditory stimuli: peak definition, variation, and measurement. *Journal of Gerontology*, 40, 721-726.

- Polich, J. and Starr, A. (1984). Evoked potentials in aging. (In) Albert, M.L. (Ed.), *Clinical neurology of aging* (pp. 149-177). New York: Oxford University Press.
- Pritchard, W.S. (1981). Psychophysiology of P300. *Psychological Bulletin*, 89, 506-540.
- Pritchard, W.S. (1989). Subjective probability and stimulus meaning: additive or interactive effects on P300 amplitude. *Journal of Psychophysiology*, 3, 259-268.
- Ragot, R. (1984). Perceptual and motor space representation: An event-related study. *Psychophysiology*, 21, 159 - 170.
- Regan, D. (1988). *Human brain electrophysiology: Evoked potentials and evoked magnetic fields in science and medicine*. London: Chapman and Hall.
- Renault, B. and Lesevre, N. (1979). A trial by trial study of the visual omission response in reaction time situations. (In) Lehman, D. and Callaway, E. (Eds.) *Human evoked potential* (pp. 317-329). New York: Plenum Press.
- Renault, B., Ragot, R., Lesevre, N. and Remond, A. (1982). Onset and offset of brain events as indices of mental chronometry. *Science*, 215, 1413-1415.
- Ritter, W., Simson, R. and Vaughan, H.G. Jr. (1983). Event-related potential correlates of two stages of information processing in physical and semantic discrimination tasks. *Psychophysiology*, 20, 168-179.
- Ritter, W., Vaughan, H.G. and Costa, L.D. (1968). Orienting and habituation to auditory stimuli: A study of short-term changes in average evoked responses. *Electroencephalography and Clinical Neurophysiology*, 25, 550-556.
- Rohrbaugh, J.W., Donchin, E. and Eriksen, C.W. (1974). Decision making and the P300 component of the cortical evoked response. *Perception and Psychophysics*, 15, 368-374.
- Roland, P.E. (1981). Somatotopical tuning of postcentral gyrus during focal attention in man. A regional cerebral blood flow study. *Journal of Neurophysiology*, 46, 744-754.

- Roth, W.T. (1973). Auditory evoked responses to unpredictable stimuli. *Psychophysiology*, 10, 125-138.
- Ruchkin, D.S. and Glaser, E. (1978). Simple digital filters for examining CNV and P300 on a single trial basis. (In) Otto, D. (Ed.). *Multidisciplinary Perspectives in Event-Related Brain Potential Research*. Washington DC: Environmental Protection Agency.
- Ruchkin, D.S., Johnson, R. Jr. and Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology*, 25, 339-353.
- Ruchkin, D.S. and Sutton, S. (1978). Emitted P300 potentials and temporal uncertainty. *Electroencephalography and Clinical Neurophysiology*, 45, 268-277.
- Ruchkin, D.S. and Sutton, S. (1983). Positive slow wave and P300: association and dissociation. (In) Gaillard, A.K.W. and Ritter, W. (Eds.). *Tutorials in Event Related Potential Research: Endogenous Components*. North-Holland Publishing Company.
- Ruchkin, D.S., Sutton, S., Kietzman, M.L. and Silver, K. (1980). Slow wave and P300 in signal detection. *Electroencephalography and Clinical Neurophysiology*, 50, 35-47.
- Rugg, M.D., Cowan, C.P., Nagy, M.E., Milner, A.D., Jacobson, J. and Brooks, D.N. (1988). Event related potentials from closed head injury patients in an auditory "oddball" task: evidence of dysfunction in stimulus categorization. *Journal of Neurology, Neurosurgery and Psychiatry*, 51, 691-698.
- Sagi, D. and Julesz, B. (1985). Detection versus discrimination of visual orientation. *Perception*, 14, 619-628.
- Sams, M., Paavilainen, P., Alho, K. and Näätänen, R. (1985). Auditory frequency discrimination and event-related potentials. *Electroencephalography and Clinical Neurophysiology*, 62, 437-448.
- Scherg, M. (1990). Fundamentals of dipole source analysis. (In) Grandor, F., Hoke, M. and Romani, G.L. (Eds.). *Auditory evoked magnetic fields and potentials*. Basel: Karger.
- Sereno, A.B. (1990). Searching for a neurophysiological view of ERP components. *Behavioural and Brain Sciences*, 13, 253 - 254.

- Simson, R., Vaughan, H.G.Jr. and Ritter, W. (1977). The scalp topography of potentials in auditory and visual go/nogo tasks. *Electroencephalography and Clinical Neurophysiology*, 43, 864-875.
- Shannon, C.E. and Weaver, W. (1963). *The Mathematical Theory of Communication*. Urbana, IL: University of Illinois Press.
- Shaw, T.G., Martel, K.F., Meyer, J.S., Rogers, R.L., Haardenberg, J. and Cutaia, M.M. (1984). Cerebral blood flow changes in benign aging and cerebrovascular disease. *Neurology*, 34, 855-862.
- Smith, D.B.D., Michalewski, H.J., Brent, G.A. and Thompson, L.W. (1980). Auditory averaged evoked potentials and aging: Factors of stimulus, task and topography. *Biological Psychology*, 11, 135 - 151.
- Snyder, E. and Hillyard, S.A. (1976). Long latency evoked potentials to irrelevant deviant stimuli. *Behavioural Biology*, 16, 319 - 331.
- Snyder, E., Hillyard, S.A. and Galambos, R. (1980). Similarities and differences among the P3 waves to detected signals in three modalities. *Psychophysiology*, 17, 112-122.
- Snyder, A.Z. (1991). Dipole source localization in the study of EP generators: a critique. *Electroencephalography and Clinical Neurophysiology*, 80, 321-325.
- Sokolov, E.N. (1963). Higher nervous functions: the orienting reflex. *Annual Review of Psychology*, 25, 545-580.
- Strayer, D.L., Wickens, C.D. and Braune, R. (1987). Adult age differences in the speed and capacity of information processing. 2. An electrophysiological approach. *Psychology and Aging*, 2, 99-110.
- Stuss, D.T. and Picton, T.W. (1978). Neurophysiological correlates of human concept formation. *Behavioural Biology*, 23, 135-162.
- Sutton, S., Braren, M., Zubin, J. and John, E.R. (1965). Evoked potential correlates of stimulus uncertainty. *Science*, 150, 1187-1188.
- Squires, K., Petuchowski, S., Wickens, C. and Donchin, E. (1977). The effects of stimulus sequence on event-related potentials: A comparison of visual and auditory sequences. *Perception and Psychophysics*, 22, 31-40.

- Squires, N.K., Squires, K.C. and Hillyard, S.A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, 38, 387-401.
- Syndulko, K., Hansch, E.C., Cohen, S.C., Pearce, J.W., Goldberg, Z., Montan, B., Tourtellotte, W.W. and Potvin, A.R. (1982). Long latency event-related potentials in normal aging and dementia. (In) Courjon, J., Mauguiere, F. and Revol, M. (Eds.). *Clinical applications of evoked potentials in neurology* (pp. 279-285). New York: Raven Press.
- Tueting, P., Sutton, S. and Zubin, J. (1971). Quantitative evoked potential correlates of the probability of events. *Psychophysiology*, 7, 385-394.
- Verleger, R. (1988). Event-related potentials and cognition: a critique of the context updating hypothesis and an alternative interpretation of P3. *Behavioral and Brain Sciences*, 11, 343-427.
- Verleger, R. and Berg, P. (1991). The waltzing oddball. *Psychophysiology*, 28, 468-477.
- Verbaten, M.N. (1983). The influence of information on habituation of cortical, autonomic and behavioural components of the orienting response (OR). (In) Gaillard, A.W.K. and Rutter, W. (Eds.). *Tutorials in Event Related Potential Research: Endogenous Components* (pp. 201-216). Amsterdam: North-Holland.
- Verbaten, R., Roelof, J.W., Sjouw, W. and Slangen, J.L. (1986a). Habituation of early and late visual ERP components and the orienting reaction: The effect of stimulus information. *International Journal of Psychophysiology*, 3, 287-98.
- Verbaten, R., Roelof, J.W., Sjouw, W. and Slangen, J.L. (1986b). Different effect of uncertainty and complexity on single trial visual ERPs and the SCR-OR in non-signal conditions. *Psychophysiology*, 23, 254-262.
- Wijers, A.A., Mulder, G., Okita, T. and Mulder, L.J.M. (1989a). Event-related potentials during memory search and selective attention to letter size and conjunctions of letter size and color. *Psychophysiology*, 26, 529-547.

- Wijers, A.A., Mulder, G., Okita, T., Mulder, L.J.M. and Scheffers, M.K. (1989b). Attention to color: An analysis of selection controlled search, and motor activation, using event-related potentials. *Psychophysiology*, 26, 89-109.
- Wijers, A.A., Okita, T., Mulder, L.J.M., Lorist, M.M., Poiesz, R. and Scheffers, K.M. (1987a). Visual search and spatial attention; ERPs in focused and divided attention conditions. *Biological Psychology*, 25, 33 - 60.
- Wijers, A.A., Okita, T., Mulder, L.J.M., Lorist, M.M., Poiesz, R. and Scheffers, K.M. (1987b). Endogenous components reflecting visual attention and controlled search to coloured stimuli. (In) R. Johnson, R., Jr., Rohrbaugh, J.W and Parasuraman, P. (Eds.), *Electroencephalography and Clinical Neurophysiology, Supplement 40: Current trends in event-related potential research* (pp. 138 - 145). Amsterdam: Elsevier.
- Woesrtenburg, J.C., Verbaten, M.N. and Slangen, J.L. (1983). Stimulus information and habituation of the visual event related potential and the skin conductance reaction under task-relevance conditions. *Biological Psychology*, 16, 225-240.
- Woldorff, M.G., Hackley, S.A. and Hillyard, S.A. (1991). The effect of channel-selective attention on the mismatch negativity wave elicited by deviant tones. *Psychophysiology*, 28, 30 - 42.
- Wood, C.C., Allison, T., Goff, W.R., Williamson, P. and Spencer, D.C. (1980). On the neural origin of P300 in man. *Progress in Brain Research*, 54, 51-56.
- Wood, C.C. and McCarthy, G. (1984). Principal component analysis of event-related potentials: simulation studies demonstrate misallocation of variance across components. *Electroencephalography and Clinical Neurophysiology*, 59, 249-260.
- Wood, C.C. and McCarthy, G. (1985). A possible frontal lobe contribution to the scalp P300. *Contribution to the scalp P300. Society of Neuroscience Contribution to the scalp P300. Society of Neuroscience Contribution to the scalp P300. Society of Neuroscience Abstracts*, 11, 879.

- Woods, D.L. (1990). The physiological basis of *seriburibution to the scalp P300*ribution to the scalp P300. Society of Neurosciencribution to the scalp P300. Society of Neurosciencribution to the scalp P300. Society of Neuroscience Abstracts, 11, 879.
- Wribution to the scalp P300. Society of Neuroscience rribution to riribution to the scalp P300. Society of Neuroscience Abstracts, 11, 879.*
- Woods, D.L. (1990). The physiologicalaials to lateralized auditory and visual stimuli. *Electroencephalography and Clinical Neurophysiology*, 82, 341 - 355.
- Woods, D.L. and Clayworth, C.C. (1987). Scalp topographies dissociate N1 and Nd components during auditory selective attention. (In) Johnson, R., Rohrbaugh, J.W. and Parasuraman, R. (Eds.), *Current research in event-related brain potentials. Electroencephalography and Clinical Neurophysiology, Suppl. 40*, (pp. 155-160). Amsterdam: Elsevier Science Publishers B.V.
- Woods, D.L. and Courchesne, E. (1987). Intersubject variability elucidates the cerebral and psychological correlates of ERP's. (In) Johnson, R., Rohrbaugh, J.W. and Parasuraman, R. (Eds.). *Current research in event-related brain potentials. Electroencephalography and Clinical Neurophysiology, Suppl. 40*, (pp. 293-299). Amsterdam: Elsevier Science Publishers B.V.
- Yamaguchi, S. and Knight, R.T (1991a). P300 generation by novel somatosensory stimuli. *Electroencephalography and Clinical Neurophysiology*, 78, 50-55.
- Yamaguchi, S. and Knight, R.T. (1991b). Anterior and posterior asociation cortex contributions to the somatosensory P300. *The Journal of Neuroscience*, 11, 2039-2054.
- Yamaguchi, S. and Knight, R.T. (1991c). Age effects on the P300 to novel somatosensory stimuli. *Electroencephalography and Clinical Neurophysiology*, 78, 297-301.

Table 3.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites within the auditory and visual modalities.

Auditory Modality	df	F	p	mse
N100				
Main Effects				
Condition CC	1,3,13.4	0.047	0.894	148.461
Site ST	1,9,18.9	2.953	0.079	164.558
Interactions				
CC X ST	2,0,20.1	2.112	0.147	96.945
N200				
Main Effects				
Condition CC	1,10	7.401	0.022*	1793.648
Site ST	1,4,14.3	1.116	0.335	172.242
Interactions				
CC X ST	1,6,15.9	0.999	0.370	267.176
P300				
Main Effects				
Condition CC	1,10	5.159	0.047*	2212.848
Site ST	1,7,17.1	2.209	0.146	578.158
Interactions				
CC X ST	1,9,19.2	0.621	0.540	404.485
Visual Modality				
N100				
Main Effects				
Condition CC	1,5,15.0	2.399	0.135	507.006
Site ST	1,3,12.7	3.295	0.087	259.006
Interactions				
CC X ST	2,1,21.4	0.678	0.526	174.642
N200				
Main Effects				
Condition CC	1,10	0.271	0.613	4636.46
Site ST	1,8,18.5	0.712	0.491	499.612
Interactions				
CC X ST	1,2,12.0	0.447	0.550	494.424
P300				
Main Effects				
Condition CC	1,10	3.328	0.098	4301.576
Site ST	1,2,12.4	0.136	0.772	1107.127
Interactions				
CC X ST	1,2,11.9	3.099	0.100	1036.630

* denotes a p level statistically significant at the 0.05% level or greater.

Table 3.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes.

