ELECTROPHYSIOLOGICAL STUDIES OF FORMAL, DERIVATIONAL AND REPETITION PRIMING

Michael Christopher Doyle

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

1996

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/10023/14693

This item is protected by original copyright

Electrophysiological Studies of Formal, Derivational and Repetition Priming

Michael Christopher Doyle

Submitted for the degree of PhD

8/12/95

BIBLIOTHECA UNIVERSITATIS ANDREANÆ

ProQuest Number: 10167382

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 10167382

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

Th B950

(i) I, Michael Christopher Doyle, hereby certify that this thesis, which is approximately 75000 words in length, has been written by me, that it is a record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

Date 8/12/95 Signature of Candidate

(ii) I was admitted as a research student in February, 1989 and as a candidate for the degree of PhD in February, 1990; the higher study for which this is a record carried out in the University of St. Andrews between 1989 and 1995.

Date 8/12/95 Signature of Candidate

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

Date 11/12/95 Signature of Supervisor

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.

Date 8/12/95 Signature of Candidate

For Steve - thanks for the Russian lessons

Acknowledgements

I am grateful to Professor Michael Rugg for supervising the work reported in this thesis. I also thank Dr. Gerry Quinn for his encouragement in the final few months of my labour. I thank the many and varied members of the Wellcome Brain Research Group with whom I have worked over the last few years. In particular I thank Tony Wells for his help in running Experiment 5, and Astrid Schloerscheidt whose competence gave me the time and space necessary for me to complete this thesis. I am also grateful to the technical and secretarial staff of the School of Psychology for their untiring assistance. I also thank my mother and father for their support over the years, but mostly for their friendship. Finally I thank my wife Jane who dispels my fear and loneliness with her love and laughter - without her, this 'Andrex' thesis would never have been finished.

Contents

Page No.

Chapter 1 : Word repetition and lexical memory: Behavioural investigations

1.0 Introduction 1

1.1 Direct and indirect memory tasks 2
- 1.1.1 The performance of memory-impaired patients on direct and indirect tests of memory 3
- 1.1.2 Stochastic independence 3
- 1.1.3 Functional independence 4
  - 1.1.3.1 The 'read-generate' effect in direct and indirect tests of memory 4
  - 1.1.3.2 Levels of processing and direct and indirect tests of memory 5

1.2 Models of memory : Systems and Processes 6
- 1.2.1 Systems models of memory 6
- 1.2.2 Processing models of memory 8
- 1.2.3 Isolating systems and processes 9

1.3 Changes of presentation format and the word repetition effect 10
- 1.3.1 Repetition across visual and auditory modalities 10
- 1.3.2 Manipulations of visual format 13

1.4 Word repetition, stimulus degradation and word frequency 14

1.5 Conceptual processing and repetition priming 16
- 1.5.1 Repetition effects across languages 16
- 1.5.2 Repetition effects with pictures 16
- 1.5.3 Repetition effects with homographic and polysemous words. 17
- 1.5.4 Repetition effects and semantic priming 18

1.6 Repetition priming effects with novel stimuli 21
- 1.6.1 Repetition effects with previously unassociated words 21
- 1.6.2 Repetition effects with non-words 22

1.7 Repetition priming and inter-item lag 27

1.8 Repetition priming effects with masked primes 29

1.9 The effects of formal similarity on word recognition 30
- 1.9.1 Position of overlap and formal similarity effects 35
- 1.9.2 Orthographic and phonological similarity and formal priming effects 36

1.10 The recognition of morphologically complex words 38
- 1.10.1 Morphological structure in English. 39
- 1.10.2 Experimental investigations of the functional significance of morphological structure 40
  - 1.10.2.1 Morpheme frequency and word frequency 42
  - 1.10.2.2 Manipulations of morphographic structure of words and non-words 42
  - 1.10.2.3 Repetition effects and the representation of morphologically complex words 45
  - 1.10.2.4 Models of the representation of morphologically complex words 51

Page No.