Auditory Modality			
	Fz	Cz	Pz
N100			
Frequent	106.1	103.2	96.0
Target	102.9	102.6	97.0
Rare	96.7	109.0	99.2
Nontarget			
N200			
Target	237.0	238.2	233.5
Rare	213.4	210.5	208.4
Nontarget			
P300			
Target	328.0	324.0	338.0
Rare	309.4	293.0	308.7
Nontarget			
 Visual Modality			
	Fz	Cz	Pz
N100			
Frequent	98.9	101.4	93.1
Target	100.0	100.7	85.4
Rare	86.5	88.7	83.6
Nontarget			
N200			
Target	254.9	257.5	244.3
Rare	241.8	245.8	242.9
Nontarget			
P300			
Target	353.4	368.7	381.0
Rare	350.5	333.4	330.9
Nontarget			

Table 3.5 ANOVA summary table for analysis of N100 amplitude elicited by auditory frequent, target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,7,16.5	2.332	0.135	27.916
Chain CH	2,19.7	24.506	0.000*	12.844
Site ST	1.2,12.4	14.841	0.001*	25.428
Interactions				
CC X CH	1.7,16.9	1.289	0.297	3.884
CC X ST	2.1,21.3	6.710	0.005*	4.394
CH X ST	1.8,17.9	2.408	0.123	6.363
CC X CH X ST	1.5,14.8	1.397	0.272	2.243

Table 3.6 summary table for analysis of N200 amplitude elicited by auditory target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	3.226	0.103	76.471
Chain CH	1.9,19.5	8.180	0.003*	6.153
Site ST	1.4,13.9	28.532	0.000*	49.945
Interactions				
CC X CH	2,19.8	4.337	0.028*	3.446
CC X ST	1.7,16.7	6.928	0.009*	9.225
CH X ST	2.1,21.4	6.398	0.006*	5.219
CC X CH X ST	3.1,30.6	2.551	0.073	1.538

Table 3.7 summary table for analysis of mean amplitude elicited by auditory stimuli within a latency range of 500 - 850 msec.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.6,15.8	4.172	0.043*	25.941
Chain CH	1.7,16.6	10.506	0.002*	8.300
Site ST	1.2,11.6	35.177	0.000*	30.243
Interactions				
CC X CH	2.2,21.6	4.943	0.015*	2.157
CC X ST	2.5,24.9	19.895	0.000*	10.637
CH X ST	2.2,21.8	10.258	0.001*	3.063
CC X CH X ST	3.5,35	4.308	0.008*	1.129

* denotes a p value statistically significant at the 0.05% level or greater.

Table 3.9 ANOVA summary table for analysis of P300 amplitude elicited by visual target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	4.798	0.061	123.826
Chain CH	1.6,16.3	6.886	0.009*	19.384
Site ST	1.2,11.6	51.094	0.000*	49.378
Interactions				
CC X CH	1.5,15.4	4.555	0.036*	21.551
CC X ST	1.4,13.7	0.754	0.439	18.792
CH X ST	2.6,25.7	7.997	0.001*	4.611
CC X CH X ST	2.7,26.6	4.784	0.011*	4.216

Table 3.10 ANOVA summary table for analysis of P300 amplitude elicited by the first ten presentations of visual target and rare nontarget stimuli.

Target Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	2.9,23.1	0.930	0.437	358.669
Site ST	1.2,9.4	6.156	0.010*	164.030
Interactions				
TR X ST	3.8,30.3	1.698	0.179	42.154
Rare Nontarget Stimuli				
	df	F	p	mse
Main Effects				
Trial TR	4,32.1	0.815	0.524	283.491
Site ST	1.5,12.1	61.368	0.000*	86.873
Interactions				
TR X ST	3.8,30.8	1.750	0.167	45.167

* denotes a p value statistically significant at the 0.05 %

Table 3.11 ANOVA summary table for analysis of N100 amplitude elicited by visual frequent, target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,7,16.5	2.332	0.135	27.916
Chain CH	2,19.7	24.506	0.000*	12.844
Site ST	1.2,12.4	14.841	0.001*	25.428
Interactions				
CC X CH	1.7,16.9	1.289	0.297	3.884
CC X ST	2.1,21.3	6.710	0.005*	4.394
CH X ST	1.8,17.9	2.408	0.123	6.363
CC X CH X ST	1.5,14.8	1.397	0.272	2.243

Table 3.12 summary table for analysis of N200 amplitude elicited by visual target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	0.093	0.766	73.134
Chain CH	1.5,14.8	4.670	0.036*	4.845
Site ST	1.2,11.6	20.660	0.001*	16.922
Interactions				
CC X CH	1.7,17.4	3.622	0.054	11.608
CC X ST	1.1,11.3	6.580	0.023*	36.254
CH X ST	2.3,23.1	2.302	0.117	2.059
CC X CH X ST	2.8,28.3	1.349	0.279	2.825

Table 3.13 summary table for analysis of mean amplitude elicited by visual stimuli within a latency range of 500 - 850 msec.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.3,13.2	2.871	0.107	49.375
Chain CH	1.6,16.4	1.597	0.233	9.736
Site ST	1.2,12.2	4.433	0.051	40.752
Interactions				
CC X CH	2.2,22.5	0.305	0.764	4.689
CC X ST	1.5,15.5	11.205	0.002*	14.708
CH X ST	2.4,23.7	46.157	0.000*	2.968
CC X CH X ST	2.8,27.5	4.965	0.008*	1.728

Table 3.14 ANOVA summary table for analysis of mean amplitude elicited by visual frequent, target and rare nontarget stimuli within a latency range of 150 - 350 msec at lateral parietal sites.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.3,13	13.985	0.001*	158.917
Chain CH	1,10	1.308	0.280	8.514
Interactions				
CC X CH	1.2,12.2	0.185	0.722	1.991

* denotes a p value statistically significant at the 0.05% level or greater.

Table 3.16 ANOVA summary table for the analysis of P300 rescaled amplitude elicited by target and rare nontarget stimuli within the visual and auditory modalities.

Rescaled Amplitude	df	F	p	mse
Main Effects				
Modality MD	1,20	0.046	0.832	1.479
Condition CC	1,20	2.324	0.144	0.391
Chain CH	1.6,31.5	12.905	0.000*	0.077
Site ST	1.2,24.7	85.683	0.000*	0.234
Interactions				
MD X CC	1,20	0.054	0.818	0.391
MD X CH	1.6,31.5	0.050	0.917	0.077
MD X ST	1.2,24.7	0.059	0.858	0.234
CC X CH	1.6,32.3	0.263	0.722	0.054
CC X ST	1.4,27	1.376	0.263	0.061
CH X ST	2.9,57.6	8.873	0.000*	0.015
MD X CC X CH	1.6,32.3	10.796	0.001*	0.054
MD X CC X ST	1.4,27	9.767	0.002*	0.061
MD X CH X ST	2.9,57.6	1.846	0.152	0.015
CC X CH X ST	2.8,55.1	6.647	0.001*	0.010
MD X CC X CH X ST	2.8,55.1	1.299	0.285	0.010

Table 3.17 ANOVA summary table for analysis of P300 rescaled amplitude elicited within the auditory modality and within the visual modality.

Auditory				
Rescaled Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	1.32	0.277	0.246
Chain CH	1.5,14.6	7.34	0.010*	0.076
Site ST	1.3,12.9	36.36	0.000*	0.274
Interactions				
CC X CH	1.9,19.2	13.77	0.000*	0.021
CC X ST	1.3,13.2	7.68	0.011*	0.048
CH X ST	2.4,24.3	2.61	0.085	0.012
CC X CH X ST	1.9,18.9	4.24	0.032*	0.005
Visual				
Rescaled Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,10	1.12	0.315	0.537
Chain CH	1.6,15.9	5.63	0.019*	0.078
Site ST	1.2,11.6	52.08	0.000*	0.193
Interactions				
CC X CH	1.5,15.2	3.49	0.067	0.086
CC X ST	1.4,13.7	4.19	0.050*	0.074
CH X ST	2.5,25.3	7.40	0.002*	0.017
CC X CH X ST	2.6,26.2	3.88	0.024*	0.015

* denotes a p value statistically significant at the 0.05% level or greater.

Table 3.18 ANOVA summary table for analysis of N100 rescaled amplitude elicited by auditory and visual stimuli.

Rescaled Amplitude	df	F	p	mse
Main Effects				
Modality MD	1,10	1.297	0.282	2.569
Condition CC	1.5,15.3	0.649	0.495	0.598
Chain CH	1.7,16.7	37.287	0.000*	0.177
Site ST	1.2,11.7	31.997	0.000*	0.521
Interactions				
MD X CC	1.3,13.5	0.053	0.886	0.294
MD X CH	1.8,17.6	1.241	0.310	0.202
MD X ST	1.1,11.3	6.495	0.024*	0.371
CC X CH	1.9,19	0.837	0.441	0.060
CC X ST	2,20.3	0.996	0.385	0.088
CH X ST	2.3,23.2	8.580	0.001*	0.076
MD X CC X CH	2.8,27.8	0.845	0.471	0.066
MD X CC X ST	2.6,25.7	6.723	0.003*	0.049
MD X CH X ST	2.6,26.3	1.402	0.266	0.061
CC X CH X ST	2.2,22.2	1.077	0.365	0.025
MD X CC X CH ST	2.5,25.4	1.414	0.263	0.027

Table 3.19 ANOVA summary table for analysis of N200 rescaled amplitude elicited by auditory and visual stimuli.

Rescaled Amplitude	df	F	p	mse
Main Effects				
Modality MD	1,10	0.137	0.718	1.171
Condition CC	1,10	0.088	0.772	1.137
Chain CH	2,19.6	8.162	0.003*	0.127
Site ST	1.7,16.9	42.551	0.000*	0.272
Interactions				
MD X CC	1,10	0.921	0.357	0.654
MD X CH	1.8,18.4	1.505	0.249	0.164
MD X ST	1.1,11.2	2.011	0.185	0.630
CC X CH	1.9,19.0	7.434	0.005*	0.090
CC X ST	1.5,14.9	11.722	0.002*	0.108
CH X ST	2.3,22.7	5.542	0.009*	0.079
MD X CC X CH	1.8,17.8	13.247	0.000*	0.106
MD X CC X ST	1.5,14.9	24.900	0.000*	0.043
MD X CH X ST	2.4,24.4	1.530	0.236	0.043
CC X CH X ST	2.6,26.4	3.503	0.034*	0.035
MD X CC X CH X ST	2.8,28.4	6.388	0.002*	0.033

* denotes a p value statistically significant at the 0.05% level or greater.

Table 3.20 ANOVA summary table for analysis of rescaled mean amplitude elicited within a latency range of 500 - 850 msec by auditory and visual stimuli.

Rescaled Amplitude	df	F	p	mse
Main Effects				
Modality MD	1,10	0.046	0.833	1.885
Condition CC	1.3,13.1	0.805	0.417	1.384
Chain CH	1.7,16.6	1.103	0.345	0.297
Site ST	1.3,12.9	12.321	0.002*	0.764
Interactions				
MD X CC	1.8,17.9	0.365	0.675	0.987
MD X CH	1.9,18.6	19.866	0.000*	0.080
MD X ST	1.1,10.9	11.489	0.005*	0.649
CC X CH	2,20.5	0.198	0.826	0.076
CC X ST	2.1,20.8	5.916	0.009*	0.278
CH X ST	2.5,24.7	28.632	0.000*	0.089
MD X CC X CH	2.7,27.5	1.809	0.173	0.070
MD X CC X ST	2.2,21.7	5.744	0.009*	0.178
MD X CH X ST	2,20.2	17.715	0.000*	0.050
CC X CH X ST	2.3,22.5	1.252	0.309	0.044
MD X CC X CH X ST	2.8,28	2.107	0.126	0.030

* denotes a p value statistically significant at the 0.05% level or greater.

Table 3.8.1 Mean amplitude elicited by auditory stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Pz	Left Chain		Lp	Right Chain		Rp
	Fz	Cz		Lf	Lt		Rf	Rt	
P300									
Target	-3.27	3.31	12.99	-4.46	3.36	10.55	-4.01	5.04	10.32
Rare	6.93	17.90	21.00	2.28	12.68	13.31	-0.32	12.33	15.01
Nontarget									
N100									
Frequent	-6.64	-9.80	6.27	-6.82	-6.93	3.25	-6.04	-5.63	1.86
Target	-10.02	-11.13	-6.64	-8.08	-7.93	-3.57	-7.13	-6.07	-1.62
Rare	-6.37	-9.16	-5.88	-3.77	-6.62	-3.76	-4.01	-5.99	-2.12
Nontarget									
N200									
Target	-6.98	-0.43	5.54	-6.65	-1.45	2.41	-5.90	-0.45	2.95
Rare	-4.58	5.41	6.47	-3.82	2.61	2.88	-3.72	1.87	2.01
Nontarget									
Slow Wave									
Frequent	-1.03	0.02	1.23	0.11	1.18	0.81	0.40	1.36	1.07
Target	-8.41	-2.58	5.91	-5.64	-0.19	3.91	-5.76	2.36	5.27
Rare	-6.33	-3.97	0.96	-3.96	-1.09	1.13	-4.14	-0.09	2.81
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 3.8.2 Mean rescaled amplitude elicited by auditory stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Lp	Right Chain		Rp
	Fz	Cz	Ff	Lt		Rf	Rt	
P300								
Target	0.07	0.45	0.00	0.45	0.86	0.03	0.54	0.84
Rare	0.34	0.54	0.12	0.61	0.73	0.00	0.59	0.72
Nontarget								
N100								
Frequent	0.39	0.00	0.37	0.36	0.82	0.47	0.52	1.00
Target	0.12	0.00	0.32	0.34	0.79	0.42	0.54	1.00
Rare	0.39	0.00	0.76	0.36	0.76	0.73	0.45	1.00
Nontarget								
N200								
Target	0.00	0.52	0.03	0.44	0.75	0.09	0.32	0.79
Rare	0.00	0.90	0.07	0.65	0.67	0.08	0.58	0.59
Nontarget								
Slow Wave								
Frequent	0.00	0.42	0.38	0.92	0.76	0.26	1.00	0.87
Target	0.00	0.41	0.19	0.57	0.86	0.18	0.75	0.95
Rare	0.00	0.26	0.26	0.57	0.82	0.24	0.68	1.00
Nontarget								

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 3.15.1 Mean amplitude elicited by visual stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. The mean amplitude evoked at lateral parietal sites is also shown.

	Midline Chain		Left Chain		Right Chain		Rp
	Fz	Cz	Lf	Lt	Rf	Rt	
P300							
Target	5.09	13.36	3.21	11.45	2.36	11.08	10.42
Rare	0.29	7.82	-1.05	6.81	-0.38	9.06	12.29
Nontarget							
N100							
Frequent	-3.28	-3.15	-2.60	-1.87	-3.03	-1.80	-1.44
Target	-3.17	-2.78	-3.04	-2.11	-2.76	-1.23	2.69
Rare	-3.26	-2.13	-3.11	-1.22	-2.87	-0.98	2.81
Nontarget							
N200							
Target	-3.73	-0.19	-2.88	0.59	-2.42	2.53	6.69
Rare	0.94	2.72	0.55	1.00	1.01	2.06	1.44
Nontarget							
Slow Wave							
Frequent	2.14	2.89	2.27	2.62	3.36	3.48	-1.98
Target	-2.15	3.08	-0.45	4.01	0.48	6.84	2.04
Rare	2.72	5.49	-2.86	5.53	5.03	6.31	1.27
Nontarget							
Lat. Par.							
Frequent					2.28		3.12
Target					2.84		3.91
Rare					7.38		7.93
Nontarget							

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec
 Lat Par refers to the amplitude evoked in a mean latency window of 150 - 350 secs at lateral parietal sites.