Chapter 2 : Word repetition and lexical memory : Electrophysiological investigations

2.0 Introduction 55

2.1 The ERP 55

- 2.1.1 The neurogenesis of the ERP 57
- 2.1.2 Recording ERPs 58
- 2.1.3 Extracting the ERP from the EEG 60
- 2.1.4 The measurement and statistical evaluation of ERPs 61
- 2.1.5 The interpretation of ERPs 61

2.2 ERPs and stimulus repetition 63

2.3 The component structure of the ERP repetition effect 64

2.4 Modulations of the LPC and their interpretation 66

2.5 Modulations of the N400 and their interpretation 67

2.6 The modulation of ERPs by semantic similarity 69

2.7 The ERP repetition effect and inter-item lag 73

2.8 ERPs and the repetition of non-words 74

2.9 The ERP repetition effect and the manipulation of task and attention 76

2.10 The ERP repetition effect and manipulations of context 77

2.11 The modulation of ERPs by formal similarity 79

2.12 Modulations of the N400 and morphological priming 80

Chapter 3 : A comparison of ERPs elicited by word repetition, formal and derivational priming at lag 0.

3.0 Introduction 82

3.1 General Procedure - Experiments 1A, 1B and 2. 83

- 3.1.1 EEG Recording 83
- 3.1.2 Procedure 84
- 3.1.3 Signal Averaging and Waveform Quantification. 85
- 3.1.4 Statistical Analysis 86
  - 3.1.4.1. ANOVA of mean amplitude measures of the non-subtracted waveforms. 86
  - 3.1.4.2. ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms 87
  - 3.1.4.3. ANOVA of the rescaled mean amplitudes of the subtraction waveforms 88

3.2 Methods 89

- 3.2.1 Subjects 89
- 3.2.2 Materials 89
- 3.2.3 Procedure 91

3.3 Results 91

- 3.3.1 Behavioural Data: 91
- 3.3.2 Event Related Potentials 92

Page No.

3.3.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms 93
3.3.2.2 ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms 97
3.3.2.3 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 99

3.4 Discussion 100

Chapter 4 : A further comparison of ERP repetition, formal and derivational priming effects at lag 0

4.0 Introduction 104

4.1 Methods 107
4.1.1 Subjects 107
4.1.2 Materials 107
4.1.3 Procedure 108

4.2 Results 108
4.2.1 Behavioural Data 108
4.2.2 Event Related Potentials 108
4.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms 109
4.2.2.2 ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms 113
4.2.2.3 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 115

4.3 Discussion 116

Chapter 5 : ERP repetition, formal and derivational priming effects at lag 6.

5.0 Introduction 119

5.1 Methods 120
5.1.1 Subjects 120
5.1.2 Materials 120
5.1.3 Procedure 121

5.2 Results 121
5.2.1 Behavioural Data 121
5.2.2 Event Related Potentials 121
5.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms. 122
5.2.2.2 ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms. 126
5.2.2.3 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 126

5.3 Discussion 127

Page No.

Chapter 6 : Formal and repetition priming with low relatedness proportions.

6.0 Introduction 131

6.1 Methods 131
- 6.1.1 Subjects 131
- 6.1.2 Materials 132
- 6.1.3 Procedure 133

6.2 Results 134
- 6.2.1 Behavioural Data 134
- 6.2.2 Event Related Potentials 134
  - 6.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms. 135
  - 6.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 136

6.3 Discussion 136

Chapter 7 : Formal and repetition priming with non-words.

7.0 Introduction 138

7.1 Methods 139
- 7.1.1 Subjects 139
- 7.1.2 Materials 139
- 7.1.3 Procedure 140

7.2 Results 140
- 7.2.1 Behavioural Data 140
- 7.2.2 Event Related Potentials 140
  - 7.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms 141
  - 7.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 142

7.3 Discussion 142

Chapter 8 : The contribution to formal priming effects of orthographic and phonological similarity

8.0 Introduction 145

8.1 Methods 145
- 8.1.1 Subjects 145
- 8.1.2 Materials 145
- 8.1.3 Procedure 146

8.2 Results 147
- 8.2.1 Behavioural Data 147
- 8.2.2Event Related Potentials 147
  - 8.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms 148

Page No.