Table 3.15.2 Mean rescaled amplitude elicited by visual stimuli within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	0.15	0.61	1.00	0.05	0.50	0.63	0.00	0.48	0.45
Rare	0.09	0.62	1.00	0.00	0.35	0.91	0.05	0.71	0.94
Nontarget									
N100									
Frequent	0.00	0.03	0.44	0.14	0.29	0.87	0.05	0.31	1.00
Target	0.00	0.06	0.41	0.02	0.18	0.66	0.07	0.33	1.00
Rare	0.00	0.19	0.49	0.02	0.34	0.92	0.06	0.37	1.00
Nontarget									
N200									
Target	0.59	0.94	1.00	0.47	0.45	0.00	0.56	0.72	0.46
Rare	0.00	0.33	0.79	0.08	0.43	0.89	0.12	0.56	1.00
Nontarget									
Slow Wave									
Frequent	0.75	0.89	0.81	0.77	0.84	0.19	0.97	1.00	0.00
Target	0.00	0.47	1.00	0.15	0.56	0.63	0.24	0.82	0.38
Rare	0.28	0.84	0.83	0.31	0.84	0.37	0.75	1.00	0.00
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 4.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes within the triangle and circle procedures.

	Triangle Procedure		Circle Procedure			
	Fz	Cz	Pz	Fz	Cz	Pz
N100						
Frequent	85.3	87.3	106.6	85.3	91.6	94.3
Target	78.3	82.0	97.6	83.3	90.0	110.3
Rare	87.3	94.0	98.6	82.3	85.0	84.3
Nontarget						
N200						
Target	266.3	261.6	253.3	283.6	276.0	254.6
Rare	244.6	245.0	246.0	244.6	244.3	235.3
Nontarget						
P300						
Target	347.6	366.6	375.6	344.0	354.6	368.6
Rare	339.0	343.0	345.0	339.6	338.6	346.0
Nontarget						

Table 4.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites within the triangle and circle procedures.

	df	F	p	mse
N100				
Main Effects				
Procedure PR	1,11	0.124	0.730	609.993
Condition CC	1.3,14.5	0.678	0.461	266.323
Site ST	1.4,15.5	5.448	0.024*	778.747
Interactions				
PR X CC	1.6,17.9	5.451	0.019*	272.923
PR X ST	1.1,12.0	0.358	0.579	473.024
CC X ST	2.3,25.6	5.637	0.007*	94.141
PR X CC X ST	1.3,14.7	0.891	0.389	280.923
N200				
Main Effects				
Procedure PR	1,11	0.347	0.566	1352.596
Condition CC	1,11	10.441	0.008*	1762.778
Site ST	1.6,17.5	5.097	0.024*	399.323
Interactions				
PR X CC	1,11	2.321	0.156	846.657
PR X ST	1.6,17.9	2.440	0.124	256.838
CC X ST	1.7,18.8	1.708	0.210	520.293
PR X CC X ST	1.9,20.4	0.079	0.912	271.384
P300				
Main Effects				
Procedure PR	1,11	0.286	0.602	2240.081
Condition CC	1,11	11.525	0.006*	974.909
Site ST	1.8,19.7	10.409	0.001*	304.414
Interactions				
PR X CC	1,11	0.250	0.626	1602.182
PR X ST	1.4,15.4	0.742	0.445	197.808
CC X ST	1.6,18.0	4.201	0.039*	300.515
PR X CC X ST	1.5,16.6	0.046	0.916	296.424

* denotes a p level statically significant at the 5% level or greater.

Table 4.4 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,11	0.194	0.667	65.161
Condition CC	1.1,12.5	7.971	0.013*	19.818
Chain CH	1.6,17.3	178.664	0.000*	28.972
Site ST	1,11.4	22.243	0.001*	105.892
Interactions				
PR X CC	1.6,18.1	0.029	0.951	15.743
PR X CH	1.2,12.9	0.077	0.824	19.117
PR X ST	1,11.5	0.022	0.893	55.047
CC X CH	1.7,18.4	5.587	0.016*	3.183
CC X ST	1.9,20.8	2.069	0.154	5.301
CH X ST	2.1,22.8	26.265	0.000*	8.420
PR X CC X CH	2.5,27.4	0.475	0.667	2.840
PR X CC X ST	1.8,19.7	1.551	0.238	4.531
PR X CH X ST	1.3,14.7	0.531	0.527	4.367
CC X CH X ST	2.8,31.3	3.151	0.041*	0.824
PR X CC X CH X ST	2.7,30.1	0.854	0.465	0.862
Rescaled Amplitude				
Main Effects				
Procedure PR	1,11	0.004	0.950	0.674
Condition CC	1.3,13.8	1.002	0.355	0.178
Chain CH	1.6,17.5	17.744	0.000*	0.304
Site ST	1,11.4	22.761	0.000*	1.109
Interactions				
PR X CC	1.7,18.7	0.387	0.650	0.161
PR X CH	1.2,13.3	0.038	0.888	0.201
PR X ST	1,11.5	0.088	0.783	0.584
CC X CH	2,22.1	3.964	3.034*	0.030
CC X ST	2.1,23.3	2.651	0.090	0.044
CH X ST	2.1,23.2	26.126	0.000*	0.090
PR X CC X CH	2.7,29.7	0.496	0.668	0.029
PR X CC X ST	1.7,19	0.035	0.950	0.039
PR X CH X ST	1.4,15.2	0.350	0.630	0.046
CC X CH X ST	3.2,35.3	2.593	0.065	0.008
PR X CC X CH X ST	3.1,33.8	0.386	0.768	0.009

* denotes a p value statistically significant at the 0.05% level or greater.

Table 4.5 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,11	0.218	0.649	52.234
Condition CC	1,11	0.020	0.890	50.372
Chain CH	1.4,15.6	5.575	0.022*	24.790
Site ST	1.3,14.6	17.588	0.000*	70.079
Interactions				
PR X CC	1,11	0.013	0.910	5.893
PR X CH	1.9,21.3	0.306	0.732	6.632
PR X ST	1.1,12.6	1.013	0.347	21.180
CC X CH	1.9,20.9	3.890	0.039*	6.771
CC X ST	1.3,14.6	38.418	0.000*	9.985
CH X ST	3.1,33.9	6.400	0.001*	9.645
PR X CC X CH	1.4,15.5	0.585	0.510	2.511
PR X CC X ST	1.2,13.1	0.556	0.497	5.743
PR X CH X ST	2.2,24.6	1.771	0.189	1.518
CC X CH X ST	3.1,34.4	7.100	0.001*	1.459
PR X CC X CH X ST	2.8,30.4	1.111	0.358	0.635
Rescaled Amplitude				
Main Effects				
Procedure PR	1,11	0.239	0.633	0.909
Condition CC	1,11	2.941	0.115	0.421
Chain CH	1.4,15.2	6.669	0.014	0.389
Site ST	1.3,14.3	12.031	0.002*	1.164
Interactions				
PR X CC	1,11	0.000	1.000	1.164
PR X CH	1.9,21.3	0.271	0.758	0.095
PR X ST	1.1,12.6	0.525	0.504	0.354
CC X CH	1.6,18.1	7.638	0.006*	0.122
CC X ST	1.2,13.4	8.455	0.009*	0.236
CH X ST	3.1,34.2	7.574	0.000*	0.150
PR X CC X CH	1.8,19.9	0.332	0.700	0.028
PR X CC X ST	1.2,13.1	0.480	0.531	0.118
PR X CH X ST	2.5,27.3	3.249	0.045*	0.026
CC X CH X ST	3.3,36.1	11.851	0.000*	0.029
PR X CC X CH X ST	2.7,29.4	1.064	0.375	0.015

* denotes a p value statistically significant at the 0.05% level or greater.

Table 4.6 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 500 - 850 msec.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,11	0.034	0.857	9.372
Condition CC	1.3,14.5	5.325	0.029*	100.032
Chain CH	1.9,21.1	31.530	0.000*	10.134
Site ST	1.4,15	14.341	0.001*	37.917
Interactions				
PR X CC	1.9,21.4	5.118	0.016	10.003
PR X CH	1.4,15.2	0.359	0.626	3.026
PR X ST	1.3,14	3.940	0.059	2.983
CC X CH	1.9,20.4	4.038	0.036*	6.955
CC X ST	2.3,25.1	14.572	0.000*	8.650
CH X ST	2.3,25.6	25.310	0.000*	6.242
PR X CC X CH	3.3,36	0.576	0.648	1.640
PR X CC X ST	1.8,19.9	2.261	0.135	4.028
PR X CH X ST	2.5,28	0.699	0.536	0.937
CC X CH X ST	4.6,50.7	4.159	0.004*	1.415
PR X CC X CH X ST	4.2,46.4	1.156	0.344	0.485
Rescaled Amplitude				
Main Effects				
Procedure PR	1,11	0.026	0.874	0.443
Condition CC	1.8,19.9	0.103	0.885	2.354
Chain CH	1.9,20.8	34.662	0.000*	0.263
Site ST	1.3,14.4	9.336	0.005*	1.339
Interactions				
PR X CC	1.5,16.3	0.818	0.423	0.471
PR X CH	1.7,19	1.153	0.331	0.088
PR X ST	1.2,12.9	3.050	0.101	0.104
CC X CH	2.2,24.1	3.331	0.049*	0.136
CC X ST	1.8,19.4	3.346	0.062	0.296
CH X ST	2.2,23.9	28.017	0.000*	0.166
PR X CC X CH	3,33.5	1.061	0.381	0.045
PR X CC X ST	2,22.2	2.447	0.109	0.101
PR X CH X ST	2.5,27.2	1.365	0.275	0.032
CC X CH X ST	3.5,38.8	4.588	0.005*	0.441
PR X CC X CH X ST	5,54.6	1.099	0.373	0.621

Table 4.7 ANOVA summary table for analysis of mean amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 150 - 350 msec at lateral parietal sites.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,11	3.214	0.101	5.122
Condition CC	1.5,16.7	14.460	0.000*	10.910
Chain CH	1,11	0.079	0.784	16.483
Interactions				
PR X CC	1.7,18.3	3.804	0.049*	2.788
PR X CH	1,11	2.335	0.155	2.486
CC X CH	1.2,13.6	0.473	0.541	2.808
PR X CC X CH	1.8,20.2	0.442	0.631	0.610

* denotes a p value statistically significant at the 0.05% level or greater.

Table 4.8.2 Mean rescaled amplitude elicited by stimuli within the circle procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Lf	Lt	Rf	Rt
P300						
Target	0.28	0.72	0.00	0.32	0.17	0.59
Rare	0.32	0.84	0.00	0.42	0.13	0.65
Nontarget						
N100						
Frequent	0.95	0.89	0.96	0.68	1.00	0.69
Target	0.89	0.82	0.89	0.59	1.00	0.67
Rare	0.96	1.00	0.89	0.73	0.93	0.63
Nontarget						
N200						
Target	0.12	0.46	0.00	0.15	0.16	0.49
Rare	0.06	0.35	0.00	0.37	0.02	0.56
Nontarget						
Slow Wave						
Frequent	0.07	0.81	0.00	0.40	0.42	0.88
Target	0.11	0.63	0.00	0.32	0.31	0.65
Rare	0.11	0.82	0.00	0.52	0.08	0.72
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 4.8a Mean amplitude elicited by stimuli within the triangle procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	7.51	15.17	20.28	2.77	7.62	11.27	5.59	12.83	11.68
Rare	8.97	15.46	18.33	2.03	8.23	11.19	3.82	11.89	11.38
Nontarget									
N100									
Frequent	3.36	2.58	0.61	3.59	0.79	-3.52	3.59	0.85	-4.15
Target	3.94	2.72	0.25	4.05	0.76	-3.51	4.10	1.03	-5.36
Rare	5.84	5.32	2.89	5.19	2.26	-1.94	5.13	2.14	-5.39
Nontarget									
N200									
Target	2.83	4.03	7.45	2.63	1.95	2.37	3.20	4.80	3.44
Rare	-0.51	2.59	9.64	-0.81	2.60	6.58	-0.64	4.49	7.66
Nontarget									
Slow Wave									
Frequent	1.12	3.49	3.76	1.13	1.73	0.96	1.98	2.77	1.02
Target	0.43	5.94	9.71	-0.39	2.64	4.27	1.90	6.25	4.48
Rare	4.45	7.96	7.95	3.93	5.09	3.32	4.62	6.88	2.12
Nontarget									
Lat. Par.									
Frequent									
Target									
Rare									
Nontarget									
							2.46		2.88
							3.22		4.22
							6.79		7.15

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Lat. Par. denotes the activity elicited within a latency range of 150 - 350 msec at lateral parietal sites.

Table 4.8b Mean rescaled amplitude elicited by stimuli within the triangle procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Pz	Left Chain			Right Chain		Rp
	Fz	Cz		Lf	Lt	Lp	Rf	Rt	
P300									
Target	0.27	0.71	1.00	0.00	0.28	0.48	0.16	0.57	0.51
Rare	0.30	0.82	1.00	0.00	0.38	0.56	0.11	0.60	0.57
Nontarget									
N100									
Frequent	0.97	0.87	0.61	1.00	0.04	0.08	0.99	0.64	0.00
Target	0.98	0.85	0.59	0.99	0.65	0.19	1.00	0.67	0.00
Rare	1.00	0.95	0.74	0.94	0.68	0.31	0.94	0.67	0.00
Nontarget									
N200									
Target	0.15	0.38	1.00	0.12	0.00	0.07	0.23	0.52	0.27
Rare	0.02	0.32	1.00	0.00	0.32	0.71	0.02	0.51	0.81
Nontarget									
Slow Wave									
Frequent	0.06	0.90	1.00	0.06	0.27	0.00	0.36	0.65	0.02
Target	0.08	0.63	1.00	0.00	0.30	0.46	0.23	0.66	0.48
Rare	0.39	1.00	0.99	0.31	0.51	0.21	0.43	0.82	0.00
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 5.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites within the single line and fragmented procedures.

	Single Line Procedure		Fragmented Procedure			
	Fz	Cz	Pz	Fz	Cz	Pz
N100						
Frequent	107.7	114.7	121.7	108.3	111.5	131.5
Target	115.7	118.0	132.7	127.5	132.7	137.7
Rare	125.2	135.2	142.7	137.5	133.5	140.2
Nontarget						
N200						
Target	276.0	272.0	264.5	279.4	273.3	272.5
Rare	280.2	278.6	279.2	289.8	275.2	274.9
Nontarget						
P300						
Target	365.2	370.5	368.2	367.7	380.2	369.0
Rare	349.2	348.7	358.5	338.2	247.7	346.5
Nontarget						

Table 5.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes within the single line and fragmented procedures.

	df	F	p	mse
N100				
Main Effects				
Procedure PR	1,15	1.103	0.311	838.100
Condition CC	1,7,24.8	12.553	0.000*	753.641
Site ST	1,5,23.2	5.692	0.015*	880.063
Interactions				
PR X CC	1,8,26.3	0.100	0.882	854.233
PR X ST	1,5,22.1	0.375	0.389	520.144
CC X ST	3,3,50.0	0.507	0.697	317.707
PR X CC X ST	3,3,49.1	1.235	0.309	372.278
N200				
Main Effects				
Procedure PR	1,14	0.169	0.686	1479.975
Condition CC	1,14	0.621	0.442	3351.086
Site ST	1,5,21.6	2.565	0.095	489.708
Interactions				
PR X CC	1,14	0.155	0.699	1061.308
PR X ST	1,8,24.9	0.613	0.529	333.213
CC X ST	1,4,19.3	0.160	0.771	471.181
PR X CC X ST	1,6,22.9	0.928	0.390	325.479
P300				
Main Effects				
Procedure PR	1,15	0.086	0.773	1799.239
Condition CC	1,15	5.325	0.036	4379.283
Site ST	1,7,25.9	1.522	0.236	542.311
Interactions				
PR X CC	1,15	1.178	0.296	1528.750
PR X ST	1,5,23.1	1.055	0.348	441.156
CC X ST	1,9,28.7	0.966	0.387	509.400
PR X CC X ST	1,5,22.5	0.011	0.970	626.733

* denotes a p level statistically significant at the 5% level or greater.

Table 5.4 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.002	0.964	14.155
Condition CC	1,4,21	11.104	0.001*	41.723
Chain CH	1,9,28.6	20.786	0.000*	22.303
Site ST	1,1,16.3	13.491	0.002	127.615
Interactions				
PR X CC	1,6,24.4	0.827	0.425	20.133
PR X CH	2,29.4	1.524	0.236	1.206
PR X ST	1,1,16.2	8.321	0.010*	5.592
CC X CH	2,2,33.2	9.788	0.000*	2.771
CC X ST	2,29.4	15.741	0.000*	6.600
CH X ST	1,8,26.7	23.353	0.000*	8.294
PR X CC X CH	2,5,37.6	0.669	0.549	1.991
PR X CC X ST	2,1,31.8	7.324	0.002*	2.640
PR X CH X ST	2,5,36.9	4.384	0.014	0.599
CC X CH X ST	1,8,27.7	16.958	0.000*	0.833
PR X CC X CH X ST	2,9,43.9	3.764	0.018*	0.680
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.097	0.759	1.590
ition CC	1,1,16.0	0.184	0.689	2.999
Chain CH	1,8,27.3	18.800	0.000*	0.534
Site ST	1,1,16.4	7.433	0.013	3.944
Interactions				
PR X CC	1,2,17.4	0.090	0.804	1.610
PR X CH	2,29.5	1.654	0.209	0.113
PR X ST	1,1,16.4	0.309	0.604	0.641
CC X CH	2,1,32.1	0.761	0.482	0.126
CC X ST	1,3,19	0.468	0.546	0.611
CH X ST	2,3,34.1	18.940	0.000*	0.194
PR X CC X CH	2,1,31.7	1.179	0.324	0.130
PR X CC X ST	1,3,18.8	0.316	0.629	0.372
PR X CH X ST	2,9,43	0.512	0.667	0.047
CC X CH X ST	3,45.1	1.940	0.137	0.042
PR X CC X CH X ST	3,44.9	1.851	0.152	0.042

* denotes a p value statistically significant at the 0.05% level or greater.

Table 5.5 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by target and rare nontarget stimuli.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.142	0.710	44.700
Condition CC	1,15	1.178	0.296	210.071
Chain CH	2,29.4	9.466	0.001*	32.129
Site ST	1.1,16.9	6.391	0.019*	127.479
Interactions				
PR X CC	1,15	0.015	0.905	55.677
PR X CH	1.9,28.2	0.737	0.478	3.811
PR X ST	1.1,16.5	6.584	0.018*	14.904
CC X CH	1.5,21.8	0.022	0.946	8.117
CC X ST	1.3,19.4	1.615	0.224	15.791
CH X ST	2.2,32.7	6.491	0.003*	7.251
PR X CC X CH	1.7,26	1.111	0.338	4.256
PR X CC X ST	1.2,18.6	2.864	0.101	8.641
PR X CH X ST	2.6,39.6	3.511	0.028*	1.053
CC X CH X ST	2.8,41.3	16.323	0.00*	1.054
PR X CC X CH X ST	3.1,46.9	3.098	0.034*	0.650
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.298	0.592	1.251
Condition CC	1,15	0.278	0.604	4.988
Chain CH	2,29.4	9.873	0.001*	0.791
Site ST	1.1,17	5.563	0.027	3.109
Interactions				
PR X CC	1,15	0.147	0.706	1.263
PR X CH	1.8,26.6	3.146	0.065	0.089
PR X ST	1.2,17.4	0.734	0.421	0.410
CC X CH	1.4,21.7	0.004	0.985	0.223
CC X ST	1.4,20.5	0.733	0.441	0.389
CH X ST	2.2,33.1	7.771	0.001*	0.175
PR X CC X CH	1.8,27.1	2.367	0.118	0.135
PR X CC X ST	1.4,20.7	0.500	0.544	0.182
PR X CH X ST	2,29.7	9.633	0.001*	0.021
CC X CH X ST	2.9,43.3	13.207	0.000*	0.028
PR X CC X CH X ST	2.9,42.9	3.223	0.034	0.022

* denotes a p value statistically significant at the 0.05% level or greater.

Table 5.6 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 500 - 850 msec.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.000	0.990	45.698
Condition CC	1.4,20.5	17.459	0.000*	74.445
Chain CH	1.7,25.8	7.316	0.004*	23.216
Site ST	2,29.8	24.749	0.000*	36.484
Interactions				
PR X CC	1.6,23.8	0.913	0.392	22.769
PR X CH	1.9,27.9	0.051	0.941	2.468
PR X ST	1.3,19.6	2.473	0.126	4.405
CC X CH	2.2,33.6	6.844	0.002*	5.453
CC X ST	2.5,38	26.928	0.000*	4.730
CH X ST	2.1,30.9	3.756	0.034	8.727
PR X CC X CH	2.2,32.5	0.819	0.456	1.699
PR X CC X ST	1.8,26.9	2.035	0.155	2.612
PR X CH X ST	2.1,32.1	2.524	0.093	1.028
CC X CH X ST	3.7,55.3	10.068	0.000*	1.198
PR X CC X CH X ST	3.7,56.2	0.904	0.461	0.507
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.285	0.600	1.905
Condition CC	1.5,22.5	0.216	0.743	2.616
Chain CH	1.8,26.7	6.027	0.009*	1.215
Site ST	1.9,28	15.630	0.000*	2.397
Interactions				
PR X CC	2,29.3	0.490	0.612	0.867
PR X CH	1.9,27.9	0.337	0.700	0.164
PR X ST	1.3,19.8	0.322	0.637	0.229
CC X CH	3.4,50.6	3.359	0.022*	0.220
CC X ST	2.4,35.6	5.598	0.005*	0.419
CH X ST	2,30.3	3.246	0.053	0.465
PR X CC X CH	2.3,35.2	0.684	0.532	0.100
PR X CC X ST	2.7,40.8	0.739	0.521	0.122
PR X CH X ST	2.3,34.8	3.681	0.030*	0.050
CC X CH X ST	3.8,56.6	5.480	0.001*	0.057
PR X CC X CH X ST	3.6,53.3	1.304	0.283	0.031

* denotes a p value statistically significant at the 0.05% level or greater.

Table 5.7 ANOVA summary table for analysis of mean amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 150 - 350 msec at lateral parietal sites.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	7.119	0.018*	3.723
Condition CC	1.4,20.8	8.385	0.005*	14.629
Chain CH	1,15	4.145	0.060	20.284
Interactions				
PR X CC	1.8,27.7	4.443	0.024*	5.524
PR X CH	1,15	1.610	0.225	0.807
CC X CH	1.6,23.6	4.864	0.023*	0.840
PR X CC X CH	2.29.6	1.785	0.186	0.642

Table 5.8.2 Mean rescaled amplitude elicited by stimuli within the single line procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Ff	Lt	Rf	Rt
P300						
Target	0.27	0.83	0.00	0.78	0.14	0.46
Rare	0.38	0.93	0.00	0.42	0.15	0.58
Nontarget						
N100						
Frequent	0.98	0.92	1.00	0.72	0.97	0.75
Target	0.97	0.94	0.96	0.68	1.00	0.77
Rare	0.93	0.87	1.00	0.57	0.89	0.69
Nontarget						
N200						
Target	0.03	0.47	0.10	0.00	0.17	0.32
Rare	0.18	0.78	0.04	0.09	0.00	0.36
Nontarget						
Slow Wave						
Frequent	0.07	0.94	0.01	0.54	0.41	1.00
Target	0.06	0.90	0.00	0.38	0.23	0.67
Rare	0.01	1.00	0.05	0.65	0.00	0.70
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 5.8.3 Mean amplitude elicited by stimuli within the fragmented procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain				
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	11.42	18.48	20.98	6.67	10.94	14.03	8.72	12.95	16.19
Rare	6.37	14.02	17.91	1.54	9.53	15.12	3.68	10.98	17.59
N100									
Frequent	2.42	1.83	0.65	2.63	0.49	-4.83	2.07	0.61	-4.22
Target	3.52	3.13	1.50	3.03	0.63	-5.93	2.88	-1.50	-3.73
Rare	-0.87	-0.41	-0.63	-1.10	-1.69	-2.42	-0.73	-1.50	-2.01
N200									
Target	2.63	4.48	9.14	2.09	2.65	3.87	2.57	4.54	6.72
Rare	0.65	4.07	7.07	-1.16	1.32	4.87	-0.45	2.96	7.88
Slow Wave									
Frequent	0.09	2.04	1.69	0.21	1.40	0.33	0.34	2.19	1.01
Target	2.51	9.04	10.23	1.33	5.08	5.92	3.01	6.87	6.84
Rare	1.09	4.94	5.17	0.60	4.91	4.15	0.99	4.35	5.13
Lat. Par.									
Frequent						3.51			4.20
Target						4.19			6.38
Rare						7.02			8.61
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec
 Lat. Par. denotes the activity elicited within a latency range of 150 - 350 msec at lateral parietal sites.

Table 5.8.4 Mean rescaled amplitude elicited by stimuli within the fragmented procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Ff	Lt	Rf	Rt
P300						
Target	0.33	0.83	0.00	0.29	0.14	0.44
Rare	0.29	0.76	0.00	0.48	0.13	0.57
Nontarget						
N100						
Frequent	0.97	0.89	1.00	0.71	0.93	0.73
Target	1.00	0.96	0.95	0.69	0.93	0.78
Rare	0.77	1.00	0.66	0.36	0.84	0.46
Nontarget						
N200						
Target	0.07	0.48	0.00	0.09	0.07	0.35
Rare	0.20	0.58	0.00	0.27	0.08	0.45
Nontarget						
Slow Wave						
Frequent	0.17	0.94	0.04	0.68	0.26	1.00
Target	0.13	0.86	0.00	0.42	0.19	0.62
Rare	0.17	0.94	0.00	0.94	0.08	0.82
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 6.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites within two and three condition procedures.

Two Condition Procedure

	df	F	p	mse
N100				
Main Effects				
Condition CC	1,15	0.145	0.712	564.125
Site ST	1.5,18.9	5.125	0.050*	556.321
Interactions				
CC X ST	1.4,21.5	3.754	0.125	366.136
N200				
Main Effects				
Condition CC	1,15	0.552	0.467	754.800
Site ST	1.3,18.9	4.150	0.048*	769.244
Interactions				
CC X ST	1.6,23.5	0.720	0.463	734.533
P300				
Main Effects				
Condition CC	1,15	1.672	0.206	923.011
Site ST	1.6,23.8	1.672	0.212	256.400
Interactions				
CC X ST	1.4,21.6	1.108	0.330	354.444

Three Condition Procedure

N100				
Main Effects				
Condition CC	1.9,28.9	0.730	0.484	1227.059
Site ST	2.0,30.0	12.107	0.000*	901.904
Interactions				
CC X ST	2.8,42.3	0.162	0.912	586.037
N200				
Main Effects				
Condition CC	1.7,25.1	12.241	0.000*	932.333
Site ST	1.5,22.0	10.121	0.002*	677.889
Interactions				
CC X ST	2.1,31.8	0.544	0.595	1004.467
P300				
Main Effects				
Condition CC	1.5,22.2	3.753	0.051	1376.556
Site ST	1.9,28.2	1.399	0.264	249.222
Interactions				
CC X ST	2.4,35.3	3.472	0.035*	299.067

* denotes a p level statistically significant at the 0.05% level or greater.

Table 6.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes.

Two Condition Procedure

	Fz	Cz	Pz
N100			
Frequent	106.0	108.2	131.2
Target	115.2	118.2	125.0
N200			
Frequent	264.0	238.2	241.5
Target	259.0	248.7	248.5
P300			
Frequent	367.7	371.2	365.2
Target	364.0	375.0	375.2

Three Condition Modality

	Fz	Cz	Pz
N100			
Frequent	104.5	128.5	138.2
Target	104.0	121.2	129.0
Rare	98.0	120.7	126.7
Nontarget			
N200			
Frequent	278.5	258.0	243.0
Target	266.5	251.2	250.2
Rare	242.7	225.2	226.2
Nontarget			
P300			
Frequent	383.2	384.0	378.7
Target	362.0	381.2	383.5
Rare	364.7	360.5	359.7
Nontarget			

Table 6.4 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by simple and target stimuli within the two condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,15	0.103	0.752	7.733
Chain CH	1.9,29.1	17.612	0.000*	4.600
Site ST	1,15.4	24.894	0.000*	39.001
Interactions				
CC X CH	1.4,21.2	1.527	0.239	0.805
CC X ST	1,15.4	0.966	0.341	3.451
CH X ST	2.2,32.7	34.948	0.000*	1.466
CC X CH X ST	2.2,33.1	1.334	0.279	0.179
Rescaled Amplitude				
Main Effects				
Condition CC	1,15	0.312	0.583	0.148
Chain CH	1.9,28.9	17.065	0.000*	0.073
Site ST	1,15.4	24.844	0.000*	0.600
Interactions				
CC X CH	1.4,21.7	0.950	0.372	0.014
CC X ST	1,158.5	0.065	0.809	0.052
CH X ST	2.2,32.6	35.073	0.000*	0.023
CC X CH X ST	2.2,32.4	1.677	0.202	0.003

Table 6.5 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by simple and target stimuli within the two condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,15	3.317	0.089	25.638
Chain CH	1.7,24.9	4.045	0.037*	8.874
Site ST	1.2,17.7	7.303	0.012*	28.326
Interactions				
CC X CH	2,29.9	4.751	0.016*	1.023
CC X ST	1.2,17.6	18.224	0.000*	4.684
CH X ST	2.6,39.2	9.656	0.000*	1.825
CC X CH X ST	2.9,42.9	1.856	0.154	0.262
Rescaled Amplitude				
Main Effects				
Condition CC	1,15	0.239	0.631	1.933
Chain CH	1.7,25.7	4.475	0.026	0.474
Site ST	1.2,17.8	4.555	0.042*	1.464
Interactions				
CC X CH	1.9,29.1	5.947	0.007*	0.124
CC X ST	1.2,18.2	3.059	0.091	0.412
CH X ST	2.5,37.4	9.058	0.000*	0.098
CC X CH X ST	2.4,35.6	4.324	0.016*	0.028

* denotes a p value statistically significant at the 0.05% level or greater.