8.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms 149

8.3 Discussion 150

Chapter 9 : General Discussion

9.0 Introduction 151

9.1 A summary of the main findings 151

9.2 The component structure of the ERP repetition and formal priming effects 153

9.3 ERPs and derivationa relations between words 154

9.4 Formal and repetition priming effects after 400 ms post-stimulus onset 156

9.5 Formal priming effects and ERPs 158

9.6 The neuroanatomical basis for formal priming effects 161

9.7 Conclusions 163

References 164

Appendices 189

Appendix 1: Derivationally similar words used in Experiments 1A, 1B and 2. 189

Appendix 2: Formally similar words used in Experiments 1A, 1B and 2. 190

Appendix 3: Formally similar words used in Experiment 3. 191

Appendix 4: Formally similar non-words used in Experiment 4. 192

Appendix 5: Formally similar words used in Experiment 5. 193

Abbreviations and Symbols

AAM	Augmented Addressed Morphology
ADC	Analogue-to-Digital
ASA	Automatic Spreading Activation
BOSS	Basic Orthographic Syllable Structure
BOB	Body of the Boss
EEG	Electroencephalogram
EOG	Electro-oculogram
ERP	Event-Related Potential
LDT	Lexical Decision Task
LoP	Levels of Processing
ms	milliseconds
PET	Positron Emission Tomography
PRS	Perceptual Representation System
RT	Reaction Time
sd	Standard Deviation
$k\Omega$	KiloOhms
μV	Microvolts

Index of Figures and Tables

Chapter 3

Figure 3.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 1A. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 3.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 1A. Electrode sites as in Figure 3.1.

Figure 3.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 1A. Electrode sites as in Figure 3.1.

Figure 3.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 1A. Electrode sites as in Figure 3.1.

Figure 3.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 1A. Electrode sites as in Figure 3.1.

Figure 3.6 Mean rescaled amplitudes of the subtraction waveforms for each prime type, collapsed over word type, between 200 and 400 ms post stimulus onset at midline and lateral sites in Experiment 1A.

Table 3.1 Word length and word frequency values for word pairs of each word type. Standard deviations are given in parentheses.

Table 3.2 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the N118 peak in Experiment 1A.

Table 3.3 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the P191 peak in Experiment 1A.

Table 3.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 1A.

Table 3.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 1A.

Table 3.6 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 600 - 800 ms post-stimulus onset in Experiment 1A.

Table 3.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and partial priming conditions for each epoch analysed in Experiment 1A.

Table 3.8 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and repetition conditions for each epoch analysed in Experiment 1A.

Table 3.9 Summary of the results of the ANOVAs performed on the non-rescaled mean amplitude of the subtraction waveforms in each epoch measured in Experiment 1A.

Table 3.10 Summary of the results of the ANOVAs performed on the rescaled mean amplitude of the subtraction waveforms in each epoch measured in Experiment 1A.

Table 3.11 Summary of the outcomes of the across-epoch ANOVAs performed on the rescaled mean amplitudes of the subtraction waveforms in Experiment 1A.

Chapter 4

Figure 4.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 1B. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 4.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 1B. Electrode sites as in Figure 4.1.

Figure 4.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 1B. Electrode sites as in Figure 1.2.

Figure 4.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 1B. Electrode sites as in Figure 4.1.

Figure 4.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 1B. Electrode sites as in Figure 4.1

Table 4.1 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the N126 peak in Experiment 1B.

Table 4.2 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the P238 peak in Experiment 1B.

Table 4.3 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 1B.

Table 4.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 1B.

Table 4.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 600 - 800 ms post-stimulus onset in Experiment 1B.

Table 4.6 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the partial priming conditions for each epoch analysed in Experiment 1B.

Table 4.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the repetition priming conditions for each epoch analysed in Experiment 1B.

Table 4.8 Summary of the results of the ANOVAs performed on the non-rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 1B

Table 4.9 Summary of the results of the ANOVAs performed on the rescaled mean amplitude measurements of the subtraction waveforms in each epoch measured in Experiment 1B.

Chapter 5

Figure 5.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 2. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 5.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 2. Electrode sites as in Figure 5.1.

Figure 5.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 2. Electrode sites as in Figure 5.1.

Figure 5.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 2. Electrode sites as in Figure 5.1.

Figure 5.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 2. Electrode sites as in Figure 5.1.

Table 5.1 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the N99 peak in Experiment 2.

Table 5.2 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the P186 peak in Experiment 2.

Table 5.3 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 2.

Table 5.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 2.

Table 5.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site, 600 - 800 ms post-stimulus onset in Experiment 2.

Table 5.6 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the partial priming conditions for each epoch analysed in Experiment 2.

Table 5.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the repetition priming conditions for each epoch analysed in Experiment 2.

Table 5.8. Summary of the results of the ANOVAs performed on the non-rescaled and rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 2.

Chapter 6

Figure 6.1 ERPs elicited at each electrode site by the first presentations of words, by repeated words and by words primed by their formal root forms in Experiment 3. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 6.2 ERPs elicited at each midline electrode by word repetition and by formal priming in Experiment 3. Electrode sites as in Figure 6.1.

Figure 6.3 Subtraction waveforms for word repetition and formal priming conditions at each electrode site in Experiment 3. Electrode sites as in Figure 6.1.

Figure 6.4 Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus in Experiment 3.

Table 6.1 Mean amplitudes of ERPs +/- 24 ms around the N81 and P150 peaks at each electrode site for the first presentation, formal priming and repetition conditions of Experiment 3.

Table 6.2 Mean amplitudes for each of the three 200 ms measurement intervals and for each electrode sites for the first presentation, formal priming and repetition conditions of Experiment 3.

Table 6.3 Summary of the results of ANOVA performed on the mean amplitudes of ERPs elicited by the words on their first presentation, when repeated and when formally primed in Experiment 3.

Table 6.4 Summary of the results of ANOVA performed on the rescaled mean amplitudes of the subtraction waveforms in Experiment 3.

Chapter 7

Figure 7.1 ERPs elicited at each electrode site by the first presentations of non-words, by repeated non-words and by non-words primed by their formal root forms in Experiment 4. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 7.2 ERPs elicited at each midline electrode by non-word repetition and by formal priming in Experiment 4. Electrode sites as in Figure 7.1.

Figure 7.3 Subtraction waveforms for non-word repetition and formal priming conditions at each electrode site in Experiment 4. Electrode sites as in Figure 7.1.

Figure 7.4 Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus onset in Experiment 4.

Table 7.1 Mean amplitudes of the N80 and P160 peaks at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 4

Table 7.2 Mean amplitudes over each of the 200 ms measurement intervals at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 4.

Table 7.3 Summary of the results of ANOVAs performed on the mean amplitudes of the waveforms elicited by the non-words on their first presentation when partially primed and when repeated in Experiment 4.

Chapter 8

Figure 8.1 ERPs elicited at each electrode site by the first presentations of words, by repeated words and by words primed by their formal PH+ or formal PH- root forms in Experiment 5. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

Figure 8.2 ERPs elicited at each midline electrode by word repetition and by formal priming in Experiment 5. Electrode sites as in Figure 8.1.

Figure 8.3 Subtraction waveforms for word repetition and formal priming conditions at each electrode site in Experiment 5. Electrode sites as in Figure 8.1.

Figure 8.4 Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus in Experiment 5.

Table 8.1 Mean amplitudes of the N90 and P160 peaks at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 5.

Table 8.2 Mean amplitudes over each of the three 200 ms measurement intervals for each electrode site and for the first presentation, formal PH, formal PH+ and repetition priming conditions of Experiment 5.

Table 8.3 Summary of the results of ANOVAs performed on the mean amplitudes of the waveforms elicited by the non-words on their first presentation when partially primed and when repeated in Experiment 5.

ABSTRACT

ERPs have been found to be sensitive to formal (i.e. orthographic and phonological) and semantic relationships between words, as well as to word repetition. Such effects have been used to argue that the N400 component of the ERP may reflect processing of the representations of words, i.e. 'lexical processing'. If ERPs do reflect lexical processes then they may also be sensitive to morphological relationships between words which are thought to be lexically represented.

The first three experiments investigated the sensitivity of ERPs to morphological relationships between words. Modulations of the ERP resulting from derivational, formal and repetition priming were compared. In each case, there was a positive-going shift in the ERP compared to the ERP elicited by unprimed words. However there was little evidence to suggest that the effects found in the derivational priming condition differed from those found when words were formally but not morphologically similar.

A subsequent three experiments focused on these ERP formal priming effects. Formal priming effects were found when the proportion of related items was relatively low, with non-words and with words which were only orthographically similar and with words which were both orthographically and phonologically similar. In each case formal and repetition priming were initially of similar magnitude, with the repetition effect subsequently becaming greater in amplitude than the formal effect. Whilst the distribution of the repetition effect for non-words and the formal priming effects for words and non-words tended to be greatest over the right hemisphere, the word repetition effect was largest over the midline.

It is concluded that the N400 does not reflect lexical processing, nor is it specific to semantic processing. Instead the N400 may reflect the operation of a similarity-sensitive mechanism which is sensitive to orthographic, phonological and/or semantic similarity and which may operate in an all-or-none fashion.