Table 6.8 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by simple, target and complex stimuli within the three condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,8,26.7	4.736	0.020*	29.238
Chain CH	1,8,26.7	30.281	0.000*	5.595
Site ST	1,15.5	16.024	0.001	72.907
Interactions				
CC X CH	2,8,41.5	1.134	0.345	1.730
CC X ST	1,6,24.4	5.026	0.020*	6.273
CH X ST	1,8,27.4	26.769	0.000*	2.992
CC X CH X ST	4,1,60.8	2.138	0.086	0.365
Rescaled Amplitude				
Main Effects				
Condition CC	1,6,23.5	0.060	0.904	0.727
Chain CH	1,7,26.2	28.603	0.000*	0.116
Site ST	1,15.5	14.810	0.001*	1.422
Interactions				
CC X CH	2,5,37.7	2.521	0.082	0.040
CC X ST	1,9,28.1	0.313	0.719	0.147
CH X ST	1,8,27.1	25.102	0.000*	0.060
CC X CH X ST	3,7,54.8	1.164	0.337	0.009

Table 6.9 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by simple, target and complex stimuli within the three condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,8,26.6	1.846	0.181	50.144
Chain CH	2,29.3	2.687	0.086	13.768
Site ST	1,2,17.8	22.531	0.000*	51.115
Interactions				
CC X CH	3,1,46.5	8.644	0.000*	2.096
CC X ST	2,2,32.3	17.603	0.000*	8.512
CH X ST	3,2,48.4	5.081	0.003*	2.934
CC X CH X ST	4,7,70.0	7.695	0.000*	0.618
Rescaled Amplitude				
Main Effects				
Condition CC	1,15	0.239	0.631	1.933
Chain CH	1,7,25.7	4.475	0.026*	0.474
Site ST	1,2,17.8	4.555	0.042*	1.464
Interactions				
CC X CH	1,9,29.1	5.947	0.007*	0.124
CC X ST	1,2,18.2	3.059	0.091	0.412
CH X ST	2,5,37.4	9.058	0.000*	0.098
CC X CH X ST	2,4,35.6	4.324	0.016*	0.028

* denotes a p value statistically significant at the 0.05% level or greater.

Table 6.6 ANOVA summary table for analysis mean amplitude and rescaled amplitude elicited by simple and target stimuli within a latency range of 500 - 850 msec within the two condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,15	15.432	0.001*	13.329
Chain CH	2,29.9	9.755	0.001*	3.378
Site ST	1.4,20.5	10.292	0.002*	11.737
Interactions				
CC X CH	1.7,25.3	5.453	0.014*	2.453
CC X ST	1.2,17.9	7.809	0.009*	6.489
CH X ST	1.9,29	20.658	0.000*	1.138
CC X CH X ST	2.7,40.9	8.539	0.000*	0.438
Rescaled Amplitude				
	df	F	p	mse
Main Effects				
Condition CC	1,15	0.247	0.625	3.570
Chain CH	2,30	6.884	0.003*	0.258
Site ST	1.3,19.8	7.806	0.007*	0.908
Interactions				
CC X CH	1.6,23.8	0.655	0.493	0.179
CC X ST	1.2,18.6	3.230	0.082	0.538
CH X ST	1.8,26.9	20.485	0.000*	0.093
CC X CH X ST	3,45	7.166	0.000*	0.034

* denotes a p value statistically significant at the 0.05 % level or greater.

Table 6.10 ANOVA summary table for analysis of amplitude and rescaled amplitude elicited by simple, target and complex stimuli within a latency range of 500 - 850 msec within the three condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,8,27.1	2.835	0.081	20.826
Chain CH	1,7,25.6	7.094	0.005*	6.024
Site ST	1,1,16.9	7.929	0.010*	19.135
Interactions				
CC X CH	3,1,47.1	3.274	0.027	1.485
CC X ST	1,9,28.1	20.976	0.000*	3.440
CH X ST	2,1,31.0	18.620	0.000*	1.399
CC X CH X ST	4,6,68.7	3.803	0.005*	0.600
Rescaled Amplitude				
Main Effects				
Condition CC	1,4,21.7	0.024	0.942	4.710
Chain CH	1,8,27.1	5.263	0.014*	0.586
Site ST	1,1,17.1	5.789	0.024*	1.785
Interactions				
CC X CH	3,5,51.8	1.039	0.391	0.157
CC X ST	2,5,36.9	7.862	0.001*	0.320
CH X ST	2,3,35.1	15.046	0.000*	0.148
CC X CH X ST	4,1,61.1	2.547	0.048*	0.069

Table 6.11 ANOVA summary table for analysis of mean amplitude elicited by simple, target and complex stimuli within a latency range of 150 - 350 msec at lateral parietal sites within the three condition procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1,7,25.9	27.68	0.000*	4.408
Chain CH	1,15	2.660	0.124	5.058
Interactions				
CC X CH	1,6,24.5	3.603	0.051	0.728

* denotes a p value statistically significant at the 0.05% level or greater.

Table 6.12 ANOVA summary table for analysis of target P300 amplitude and rescaled amplitude elicited within the three and two condition procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.059	0.811	36.271
Chain CH	1,9,27.9	29.388	0.000*	20.670
Site ST	1,4,20.8	31.532	0.000*	42.495
Interactions				
PR X CH	1,9,28.5	0.482	0.611	1.432
PR X ST	1,1,17	6.134	0.021*	2.617
CH X ST	3,44.3	18.021	0.000*	0.293
PR X CH X ST	2,3,33.9	2.151	0.127	0.293
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.054	0.819	0.213
Chain CH	1,9,27.9	29.346	0.000*	0.127
Site ST	1,4,20.9	31.198	0.000*	0.260
Interactions				
PR X CH	1,9,28.3	0.806	0.454	0.009
PR X ST	1,2,17.4	1.517	0.240	0.020
CH X ST	2,9,44	18.098	0.000*	0.016
PR X CH X ST	2,4,35.5	4.049	0.021*	0.002

ANOVA summary table for analysis of simple stimuli P300 amplitude and rescaled amplitude elicited within the three and two condition procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	6.814	0.020*	33.066
Chain CH	1,7,25.3	30.802	0.000*	17.345
Site ST	1,5,22.9	19.939	0.000*	27.036
Interactions				
PR X CH	1,9,29	1.258	0.299	1.482
PR X ST	1,5,23.1	1.762	0.190	0.892
CH X ST	3,1,46.6	11.942	0.000*	2.336
PR X CH X ST	2,8,42.3	0.659	0.571	0.351
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.095	0.761	0.396
Chain CH	1,7,25.1	30.782	0.000*	0.216
Site ST	1,5,22.9	19.978	0.000*	0.336
Interactions				
PR X CH	1,9,28.1	0.018	0.978	0.018
PR X ST	1,7,25.4	1.322	0.283	0.010
CH X ST	3,1,46.6	12.050	0.000*	0.029
PR X CH X ST	2,8,41.6	0.443	0.707	0.004

* denotes a p value statistically significant at the 0.05% level or greater.

Table 6.13.1 Mean amplitude elicited by stimuli within the two condition procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain				
	Fz	Cz	Fz	Pz	Lt	Lp	Rf	Rt	Rp
P300									
Simple	6.57	12.36	3.89	11.83	7.38	7.58	4.71	7.07	7.85
Target	8.78	15.19	5.61	17.50	9.13	12.24	8.37	11.01	12.42
N100									
Simple	2.19	1.09	2.29	-0.93	0.01	-4.94	2.55	0.71	-4.59
Target	2.32	1.21	2.16	-1.34	-0.29	-5.57	3.09	0.98	-5.13
N200									
Simple	-1.05	2.46	-0.79	5.37	1.61	3.50	-0.16	1.86	3.53
Target	2.35	3.43	1.92	5.12	1.62	2.48	3.06	3.17	2.95
Slow Wave									
Simple	0.26	2.37	1.02	2.24	1.85	0.75	1.25	2.18	0.99
Target	0.73	5.04	0.63	6.24	1.98	3.69	2.02	4.18	3.61

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 6.13.2 Mean rescaled amplitude elicited by stimuli within the two condition procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Lf	Lt	Rf	Rt
P300						
Simple	0.32	1.00	0.00	0.41	0.09	0.37
Target	0.27	0.81	0.00	0.29	0.23	0.51
N100						
Simple	0.95	0.81	0.96	0.66	1.00	0.75
Target	0.91	0.78	0.89	0.61	1.00	0.76
N200						
Simple	0.00	0.55	0.04	0.41	0.14	0.45
Target	0.21	0.52	0.09	0.00	0.41	0.44
Slow Wave						
Simple	0.00	1.00	0.36	0.75	0.47	0.91
Target	0.02	0.78	0.00	0.24	0.25	0.63

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 6.13.3 Mean amplitude elicited by stimuli within the three condition procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Simple	8.31	14.90	13.81	5.42	9.04	9.06	6.15	9.04	9.42
Target	7.98	15.07	18.48	4.74	8.77	12.70	7.06	11.01	13.48
Complex	9.41	16.69	17.39	5.63	10.79	12.87	6.98	11.11	14.94
N100									
Simple	3.11	1.53	-1.02	3.42	0.17	-5.58	3.32	0.81	-5.77
Target	2.69	1.90	0.63	2.38	0.16	-3.78	3.02	1.31	-3.05
Complex	3.87	3.77	2.07	3.59	1.88	-2.17	3.99	2.21	-2.02
N200									
Simple	-0.31	3.09	6.35	0.27	2.19	3.76	0.62	2.55	4.12
Target	2.16	3.13	6.73	1.64	1.43	3.39	2.83	3.42	7.95
Complex	-3.24	0.84	6.20	-2.85	1.04	6.39	-2.21	1.53	7.56
Slow Wave									
Simple	1.33	3.26	3.02	1.89	2.49	1.15	2.49	3.43	1.67
Target	0.18	4.81	6.48	0.03	2.30	3.95	1.54	4.19	3.90
Complex	2.92	4.09	4.06	2.89	4.45	2.32	3.31	4.57	2.61
Lat. Par.									
Simple						2.59			2.71
Target						3.81			5.03
Complex						6.09			7.01

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Lat. Par. denotes the activity elicited within a latency range of 150 - 350 msec at lateral parietal sites.

Table 6.13.4 Mean rescaled amplitude elicited by stimuli within the three condition procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Simple	0.30	1.00	0.88	0.00	0.38	0.39	0.08	0.38	0.42
Target	0.24	0.75	1.00	0.00	0.29	0.58	0.17	0.46	0.64
Complex	0.32	0.94	1.00	0.00	0.44	0.62	0.12	0.46	0.79
N100									
Simple	0.96	0.79	0.52	1.00	0.65	0.02	0.98	0.72	0.00
Target	0.95	0.83	0.65	0.91	0.58	0.00	1.00	0.75	0.12
Complex	0.98	0.96	0.69	0.93	0.65	0.00	1.00	0.71	0.02
N200									
Simple	0.00	0.51	1.00	0.08	0.37	0.61	0.14	0.43	0.66
Target	0.13	0.32	1.00	0.04	0.00	0.37	0.26	0.37	0.66
Complex	0.00	0.37	0.87	0.03	0.39	0.89	0.09	0.44	1.00
Slow Wave									
Simple	0.08	0.93	0.82	0.33	0.59	0.00	0.59	1.00	0.24
Target	0.02	0.74	1.00	0.00	0.35	0.01	0.23	0.65	0.60
Complex	0.22	1.00	0.63	0.21	0.77	0.00	0.36	0.81	0.11

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 7.4 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli across the target heterogeneous and target homogeneous procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.100	0.756	29.841
Condition CC	2,29.9	0.772	0.469	25.146
Chain CH	1.8,27.4	13.862	0.000*	18.551
Site ST	1,15.7	27.265	0.000*	59.311
Interactions				
PR X CC	1.8,26.9	4.694	0.021*	15.917
PR X CH	1.6,24	0.945	0.382	2.092
PR X ST	1.1,16.6	0.903	0.364	3.380
CC X CH	3.1,46.6	2.125	0.108	1.268
CC X ST	2.1,31.5	0.625	0.547	5.173
CH X ST	1.3,19.8	23.109	0.000*	7.128
PR X CC X CH	3.2,48.7	0.832	0.489	1.244
PR X CC X ST	1.6,24.3	0.661	0.493	3.565
PR X CH X ST	3,45.7	1.814	0.158	0.272
CC X CH X ST	4.9,73.1	4.300	0.002*	0.308
PR X CC X CH X ST	4.1,61.7	1.917	0.118	0.347
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.148	0.704	0.644
Condition CC	2,29.3	0.062	0.937	0.580
Chain CH	1.8,27.2	13.644	0.000*	0.411
Site ST	1,15.6	27.761	0.000*	1.281
Interactions				
PR X CC	1.8,27.2	0.224	0.778	0.327
PR X CH	1.6,24.5	0.575	0.535	0.042
PR X ST	1.1,16.9	0.112	0.771	0.064
CC X CH	2.8,42.2	0.995	0.398	0.026
CC X ST	2,30.5	0.206	0.817	0.106
CH X ST	1.3,19.7	23.18	0.000*	0.155
PR X CC X CH	3.2,48.6	0.865	0.471	0.027
PR X CC X ST	1.7,26	0.118	0.861	0.065
PR X CH X ST	3,44.3	1.115	0.354	0.005
CC X CH X ST	5.2,77.8	0.706	0.624	0.006
PR X CC X CH X ST	4.5,68.0	2.278	0.062	0.007

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.5 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli across the target heterogeneous and target homogeneous procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	0.008	0.931	20.897
Condition CC	1.8,27.6	1.095	0.346	44.429
Chain CH	1.8,26.5	1.235	0.304	37.704
Site ST	1.3,19.7	21.389	0.000*	67.337
Interactions				
PR X CC	1.7,25.2	2.639	0.099	18.433
PR X CH	1.9,28.2	0.609	0.539	2.235
PR X ST	1.2,17.7	0.258	0.656	5.575
CC X CH	3.1,46.4	3.907	0.014*	3.349
CC X ST	2.4,36.3	11.636	0.000*	6.044
CH X ST	2.4,36.1	3.372	0.038*	10.179
PR X CC X CH	2.6,39.2	6.345	0.002*	1.843
PR X CC X ST	1.6,23.4	13.621	0.000*	6.749
PR X CH X ST	3.2,47.7	2.209	0.096	0.673
CC X CH X ST	4,60.5	2.982	0.026	0.802
PR X CC X CH X ST	3,45.3	2.567	0.066	0.798
Rescaled Amplitude				
Main Effects				
Procedure PR	1,15	0.398	0.282	0.708
Condition CC	1.6,24.4	0.190	0.783	1.353
Chain CH	1.8,26.3	1.842	0.182	1.170
Site ST	1.3,19	17.629	0.000*	2.169
Interactions				
PR X CC	1.9,28.6	0.574	0.560	0.498
PR X CH	1.9,28.1	0.255	0.762	0.072
PR X ST	1.1,16.8	0.086	0.801	0.167
CC X CH	2.9,43.3	5.712	0.002*	0.093
CC X ST	2.5,37.9	3.078	0.047*	0.168
CH X ST	2.4,35.7	3.911	0.023*	0.305
PR X CC X CH	3.2,47.8	7.347	0.000*	0.049
PR X CC X ST	1.6,23.5	2.916	0.085	0.177
PR X CH X ST	3.2,47.9	2.513	0.066	0.024
CC X CH X ST	4.6,69.5	3.819	0.005*	0.022
PR X CC X CH X ST	4.3,64	4.828	0.001*	0.017

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.6 ANOVA summary table for analysis of mean amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 500 - 850 msec across the target heterogeneous and target homogeneous procedures.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	12.908	0.003*	11.231
Condition CC	1.5,22	10.376	0.002*	46.896
Chain CH	1.5,22.8	8.090	0.004*	14.084
Site ST	1.4,21.4	9.211	0.003*	32.436
Interactions				
PR X CC	1.9,27.9	11.500	0.000*	14.953
PR X CH	1.9,29.2	2.936	0.070	1.148
PR X ST	1.3,19.6	1.360	0.269	1.851
CC X CH	2.6,39.2	4.576	0.010*	2.980
CC X ST	1.9,27.8	15.303	0.000*	7.201
CH X ST	2.4,36.4	24.959	0.000*	2.990
PR X CC X CH	3,45.5	1.737	0.173	1.024
PR X CC X ST	1.4,21.5	1.076	0.339	2.499
PR X CH X ST	3.4,50.7	2.914	0.038*	0.378
CC X CH X ST	3.8,57.6	13.955	0.000*	0.875
PR X CC X CH X ST	4,60.7	1.399	0.246	0.469

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.6.1 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 500 - 850 msec across the target heterogeneous procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.3,20.2	14.502	0.000*	26.524
Chain CH	1.7,25.5	9.647	0.001*	6.870
Site ST	1.5,22.2	7.596	0.006*	16.237
Interactions				
CC X CH	2.6,39.2	5.636	0.004*	1.507
CC X ST	1.7,26.1	8.269	0.002*	5.828
CH X ST	2.4,36	18.742	0.000*	1.550
CC X CH X ST	4.1,61.8	9.938	0.000*	0.667
Rescaled Amplitude				
Main Effects				
Condition CC	1.6,24.1	0.052	0.918	3.332
Chain CH	1.8,27.1	6.974	0.005*	0.947
Site ST	1.5,22.4	5.311	0.020*	1.825
Interactions				
CC X CH	3.3,48.8	2.245	0.090	0.190
CC X ST	1.7,25.9	2.331	0.124	0.525
CH X ST	2.1,30.9	12.946	0.000*	0.197
CC X CH X ST	4.9,73.2	0.975	0.436	0.066

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.6.2 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 500 - 850 msec across the target homogeneous procedure.