Chapter 1

Word repetition and lexical memory: Behavioural investigations

1.0 Introduction

Written words may be similar in respect of their visual form, i.e. what they look like, their graphemic form (i.e. the sequence of letters of which they are composed), their phonological form (i.e. the sequence of sounds of which they are composed when spoken), their morphology (i.e. their internal structure) and their semantic properties (i.e. their meaning). That we can apprehend these similarities between words, implies that these dimensions have 'psychological reality'. Under any materialist account of the relation between psychological or 'cognitive' processes and neural processes, such similarity must be coded within the neural processes of the brain. This relation between brain activity and cognitive process means that the adequacy of current models of cognition can be assessed by comparing the neural activity elicited by different classes of stimuli defined by the models under investigation. Furthermore, differences in neural activity elicited by various classes of stimuli may help us to discriminate between equally plausible alternative cognitive models.

In each of the experiments reported in this thesis I compare the neural activity elicited by different classes of visual stimuli. The first three experiments investigate the degree to which event-related potentials (ERPs) are sensitive to the morphological relationship between derivationally related words. These experiments also determine the degree to which any such sensitivity truly reflects a morphological relationship, rather than a similarity of orthography and/or phonology which generally is also common to derivationally related words. I shall refer to similarity of orthography and/or phonology between words as 'formal similarity'. Only effects which cannot be accounted for in terms of such formal similarity, or as a result of a semantic relationship between words, can be properly attributed to their morphological relationship.

The results of the first three experiments suggested that ERPs are sensitive to formal, rather than morphological, similarity. A further three experiments, investigated the degree to which these effects of formal similarity reflect processes involved in word identification and the relative importance of orthographic and phonological similarity in their generation.

The relationship between morphologically related words has been extensively investigated using variations on the experimental paradigm of 'repetition priming'. Generally, a repetition priming paradigm includes an experimental condition in which a dependent variable is measured during the identification (or production) of a stimulus being encountered for the first time in the experiment, and during the identification (or production) of a stimulus that has been encountered previously during the experiment. The prior encounter may have been in an identical form, or in a different form of presentation. Thus if the second encounter with an item was as text, then the first encounter may have been in the auditory or pictorial modality , or as text but in a different letter case or font. I shall use the term 'repetition priming effect' or 'repetition effect' to refer to the difference between the value of a dependent variable in response to a 'repeating' item and its value elicited by an item being encountered for the first time in the experiment.

In the remainder of this chapter, I will describe the results of some studies which have sought to determine the nature of the representations and/or processes underlying memory in general and memory for words in particular. I will first discuss evidence that there are different forms of memory, and briefly consider two classes of memory model that have been proposed. I will pay particular attention to the form of memory proposed by these models that allows for the recognition of words, i.e. 'lexical memory'. This discussion of models of memory will provide the context and rationale for a selective review of experiments which have investigated the effects on behavioural dependent measures of the repetition of visually presented stimuli. These experiments have manipulated a range of experimental variables. Each experiment has, in different ways, attempted to constrain the range of cognitive processes used by subjects to perform a particular task. Different tasks which utilise similar cognitive processes should respond in similar ways to experimental manipulation.

In chapter 2, I will introduce ERP methodology and selectively review experiments which have investigated the response of ERPs to stimulus repetition. Finally I will discuss the reasons why the use of ERPs may address questions concerning the relationship between derivationally related words.

1.1 Direct and indirect tasks

Direct memory tasks explicitly require subjects to attempt to remember previously encountered material (Johnson & Hasher, 1987; Richardson-Klavehn & Bjork, 1988). For example, in a typical recognition memory task, subjects have to discriminate between items previously encountered in the experiment and those items being seen for the first time.

Memory effects in indirect tasks occur in the absence of any specific instruction to subjects to remember the previous occurrence of an item. The experiments reported in this thesis use one such indirect task, the lexical decision task (LDT; Rubinstein, Garfield, & Millikan, 1970). In the LDT subjects are required to discriminate between real words and nonsense words (hereafter referred to as 'non-words'). Non-words may be orthographically legal (e.g. BLINT) or orthographically illegal (e.g. ZWSFQ). Another indirect task which has been frequently used in one form or another is the perceptual identification task in which subjects are required to identify experimental items presented under perceptually degraded conditions. Subjects will have encountered some items previously in a study phase. A priming effect is seen when a higher proportion of the previously encountered items are identified compared to items being seen for the first time. Other indirect tasks include the naming task, the stem completion task and the word fragment completion task.

Typically in the LDT, responses to repeating words are faster than to words being encountered for the first time (Forbach, Stanners, & Hochhaus, 1974; Kirsner & Smith, 1974). This facilitation in response times, and the changes in performance levels seen in other indirect tasks, has been taken as evidence of the operation of a form of memory distinct from that underlying the performance of direct tasks. This form of memory has been referred to descriptively as 'implicit memory' and has been contrasted with 'explicit memory' thought to underlie performance on direct tasks (Graf & Schacter, 1985). Extensive reviews of the evidence for, and nature of, implicit memory have been provided by Schacter (1987), Richardson-Klavehn and Bjork (1988), and by Roediger and McDermott (1993), but I will briefly review the three sources of evidence which have been used to support the distinction between implicit and explicit memory.

1.1.1 The performance of memory-impaired patients on direct and indirect tests of memory

Memory impaired subjects generally perform poorly on direct tests of memory (e.g. Warrington & Weiskrantz, 1970), but a large number of studies have suggested that they perform normally, or near normally, on indirect tests of memory (e.g. Cermak, Talbot, Chandler, & Wolbarst, 1985; Cohen & Squire, 1980; Graf, Shimamura, & Squire, 1985; Graf, Squire, & Mandler, 1984; Haist, Musen, & Squire, 1991; Jacoby & Witherspoon, 1982; Moscovitch, 1982; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1968; 1974).

Such dissociations in performance of memory-impaired subjects on the two types of task has been taken as support for the view that memory is not a unitary phenomenon (e.g. Schacter, 1987; Schacter, Chui, & Ochsner, 1993; Squire, 1992; Tulving & Schacter, 1990). Instead, it has been argued that the performance of memory impaired subjects on indirect tasks reflects the normal operation of implicit memory, whilst their poor performance on direct tasks reflects a dysfunctional explicit memory. However, this account has been challenged, firstly by apparent demonstrations in amnesic patients of impaired implicit memory (e.g. Ostergaard, 1994), and secondly by demonstrations that memory impaired subjects perform better on some indirect tasks than on others (Keane, Gabrieli, Fennema, Growden, & Corkin, 1991; Squire, Shimamura, & Graf, 1987). Such dissociations suggest that a dissociation between performance on direct and indirect test cannot be taken as diagnostic of two forms of memory.

1.1.2 Stochastic independence

Stochastic independence refers to the condition in which demonstrations of memory of an item on one test is uncorrelated with demonstrations of memory for the same item on a second test. A number of studies have demonstrated stochastic independence between performance on direct and indirect tests of memory (e.g. Hayman & Rickards, 1995; Jacoby & Witherspoon, 1982; Tulving, Schacter, & Stark, 1982). According to Tulving (1985), stochastic independence is a stronger test of the dissociability of tests than is functional independence (see Section 1.1.3). Demonstrations of stochastic independence involve a direct comparison of tests, whilst demonstrations of functional independence are indirect and depend upon differential effects of an experimental variable. The usefulness of stochastic independence as a criterion for different memory systems has been challenged on grounds of empirical (Shimamura, 1985) and logical (Hintzman, 1990) validity.

1.1.3 Functional independence

The main body of evidence concerning the dissociability of implicit and explicit memory comes from findings of functional independence between tasks. For present purposes, the term 'functional independence' refers to a situation in which a given experimental variable has different effects on an indirect task and on a direct task. A number of different variables have been used to show functional independence. Some of the most influential studies of the functional independence of direct and indirect tests have manipulated whether words are read or generated in the study phase and the 'level of processing' (LoP; Craik & Lockhart, 1972) required by the task performed by subjects when first encountering the word in the experiment. I will discuss studies which have used these manipulations in more detail below.

Other studies which have demonstrated functional independence between direct and indirect tests have manipulated the retention interval between first and second encounters (e.g. Cave & Squire, 1992; Roediger, Weldon, Stadler, & Riegler, 1992; Scarborough, Cortese, & Scarborough, 1977; Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tulving, et al., 1982), word frequency (e.g. Rajaram & Neely, 1992; Scarborough, et al., 1977), changes of presentation modality between study and test (e.g. Hayman & Rickards, 1995; Jacoby & Dallas, 1981; Light, LaVoie, Valencia-Laver, Albertson-Owens, & Mead, 1992), whether attention is full or divided at study (e.g. Jacoby, Woloshyn, & Kelley, 1989) and whether repetitions at study are massed or spaced (Challis & Sidhu, 1993).