Amplitude	df	F	p	mse
Main Effects				
Condition CC	1.7,25.7	7.753	0.002*	35.325
Chain CH	1.4,21.6	6.103	0.014*	8.362
Site ST	1.3,20.1	9.859	0.003*	18.051
Interactions				
CC X CH	2.6,39.1	2.773	0.062	2.497
CC X ST	2.4,36.5	16.709	0.000*	3.872
CH X ST	2.7,40	25.672	0.000*	1.819
CC X CH X ST	4.8,71.8	9.210	0.000*	0.677
Rescaled Amplitude				
Main Effects				
Condition CC	1.7,25.9	0.004	0.993	3.638
Chain CH	1.6,23.6	4.608	0.028*	0.680
Site ST	1.3,19.9	7.321	0.009*	1.460
Interactions				
CC X CH	2.7,40.8	0.939	0.421	0.201
CC X ST	2.2,32.3	4.491	0.017*	0.337
CH X ST	2.3,34.8	20.551	0.000*	0.146
CC X CH X ST	4,59.9	2.101	0.092	0.054

Table 7.7 ANOVA summary table for analysis of mean amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 150 - 350 msec at lateral parietal sites.

Amplitude	df	F	p	mse
Main Effects				
Procedure PR	1,15	7.119	0.018*	3.723
Condition CC	1.4,20.8	8.385	0.005*	14.629
Chain CH	1,15	4.145	0.060	20.284
Interactions				
PR X CC	1.8,27.7	4.443	0.024*	5.524
PR X CH	1,15	1.610	0.225	0.807
CC X CH	1.6,23.6	4.864	0.023*	0.840
PR X CC X CH	2,29.6	1.785	0.186	0.642

* denotes a p value statistically significant at the 0.05% level or greater.

Table 7.8.1 Mean amplitude elicited by stimuli within the target homogeneous procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. Mean amplitude elicited at lateral parietal sites is also shown.

	Midline Chain			Left Chain		Right Chain			
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Frequent	5.04	7.41	7.03	3.78	5.42	4.89	4.73	5.67	4.27
Target	8.95	15.32	17.89	6.87	10.17	12.68	9.01	11.48	11.42
Rare	8.15	14.99	16.01	5.76	11.31	12.59	6.75	11.94	12.14
Nontarget									
N100									
Frequent	1.74	1.26	0.37	1.88	0.31	-3.18	1.87	0.55	-4.37
Target	1.71	1.29	0.09	1.95	0.20	-3.77	1.89	0.35	-5.01
Rare	2.88	2.80	1.01	2.83	1.19	-2.68	3.15	1.37	-4.48
Nontarget									
N200									
Frequent	2.48	4.65	5.95	2.04	3.54	4.92	2.64	3.43	3.65
Target	2.22	3.87	7.75	2.65	3.04	5.71	3.24	3.79	5.08
Rare	1.78	5.57	9.39	1.32	4.89	9.38	2.11	4.59	7.76
Nontarget									
Slow Wave									
Frequent	0.88	1.95	1.63	0.87	1.51	0.55	1.25	1.76	0.64
Target	0.78	6.10	6.98	0.91	3.85	3.73	3.43	6.46	3.87
Rare	0.82	2.93	2.21	0.13	0.90	0.27	1.27	2.09	0.82
Nontarget									
Lat. Par.									
Frequent						3.69			2.39
Target						5.19			4.41
Rare						7.26			5.72
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec
 Lat. Par. denotes the activity elicited within a latency range of 150 - 350 msec at lateral parietal sites.

Table 7.8.2 Mean rescaled amplitude elicited by stimuli within the target homogeneous procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Frequent	0.34	1.00	0.89	0.00	0.45	0.30	0.26	0.52	0.13
Target	0.18	0.76	1.00	0.00	0.30	0.43	0.19	0.42	0.41
Rare	0.23	0.89	1.00	0.00	0.53	0.66	0.09	0.59	0.62
Nontarget									
N100									
Frequent	0.97	0.94	0.66	0.99	0.77	0.22	1.00	0.80	0.00
Target	0.92	0.88	0.64	0.91	0.68	0.23	1.00	0.74	0.00
Rare	0.93	0.85	0.71	0.89	0.63	0.13	1.00	0.77	0.00
Nontarget									
N200									
Frequent	0.11	0.67	1.00	0.00	0.38	0.74	0.15	0.35	0.41
Target	0.00	0.29	1.00	0.07	0.14	0.63	0.18	0.28	0.52
Rare	0.03	0.051	1.00	0.00	0.42	0.99	0.07	0.39	0.78
Nontarget									
Slow Wave									
Frequent	0.19	0.84	0.74	0.32	0.78	0.00	0.48	1.00	0.18
Target	0.00	0.83	1.00	0.08	0.46	0.52	0.31	0.45	0.47
Rare	0.24	1.00	0.87	0.23	0.61	0.07	0.46	0.86	0.00
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 7.8.3 Mean amplitude elicited by stimuli within the target heterogeneous procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. Mean amplitude elicited at lateral parietal sites is also shown.

	Midline Chain		Pz	Left Chain			Right Chain		Rp
	Fz	Cz		Lf	Lt	Lp	Rf	Rt	
P300									
Frequent	3.57	5.23	4.72	2.78	4.07	3.37	3.91	4.56	2.84
Target	12.50	20.47	24.19	8.65	13.82	17.99	11.55	16.52	17.78
Rare	4.61	7.29	7.65	3.13	4.97	5.01	4.78	6.36	5.41
Nontarget									
N100									
Frequent	1.26	1.10	-0.42	1.38	0.16	-2.87	1.44	0.31	-4.16
Target	2.71	2.42	0.56	2.69	0.92	-2.54	3.34	1.31	-4.34
Rare	1.55	1.01	0.12	1.30	-0.37	-3.57	1.99	0.54	-4.44
Nontarget									
N200									
Frequent	2.89	5.35	6.51	2.14	3.98	5.78	2.63	3.67	4.52
Target	1.03	2.84	8.91	1.28	3.72	9.20	1.98	4.64	8.58
Rare	2.96	5.51	7.32	1.89	3.60	5.44	2.93	4.05	4.88
Nontarget									
Slow Wave									
Frequent	0.78	1.98	1.79	1.01	1.86	0.41	1.31	2.27	0.76
Target	0.18	6.22	7.45	0.81	3.55	3.95	2.41	5.60	3.63
Rare	2.96	5.39	4.99	2.91	4.13	2.41	3.67	4.95	2.16
Nontarget									
Lat. Par.									
Frequent						4.06			2.67
Target						8.23			7.20
Rare						4.71			4.01
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Lat. Par. denotes the activity elicited within a latency range of 150 - 350 msec at lateral parietal sites.

Table 7.8.4 Mean rescaled amplitude elicited by stimuli within the target heterogeneous procedure within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain		Right Chain			
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	0.32	1.00	0.79	0.00	0.53	0.24	0.45	0.73	0.02
Rare	0.25	0.26	1.00	0.00	0.33	0.60	0.18	0.51	0.58
Nontarget	0.33	0.92	1.00	0.00	0.41	0.42	0.37	0.71	0.51
N100									
Frequent	0.98	0.90	0.64	1.00	0.75	0.19	0.99	0.78	0.00
Target	0.96	0.91	0.73	1.00	0.75	0.19	0.99	0.77	0.00
Rare	0.96	0.95	0.72	0.96	0.74	0.27	1.00	0.76	0.00
Nontarget									
N200									
Frequent	0.17	0.74	1.00	0.00	0.42	0.83	0.11	0.35	0.54
Target	0.00	0.22	0.96	0.03	0.33	1.00	0.12	0.44	0.93
Rare	0.19	0.66	1.00	0.00	0.31	0.65	0.19	0.39	0.55
Nontarget									
Slow Wave									
Frequent	0.23	1.00	0.77	0.23	0.69	0.00	0.50	0.86	0.06
Target	0.00	0.85	1.00	0.02	0.49	0.47	0.42	0.91	0.49
Rare	0.42	1.00	0.96	0.16	0.45	0.00	0.61	0.92	0.43
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 8a.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites between groups of subjects within the auditory modality.

	df	F	p	mse
N100				
Main Effects				
Group GR	1,30	0.098	0.756	1307.252
Condition CC	1.7,49.5.5	4.829	0.017*	147.763
Site ST	1.2,37.2	3.207	0.074	78.607
Interactions				
GR X CC	1.7,49.5	0.663	0.517	147.763
GR X ST	1.2,37.2	4.404	0.035*	78.607
CC X ST	2.5,73.9	0.526	0.629	30.535
GR X CC X ST	2.5,73.9	0.448	0.680	30.535
N200				
Target Stimuli				
Main Effects				
Group GR	1,30	6.741	0.015*	2151.500
Site ST	1.7,50.5	2.914	0.072	222.433
Interactions				
GR X ST	1.7,50.5	0.774	0.444	222.433
Rare Nontarget Stimuli				
Main Effects				
Group GR	1,30	1.777	0.193	1465.544
Site ST	1.6,48.8	1.105	0.330	191.144
Interactions				
GR X ST	1.6,48.8	1.848	0.175	191.144
P300				
Target Stimuli				
Main Effects				
Group GR	1,30	9.789	0.004*	2003.011
Site ST	1.9,55.8	1.691	0.196	484.878
Interactions				
GR X ST	1.9,55.8	2.615	0.086	484.878
Rare Nontarget Stimuli				
Main Effects				
Group GR	1,30	22.752	0.000*	2081.011
Site ST	2.0,60.0	0.084	0.919	512.444
Interactions				
GR X ST	2.0,60.0	5.375	0.007*	512.444
Young Group				
Main Effects				
Condition CC	1,15	1.279	0.277	1605.144
Site ST	2.0,29.9	2.516	0.098	439.511
Interactions				
CC X ST	1.6,24.0	0.861	0.411	322.978
Elderly Group				
Main Effects				
Condition CC	1,15	0.651	0.430	1598.389
Site ST	1.9,28.3	5.108	0.014*	608.700
Interactions				
CC X ST	1.7,26.0	0.629	0.517	623.456

* denotes a p level statistically significant at the 0.05% level or greater.

Table 8a.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes between groups of subjects within the auditory modality.

Young Group				Elderly Group		
	Fz	Cz	Pz	Fz	CzPz	
N100						
Frequent	107.2	103.0	100.2	102.2	104.5	104.0
Target	107.5	104.5	99.7	104.2	105.0	103.0
Rare	110.2	105.0	104.7	109.5	111.5	110.0
Nontarget						
N200						
Target	219.5	217.5	208.5	244.5	237.2	237.5
Rare	206.0	207.0	201.5	220.0	209.7	216.0
Nontarget						
P300						
Target	324.7	318.7	322.5	339.2	351.2	361.2
Rare	322.0	304.5	311.7	346.0	364.7	360.7
Nontarget						

Table 8a.10 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by auditory stimuli between the elderly and young groups of subjects.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	0.003	0.960	172.957
Condition CC	1.9,56.2	2.713	0.079	16.228
Chain CH	1.7,50.3	47.084	0.000*	5.330
Site ST	1.5,44.7	142.554	0.000*	12.536
Interactions				
GP X CC	1.9,56.2	2.703	0.075	16.228
GP X CH	1.7,50.3	1.092	0.343	5.330
GP X ST	1.5,44.7	0.432	0.650	12.536
CC X CH	3.5,106.2	0.560	0.670	1.023
CC X ST	2.8,83.5	3.298	0.027*	1.959
CH X ST	3.4,101.2	3.835	0.009*	1.276
GP X CC X CH	3.5,106.2	1.964	0.114	1.023
GP X CC X ST	2.8,83.5	0.995	0.393	1.959
GP X CH X ST	3.4,101.2	1.105	0.356	1.276
CC X CH X ST	4.1,124.2	1.014	0.406	0.285
GP X CC X CH X ST	4.1,124.2	0.724	0.580	0.285
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.005	0.943	4.323
Condition CC	1.8,55.3	0.089	0.901	0.408
Chain CH	1.7,50.5	47.413	0.000*	0.132
Site ST	1.5,44.6	142.937	0.000*	0.313
Interactions				
GP X CC	1.8,55.3	0.282	0.737	0.408
GP X CH	1.7,50.5	1.108	0.331	0.132
GP X ST	1.5,44.6	0.449	0.582	0.313
CC X CH	3.5,105.1	1.038	0.387	0.025
CC X ST	2.8,84	2.063	0.116	0.048
CH X ST	3.4,100.9	3.858	0.009*	0.032
GP X CC X CH	3.5,105.1	1.346	0.262	0.025
GP X CC X ST	2.8,84	0.834	0.470	0.048
GP X CH X ST	3.4,100.9	1.122	0.348	0.032
CC X CH X ST	4.1,122.5	1.028	0.398	0.007
GP X CC X CH X ST	4.1,122.5	0.717	0.583	0.007