1.1.3.1 The 'read-generate' effect in direct and indirect tests of memory

Jacoby (1983a) demonstrated that performance on a perceptual identification task was enhanced more as a result of the prior reading of a word than as a result of generating the word from a cue. In contrast, performance in a recognition memory task was better for words which had been generated than for those which had been read. Such dissociations have been taken as evidence that performance of direct and indirect tasks utilise qualitatively different cognitive processes. Jacoby (1983a) argued that if task performance was enhanced most by prior reading of a word, then such tasks could be characterised as being sensitive to 'data-driven' processing.

In contrast, tasks in which performance was most enhanced by generating the target word could best be characterised as being sensitive to 'conceptually driven' processing.

This 'read-generate' effect has been used as a criterion to discriminate between tasks which utilise one or other form of processing (Blaxton, 1985; 1989; Roediger, Weldon, & Challis, 1989; Roediger & Blaxton, 1987; Srinivas & Roediger, 1990). The correspondence between data-driven processing and indirect tasks and between conceptually driven processing and indirect tasks was explored by Blaxton (1985) and by Roediger and Blaxton (1987). They argued that, typically, demonstrations of functional independence between direct and indirect tasks confound the two tasks with the two types of processing . In addition to a data-driven indirect task and a conceptually driven direct task, Blaxton (1985) constructed a conceptually driven indirect task (answering general knowledge questions) and a data-driven direct task ('graphemic cued recall' in which the cue was orthographically similar to the target word, e.g CHOPPER for COPPER).

Blaxton (1985) found that a 'generate' study task enhanced performance more on conceptually driven tasks than on data-driven tasks regardless of the direct or indirect nature of the task. Similarly, 'read' study conditions enhanced 'data-driven' tasks more than conceptually-driven tasks irrespective of whether the task was direct or indirect. She concluded that the critical distinction between tasks is not whether they are direct or indirect, but whether the task is dependent upon data- or conceptually-driven processing.

Srinivas and Roediger (1990, experiment 1) also used 'read vs generate' study conditions to dissociate performance on direct and indirect tasks. However performance on two indirect tasks, word fragment completion and category association, was also dissociated. Srinivas and Roediger (1990) argued that this result suggested that no single process could be responsible for the performance of all indirect tests. A number of studies have now reported dissociations in performance between different indirect tasks (e.g. Rajaram & Roediger, 1993; Roediger, et al., 1992).

1.1.3.2 Levels of processing and direct and indirect tests of memory

Typically in experiments manipulating LoP, items are initially presented in a 'shallow' (e.g. count the vowels) or a 'deep' (e.g. semantic categorisation) encoding task. The same items are presented in a subsequent test phase. Jacoby and Dallas (1981) manipulated LoP and demonstrated functional independence between perceptual identification and recognition memory tasks. Priming effects in a perceptual identification task were unaffected by whether words had initially been studied in a deep or a shallow encoding condition, but recognition memory was better when words had been encountered under deep encoding conditions (see also Hashtroudi, Ferguson, Rappold, & Chrosniak, 1988; Light & Singh, 1987).

Other indirect tests have also been shown to be insensitive to LoP (e.g. for the stem completion task; Graf & Mandler, 1984; Roediger, et al., 1992: for the word fragment completion task; Squire, et al., 1987). However Duchek and Neely (1989, see also Kirsner, Milech, & Standen, 1983) found that there was a LoP effect in recognition memory and the LDT. Although the two effects were dissociable with respect to the way they interacted with word frequency, these results raised doubts concerning the use of LoP manipulations in demonstrating functional independence between direct and indirect tasks.

The claim that indirect tasks are insensitive to manipulations of LoP has also been challenged by Challis and Brodbeck (1992), by Hamman (1990) and by Toth, Reingold and Jacoby (1994). Challis and Brodbeck (1992) found that only when the study tasks were intermixed were non-significant LoP effects obtained. Furthermore of 35 reports of the effects of LoP manipulations on performance of indirect tests, in only 2 cases was performance in the deeper encoding condition worse than after the more shallow encoding condition. Hamann (1990) demonstrated reliable effects of LoP on a conceptual indirect task. This result suggests that LoP effects can be observed when subjects engage in conceptual processing irrespective of the nature of the task being performed and are not specific to a form of memory engaged only during the performance of a direct test. Toth, Reingold and Jacoby (1994) demonstrated a LoP effect on performance in the stem completion task. Toth et al (1994) used Jacoby's (1991; Jacoby, Toth, & Yonelinas, 1993) 'process dissociation procedure' to argue that performance in an indirect task did not reflect only one type of processing (or only one type of memory system).