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8a.11.1 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by target stimuli between the young and elderly groups of subjects within the auditory modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,27	0.258	0.614	130.748
Chain CH	1.9,50.7	1.572	0.219	13.470
Site ST	1.3,35.8	11.404	0.001*	16.374
Interactions				
GP X CH	1.9,50.7	6.622	0.003*	13.470
GP X ST	1.3,35.8	12.361	0.000*	16.374
CH X ST	3.2,85.7	1.749	0.161	2.443
GP X CH X ST	3.2,85.7	5.471	0.001*	2.443
Rescaled Amplitude				
Main Effects				
Group GP	1,27	0.464	0.500	4.475
Chain CH	2,52.8	0.833	0.436	0.594
Site ST	1.4,37	3.587	0.054	0.411
Interactions				
GP X CH	2,52.8	4.502	0.016*	0.594
GP X ST	1.4,37	14.469	0.000*	0.411
CH X ST	3.1,83.6	2.328	0.079	0.082
GP X CH X ST	3.1,83.6	5.968	0.001*	0.082

Table 8a.11.2 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by rare nontarget stimuli between the young and elderly groups of subjects within the auditory modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,27	0.158	0.693	189.169
Chain CH	1.8,49.1	0.986	0.71	12.106
Site ST	1.6,42.1	9.602	0.001*	15.050
Interactions				
GP X CH	1.8,49.1	5.530	0.008	12.106
GP X ST	1.6,42.1	31.219	0.000*	15.050
CH X ST	2.8,76	4.677	0.006*	2.145
GP X CH X ST	2.8,76	4.700	0.005*	2.145
Rescaled Amplitude				
Main Effects				
Group GP	1,27	0.243	0.624	3.258
Chain CH	1.8,48.7	1.502	0.234	0.253
Site ST	1.6,42.1	5.820	0.010*	0.271
Interactions				
GP X CH	1.8,48.7	6.005	0.004*	0.253
GP X ST	1.6,42.1	28.946	0.000*	0.271
CH X ST	2.6,70.1	5.246	0.003*	0.043
GP X CH X ST	2.6,70.1	5.130	0.004*	0.043

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8a.12 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by auditory stimuli within a latency range of 500 - 850 msec between the elderly and young groups of subjects.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	1.28	0.26	202.41
Condition CC	1,9,58.2	6.99	0.002*	70.480
Chain CH	2,59.8	11.18	0.000*	11.760
Site ST	1,4,41.7	76.87	0.000*	17.260
Interactions				
GP X CC	1,9,58.2	1.29	0.283	70.480
GP X CH	2,59.8	0.86	0.426	11.762
GP X ST	1,4,41.7	1.46	0.241	17.262
CC X CH	2,7,81.9	9.59	0.000*	4.564
CC X ST	2,1,64.1	25.77	0.000*	7.403
CH X ST	3,2,96.2	5.75	0.001*	2.371
GP X CC X CH	2,7,81.9	1.18	0.319	4.564
GP X CC X ST	2,1,64.1	2.68	0.073	7.403
GP X CH X ST	3,2,96.2	2.52	0.058	2.371
CC X CH X ST	5,6,168,3	4.53	0.000*	0.701
GP X CC X CH X ST	5,6,168,3	3.11	0.008*	0.701
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.072	0.789	11.315
Condition CC	1,2,35.6	0.049	0.865	5.795
Chain CH	2,59.6	5.562	0.006*	0.680
Site ST	1,2,37.3	31.707	0.000*	1.210
Interactions				
GP X CC	1,2,35.6	0.011*	0.943	5.795
GP X CH	2,59.6	1.131	0.331	0.680
GP X ST	1,2,37.3	0.205	0.706	1.210
CC X CH	2,4,72.3	1.654	0.194	0.344
CC X ST	1,5,46.1	0.927	0.378	0.640
CH X ST	3,4,103.5	2.726	0.041*	0.124
GP X CC X CH	2,4,72.3	0.569	0.599	0.344
GP X CC X ST	1,5,46.1	0.713	0.458	0.640
GP X CH X ST	3,4,103.5	1.981	0.113	0.124
CC X CH X ST	4,1,122.4	1.418	0.232	0.067
GP X CC X CH X ST	4,1,122.4	1.215	0.309	0.067

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8a.13.2 Mean rescaled amplitude elicited by auditory stimuli within the young group of subject within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Pz	Left Chain			Right Chain		Rp
	Fz	Cz		Lf	Lt	Lp	Rf	Rt	
P300									
Target	0.19	0.69	1.00	0.00	0.33	0.72	0.05	0.43	0.73
Rare	0.49	1.00	0.97	0.00	0.39	0.58	0.04	0.43	0.63
Nontarget									
N100									
Frequent	0.00	0.09	0.71	0.28	0.34	0.94	0.23	0.45	1.00
Target	0.00	0.07	0.77	0.29	0.28	1.00	0.14	0.27	0.99
Rare	0.05	0.00	0.74	0.32	0.23	0.91	0.19	0.29	1.00
Nontarget									
N200									
Target	0.14	0.75	1.00	0.06	0.29	0.66	0.00	0.38	0.71
Rare	0.02	0.71	1.00	0.11	0.54	0.82	0.00	0.46	0.69
Nontarget									
Slow Wave									
Frequent	0.00	0.64	0.76	0.01	0.73	0.47	0.24	1.00	0.58
Target	0.00	0.77	1.00	0.02	0.37	0.67	0.21	0.67	0.83
Rare	0.01	0.63	1.00	0.00	0.40	0.82	0.01	0.53	0.87
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 8b.14.3 Mean amplitude elicited by visual stimuli within the elderly group of subjects within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. Mean amplitude evoked by visual stimuli at lateral parietal sites within a latency range of 150 - 350 msec is also shown.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Ff	Lt	Rf	Rt
P300						
Target	15.44	17.66	12.71	13.58	13.28	13.87
Rare	14.37	19.89	11.25	14.98	9.41	12.41
Nontarget						
N100						
Frequent	3.65	2.53	3.97	1.09	4.08	2.01
Target	5.36	3.65	4.84	1.95	5.64	2.62
Rare	5.97	4.86	5.66	3.21	6.14	3.75
Nontarget						
N200						
Target	3.35	1.73	3.31	1.32	4.23	2.61
Rare	2.55	3.25	3.13	2.86	3.59	3.79
Nontarget						
Slow Wave						
Frequent	2.70	5.22	1.57	3.61	2.96	3.22
Target	6.34	9.63	5.07	6.19	6.25	7.47
Rare	8.28	13.14	6.62	8.99	5.86	7.72
Nontarget						
Lat. Par.						
Frequent				2.00		2.56
Target				1.67		2.80
Rare				5.12		5.01
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec.
 Lat. Par. denotes activity elicited within a latency range of 150 - 350 msec.

Table 8a.13.4 Mean rescaled amplitude elicited by auditory stimuli within the elderly group of subject within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Lf	Lt	Rf	Rt
P300						
Target	0.56	0.04	0.00	0.24	0.20	0.43
Rare	0.67	0.96	0.26	0.57	0.00	0.26
Nontarget						
N100						
Frequent	0.07	0.00	0.27	0.21	0.32	0.39
Target	0.01	0.00	0.23	0.27	0.31	0.38
Rare	0.13	0.00	0.36	0.25	0.37	0.36
Nontarget						
N200						
Target	0.75	0.00	0.77	0.52	1.00	0.82
Rare	0.64	0.00	1.00	0.63	0.89	0.55
Nontarget						
Slow Wave						
Frequent	0.00	0.64	0.01	0.73	0.24	1.00
Target	0.00	0.77	0.02	0.37	0.21	0.67
Rare	0.01	0.63	0.00	0.40	0.01	0.53
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 8b.1 ANOVA summary table for analysis of latency data of the N100, N200 and P300 deflections measured at Fz, Cz and Pz sites between groups of subjects within the visual modality.

	df	F	p	mse
N100				
Main Effects				
Group GR	1,30	2.248	0.145	3172.354
Condition CC	2,0,58.8	2.953	0.061	455.247
Site ST	1,7,52.3	2.074	0.142	450.624
Interactions				
GR X CC	2,0,58.8	2.285	0.112	455.247
GR X ST	1,7,52.3	0.906	0.396	450.624
CC X ST	3,2,94.7	0.243	0.913	282.374
GR X CC X ST	3,2,94.7	0.989	0.402	282.374
N200				
Target Stimuli				
Main Effects				
Group GR	1,30	10.279	0.003*	3735.622
Site ST	1,8,54.1	5.590	0.008	573.556
Interactions				
GR X ST	1,8,54.1	3.623	0.038	573.556
Rare Nontarget Stimuli				
Main Effects				
Group GR	1,30	0.980	0.328	3053.111
Site ST	1,6,49.0	0.616	0.511	675.444
Interactions				
GR X ST	1,6,49.0	0.108	0.859	675.444
P300				
Target Stimuli				
Main Effects				
Group GR	1,30	20.052	0.000*	1923.011
Site ST	1,9,56.2	5.463	0.008*	504.178
Interactions				
GR X ST	1,9,56.2	0.387	0.666	504.178
Rare Nontarget Stimuli				
Main Effects				
Group GR	1,30	61.853	0.000*	1896.744
Site ST	1,6,48.2	4.704	0.020*	440.544
Interactions				
GR X ST	1,6,48.2	2.111	0.142	440.544
Young Group				
Main Effects				
Condition CC	1,15	31.737	0.000*	790.578
Site ST	1,5,22.5	2.664	0.104	483.700
Interactions				
CC X ST	1,4,21.0	1.476	0.248	465.478
Elderly Group				
Main Effects				
Condition CC	1,15	0.094	0.763	1603.156
Site ST	1,7,25.0	6.478	0.008	583.778
Interactions				
CC X ST	1,7,25.2	0.544	0.555	356.489

* denotes a p level statistically significant at the 0.05% level or greater.

Table 8b.2 Mean latency in milliseconds of the peak deflections elicited within the latency range of the N100, N200 and P300 deflections across the midline chain of electrodes between groups of subjects within the visual modality.

Young Group	Fz	Cz	Pz	Elderly Group		
				Fz	Cz	Pz
N100						
Frequent	92.5	100.0	95.0	92.0	90.0	81.7
Target	92.5	98.7	99.2	92.1	98.7	85.7
Rare	108.0	112.7	103.0	93.2	90.6	88.8
Nontarget						
N200						
Target	280.2	269.2	249.2	221.7	236.5	220.2
Rare	255.0	246.2	254.2	243.5	238.2	240.2
Nontarget						
P300						
Target	344.2	347.7	350.7	402.2	426.7	423.5
Rare	369.2	390.5	380.0	410.2	425.2	424.5
Nontarget						

Table 8b.10 ANOVA summary table for analysis of N100 amplitude and rescaled amplitude elicited by visual stimuli between the elderly and young groups of subjects.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	3.685	0.065	220.926
Condition CC	1.8,53.8	11.533	0.000*	11.025
Chain CH	1.5,44.8	24.259	0.000*	10.910
Site ST	1.1,34.5	56.496	0.000*	31.077
Interactions				
GP X CC	1.8,53.8	10.144	0.000*	11.025
GP X CH	1.5,44.8	2.473	0.110	10.910
GP X ST	1.1,34.5	13.402	0.001*	31.077
CC X CH	3.6,108.8	1.469	0.222	1.184
CC X ST	2.4,71.0	4.844	0.007*	2.157
CH X ST	2.2,65.7	38.215	0.000*	2.756
GP X CC X CH	3.6,108.8	1.612	0.182	1.184
GP X CC X ST	2.4,71.0	1.788	0.169	2.157
GP X CH X ST	2.2,65.7	3.822	0.024*	2.756
CC X CH X ST	3.9,117.6	1.672	0.163	0.357
GP X CC X CH X ST	3.9,117.6	1.591	0.183	0.357
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.219	0.642	3.675
Condition CC	1.8,54.6	0.138	0.852	0.388
Chain CH	1.3,39.3	23.169	0.000*	0.299
Site ST	1.1,31.5	26.571	0.000*	1.428
Interactions				
GP X CC	1.8,54.6	0.086	0.902	0.388
GP X CH	1.3,39.3	0.520	0.521	0.299
GP X ST	1.1,31.5	0.110	0.754	1.428
CC X CH	3.1,93.8	0.852	0.471	0.039
CC X ST	2,60.7	0.329	0.723	0.069
CH X ST	1.7,51.8	26.665	0.000*	0.105
GP X CC X CH	3.1,93.8	1.207	0.313	0.039
GP X CC X ST	2,60.7	0.740	0.481	0.069
GP X CH X ST	1.7,51.8	0.981	0.391	0.105
CC X CH X ST	3.7,110.8	1.143	0.340	0.010
GP X CC X CH X ST	3.7,110.8	1.623	0.179	0.010

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8b.11.1 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by target stimuli between the young and elderly groups of subjects within the visual modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	0.260	0.612	188.235
Chain CH	1.9,56.6	6.403	0.004*	10.351
Site ST	1.2,36.3	1.220	0.304	30.297
Interactions				
GP X CH	1.9,56.6	0.994	0.374	10.251
GP X ST	1.2,36.3	11.193	0.001*	30.297
CH X ST	2.8,83	13.639	0.000*	2.002
GP X CH X ST	2.8,83	1.578	0.205	2.002
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.218	0.642	8.522
Chain CH	1.9,57.2	5.005	0.011*	0.362
Site ST	1.3,38	0.218	0.700	1.040
Interactions				
GP X CH	1.9,57.2	0.306	0.737	0.362
GP X ST	1.3,38	9.057	0.003*	1.040
CH X ST	3,90.6	12.939	0.000*	0.755
GP X CH X ST	3,90.6	0.601	0.616	0.060

Table 8b.11.2 ANOVA summary table for analysis of N200 amplitude and rescaled amplitude elicited by rare nontarget stimuli between the young and elderly groups of subjects within the visual modality.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	0.544	0.465	102.019
Chain CH	2,58.8	2.753	0.073	9.364
Site ST	1.2,35.1	35.985	0.000*	38.883
Interactions				
GP X CH	2,58.8	0.971	0.381	9.364
GP X ST	1.2,35.1	23.094	0.000*	38.883
CH X ST	2.5,75.7	3.235	0.034*	2.321
GP X CH X ST	2.5,75.7	2.152	0.111	2.321
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.127	0.724	6.132
Chain CH	2,58.9	1.307	0.279	0.308
Site ST	1.1,33.3	6.531	0.013	1.915
Interactions				
GP X CH	2,58.9	0.097	0.904	0.308
GP X ST	1.1,33.3	0.680	0.428	1.915
CH X ST	2.8,85.3	5.846	0.001*	0.086
GP X CH X ST	2.8,85.3	5.196	0.003*	0.086

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8b.12 ANOVA summary table for analysis of mean amplitude and rescaled amplitude elicited by visual stimuli within a latency range of 500 - 850 msec between the elderly and young groups of subjects.

Amplitude	df	F	p	mse
Main Effects				
Group GP	1,30	4.539	0.042*	185.872
Condition CC	1.5,44.9	32.597	0.000*	68.258
Chain CH	2,58.9	40.156	0.000*	12.544
Site ST	1.6,46.9	25.906	0.000*	22.544
Interactions				
GP X CC	1.5,44.9	0.076	0.876	68.258
GP X CH	2,58.9	2.972	0.060	12.556
GP X ST	1.6,46.9	1.985	0.158	22.544
CC X CH	3.5,104.1	14.037	0.000*	3.343
CC X ST	2.6,76.7	10.272	0.000*	8.578
CH X ST	2.7,79.8	30.347	0.000*	2.443
GP X CC X CH	3.5,104.1	2.047	0.103	3.343
GP X CC X ST	2.6,76.7	4.742	0.007*	8.578
GP X CH X ST	2.7,79.8	0.832	0.466	2.443
CC X CH X ST	5.1,153.9	8.056	0.000*	0.967
GP X CC X CH X ST	5.1,153.9	1.847	0.105	0.967
Rescaled Amplitude				
Main Effects				
Group GP	1,30	0.275	0.602	7.066
Condition CC	1.9,56.9	0.123	0.874	2.300
Chain CH	2,59.4	32.979	0.000*	0.482
Site ST	1.6,46.6	18.484	0.000*	0.911
Interactions				
GP X CC	1.9,56.9	0.010	0.988	2.300
GP X CH	2,59.4	3.289	0.045*	0.482
GP X ST	1.6,46.6	0.575	0.523	0.911
CC X CH	3.5,105	5.843	0.001*	0.124
CC X ST	2.4,71.7	2.487	0.081	0.356
CH X ST	2.6,77.8	26.574	0.000*	0.101
GP X CC X CH	3.5,105	1.553	0.199	0.124
GP X CC X ST	2.4,71.7	0.392	0.713	0.356
GP X CH X ST	2.6,77.8	1.237	0.302	0.101
CC X CH X ST	5.3,159.3	3.281	0.006*	0.042
GP X CC X CH X ST	5.3,159.3	2.291	0.045*	0.042

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8b.13 ANOVA summary table for analysis of mean amplitude elicited by frequent, target and rare nontarget stimuli within a latency range of 150 - 350 msec at lateral parietal sites by the elderly and young groups of subjects.

Amplitude	df	F	p	mse
Main Effects				
Group Gp	1,30	3.354	0.077	47.528
Condition CC	1,8,54.6	45.225	0.000*	7.167
Chain CH	1,30	2.358	0.136	7.484
Interactions				
GR X CC	1,8,54.6	3.865	0.031*	7.167
GR X CH	1,30	0.041	0.841	7.484
CC X CH	2,59.4	2.805	0.069	1.028
GR X CC X CH	2,59.4	0.636	0.530	1.028

* denotes a p value statistically significant at the 0.05% level or greater.

Table 8b.14.1 Mean amplitude elicited by visual stimuli within the young group of subjects within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. Mean amplitude evoked by visual stimuli at lateral parietal sites within a latency range of 150 - 350 msec is also shown.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Fz	Pz	Ff	Rt
P300						
Target	8.80	16.95	5.13	20.62	6.63	11.65
Rare	9.16	19.04	4.12	22.06	5.93	12.88
Nontarget						
N100						
Frequent	0.03	0.87	-2.48	1.09	-0.22	-0.02
Target	-0.14	0.57	-0.40	0.22	-0.03	-0.17
Rare	0.42	1.15	-0.07	1.59	0.32	0.21
Nontarget						
N200						
Target	0.38	3.58	0.50	7.91	1.27	3.34
Rare	-1.80	5.34	-2.41	12.38	-2.35	4.36
Nontarget						
Slow Wave						
Frequent	0.36	1.75	0.34	1.89	1.13	2.11
Target	1.56	9.04	0.39	10.70	2.88	7.14
Rare	4.84	9.15	3.82	9.30	4.29	7.06
Nontarget						
Lat. Par.						
Frequent						3.25
Target						4.25
Rare						8.57
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec.
 Lat. Par. denotes activity elicited within a latency range of 150 - 350 msec.

Table 8b.14.2 Mean rescaled amplitude elicited by visual stimuli within the young group of subject within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Pz	Left Chain			Right Chain		Rp
	Fz	Cz		Lf	Lt	Lp	Rf	Rt	
P300									
Target	0.24	0.76	1.00	0.00	0.32	0.57	0.09	0.42	0.56
Rare	0.28	0.83	1.00	0.00	0.43	0.65	0.09	0.48	0.76
Nontarget									
N100									
Frequent	0.25	0.84	1.00	0.05	0.13	0.00	0.07	0.21	0.43
Target	0.75	1.00	0.88	0.65	0.49	0.00	0.73	0.76	0.52
Rare	0.56	0.83	1.00	0.37	0.19	0.00	0.52	0.48	0.71
Nontarget									
N200									
Target	0.00	0.42	1.00	0.02	0.12	0.42	0.12	0.39	0.66
Rare	0.04	0.52	1.00	0.00	0.37	0.86	0.01	0.46	0.96
Nontarget									
Slow Wave									
Frequent	0.13	0.82	0.89	0.13	0.57	0.00	0.52	1.00	0.43
Target	0.11	0.84	1.00	0.00	0.38	0.58	0.24	0.65	0.58
Rare	0.19	0.97	1.00	0.00	0.50	0.22	0.08	0.59	0.28
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 8a.13.3 Mean amplitude elicited by auditory stimuli within the elderly group of subjects within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	9.26	9.85	12.30	5.361	7.09	9.40	6.76	8.40	10.98
Rare	12.17	14.95	15.29	9.15	11.74	11.72	6.95	9.09	11.48
Nontarget									
N100									
Frequent	-8.34	-8.72	-4.78	-7.19	-7.51	-3.39	-6.91	-6.47	-3.01
Target	-9.23	-9.26	-4.85	-7.79	-7.49	-3.47	-7.25	-6.81	-2.81
Rare	-9.55	-10.52	-5.07	-8.01	-8.87	-3.75	-7.96	-8.03	-3.58
Nontarget									
N200									
Target	0.90	-1.47	1.01	1.04	0.48	0.76	1.73	1.65	1.86
Rare	-0.66	-4.46	-1.54	1.50	-0.89	-1.20	0.81	-1.05	-0.88
Nontarget									
Slow Wave									
Frequent	-0.19	1.13	1.36	-0.73	0.26	0.74	-0.19	0.52	0.98
Target	0.62	4.66	5.79	-1.47	1.79	3.78	1.09	3.86	5.66
Rare	0.99	5.08	5.85	0.1	2.81	3.69	-0.74	1.42	4.15
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Table 8b.14.3 Mean amplitude elicited by visual stimuli within the elderly group of subjects within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain. Mean amplitude evoked by visual stimuli at lateral parietal sites within a latency range of 150 - 350 msec is also shown.

	Midline Chain			Left Chain			Right Chain		
	Fz	Cz	Pz	Lf	Lt	Lp	Rf	Rt	Rp
P300									
Target	15.44	17.66	20.09	12.71	13.58	14.68	13.28	13.87	14.31
Rare	14.37	19.89	19.47	11.25	14.98	14.75	9.41	12.41	13.31
Nontarget									
N100									
Frequent	3.65	2.53	0.26	3.97	1.09	-3.99	4.08	2.01	-3.07
Target	5.36	3.65	0.59	4.84	1.95	-4.38	5.64	2.62	-3.79
Rare	5.97	4.86	1.89	5.66	3.21	-2.44	6.14	3.75	-2.05
Nontarget									
N200									
Target	3.35	1.73	2.17	3.31	1.32	-0.04	4.23	2.61	0.97
Rare	2.55	3.25	5.58	3.13	2.86	4.18	3.59	3.79	4.00
Nontarget									
Slow Wave									
Frequent	2.70	5.22	4.78	1.57	3.61	1.92	2.96	3.22	2.28
Target	6.34	9.63	10.58	5.07	6.19	6.75	6.25	7.47	6.25
Rare	8.28	13.14	11.99	6.62	8.99	7.08	5.86	7.72	6.59
Nontarget									
Lat. Par.									
Frequent						2.00			2.56
Target						1.67			2.80
Rare						5.12			5.01
Nontarget									

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec.
 Lat. Par. denotes activity elicited within a latency range of 150 - 350 msec.

Table 8b.14.4 Mean rescaled amplitude elicited by visual stimuli within the elderly group of subject within the latency range of the P300, N100, N200 deflections and within a mean latency range of 500-850 msec for each site, of each electrode chain.

	Midline Chain		Left Chain		Right Chain	
	Fz	Cz	Lf	Lt	Rf	Rt
P300						
Target	0.37	0.67	0.00	0.12	0.08	0.16
Rare	0.47	1.00	0.18	0.53	0.00	0.29
Nontarget						
N100						
Frequent	0.95	0.81	0.92	0.63	1.00	0.74
Target	0.97	0.81	0.92	0.64	1.00	0.76
Rare	0.98	0.85	0.95	0.66	1.00	0.72
Nontarget						
N200						
Target	0.77	0.41	0.76	0.31	1.00	0.61
Rare	0.00	0.23	0.19	0.10	0.34	0.41
Nontarget						
Slow Wave						
Frequent	0.31	1.00	0.00	0.39	0.25	0.45
Target	0.23	0.82	0.00	0.20	0.22	0.44
Rare	0.33	1.00	0.10	0.43	0.00	0.25
Nontarget						

Slow Wave denotes the activity elicited within a latency range of 500 - 850 msec

Figure 1.

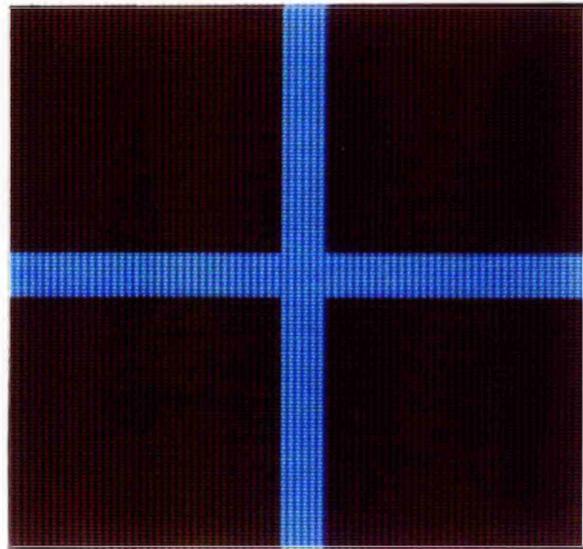


Figure 2.

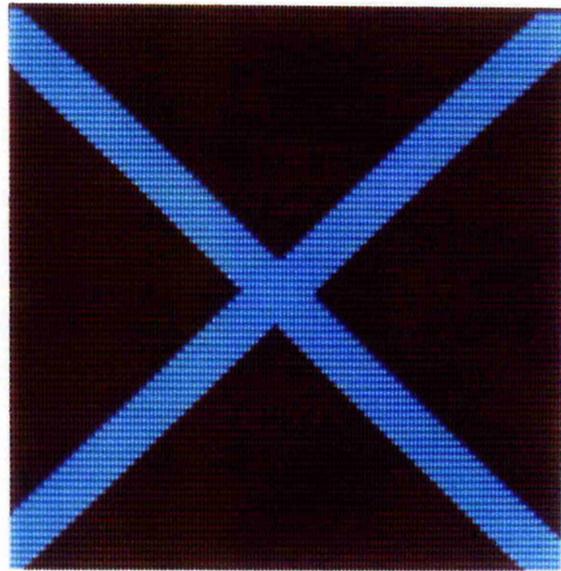


Figure 3.

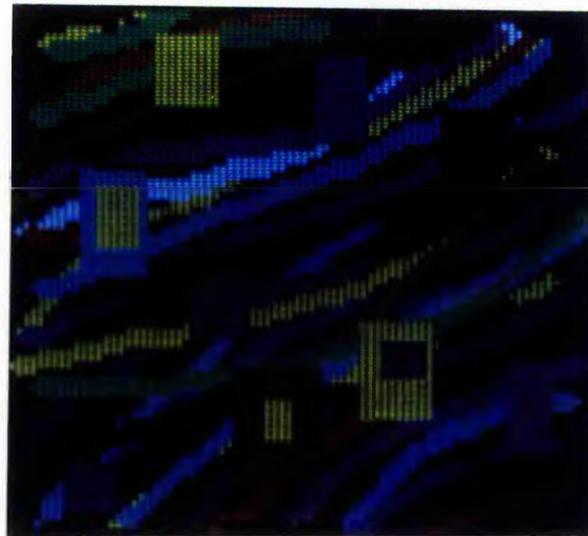


Figure 4.

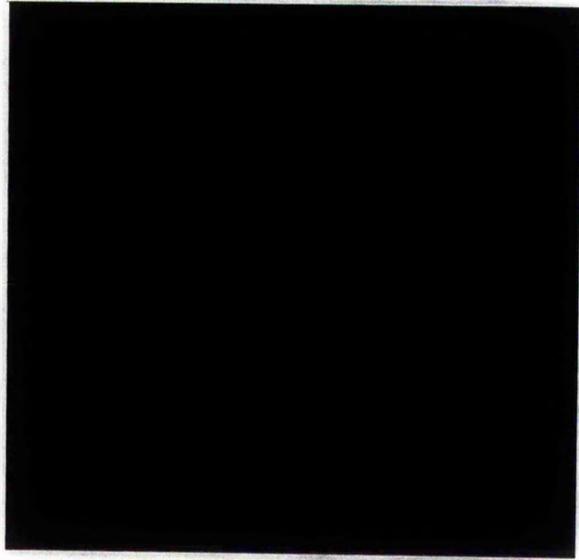


Figure 5.

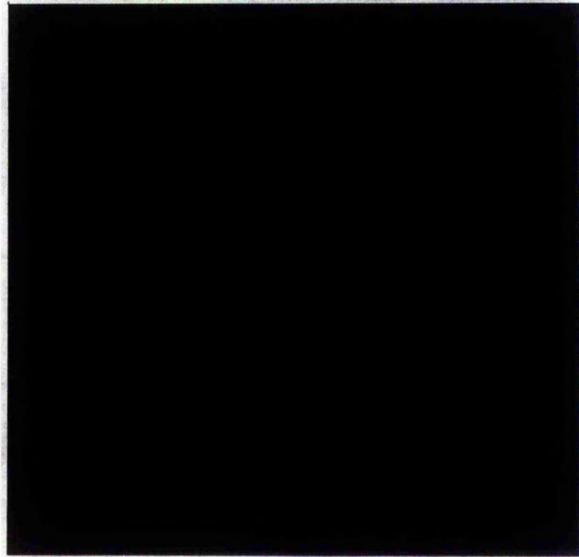


Figure 6.

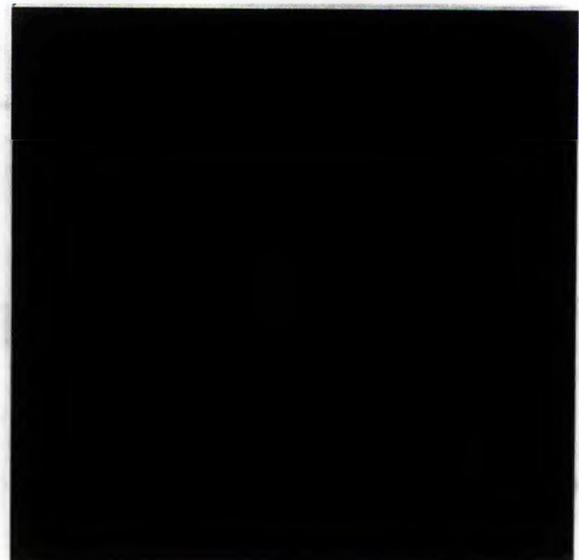


Figure 7.