The lack of functional independence between direct and indirect tasks in respect of LoP manipulations means that functional independence cannot so readily be taken as evidence that the two forms of test are performed using different forms of memory. Jacoby (1991) has argued that performance of tasks is not 'process-pure' but always involves contributions from different forms of memory (see also Challis & Brodbeck, 1992; Dunn & Kirsner, 1989; Merikle & Reingold, 1990; Richardson-Klavehn & Bjork, 1988). Only when steps are taken to disentangle the contributions of the different processes or systems to performance on a particular task can the sensitivity of each of these components to different experimental variables be assessed.

1.2 Models of memory : Systems and Processes

The next two sections outline the two main classes of model which have been proposed to account for performance on direct and indirect tests of memory. I pay particular attention to the way each class of model accounts for lexical memory.

1.2.1 Systems models of memory

A number of models of memory have proposed that memory is a consequence of the action, either alone or jointly, of a number of different memory systems. Such models claim that performance on direct and indirect tests of memory can best be understood as a reflection of the operation of memory systems which are computationally and neuroanatomically distinct.

Tulving (1983; 1985) has argued that memory can best be understood as reflecting the combined operation of procedural, episodic and semantic memory systems. Procedural memory allows the performance of skilled behaviour. The episodic system underlies memory for particular prior occurrences of an event and allows for conscious recollection of prior events. The semantic system is responsible for memory for general knowledge of the world, including of particular word forms and their meanings.

A similar distinction between memory systems responsible for memory for specific events and for general knowledge have been made by Squire and by Schacter. Squire (1992; 1993; Cohen & Squire, 1980) suggests that memory in direct tasks is dependent upon 'declarative' memory, whilst 'nondeclarative' memory is responsible for memory effects on indirect tasks and allows memory for more general knowledge, as well as of skills and habits. Schacter (1987) distinguishes between explicit and implicit memory systems. Explicit memory underlies performance on direct tasks, whilst implicit memory underlies performance in indirect tasks.

Schacter (1990; 1992; Tulving & Schacter, 1990) argued that implicit memory effects may result from changes occurring within a number of different 'perceptual representation systems' (PRSs). A similar proposal for the memory of word forms was proposed by Shallice and Warrington (1980). Such PRSs form a distinct memory system, but one which has aspects in common with procedural memory and semantic memory systems. Tulving and Schacter (1990) identify separate PRSs for the identification of visual word forms, auditory word forms and visual objects. Rather than the representations within a PRS being abstract, Tulving and Schacter (1990) argued that they were specific to a particular encounter. However Schacter, Rapscak, Rubens, Tharan and Laguna (1990) suggested that the PRSs may include specific and abstract representations of the form of words (see also Marsolek, Kosslyn, & Squire, 1992; Marsolek, Squire, Kosslyn, & Lulenski, 1994). Gabrieli et al (1994) suggest that there is a lexical-semantic representation system separate from the PRSs. This lexical-semantic system is intact in amnesic patients but is compromised in patients with Alzheimer's Disease. Such a system of abstract representations of word forms has similarities to a system of word recognition units, or logogens, as proposed by Morton (1969; 1979; Morton & Patterson, 1980). Since the logogen model has provided the theoretical framework in which work on the morphological relationship between words has largely been conducted, I will discuss it in some detail.

The central feature of Morton's model is a set of independent word recognition units termed 'logogens'. Logogens act as 'evidence collectors' and become activated in proportion to the degree the word they represent is compatible with the input to the logogen. This input derives from systems concerned with perceptual analysis, and from a cognitive system which is concerned with conceptual processing. When the activation state of a particular logogen reaches its threshold, the logogen fires and the output from the logogen is available to other systems. When a logogen fires, its threshold is temporarily reduced. As a consequence of this reduction in threshold, if the same word is encountered again then less evidence is required in order for this new lower threshold to be reached. Thus the logogen fires more quickly than it did on the previous presentation of the word. This decrease in time required to reach threshold can be observed as a repetition effect in a task requiring word recognition.

In the original logogen model, activation within a logogen is undifferentiated. The activation may have originated from perceptual or conceptual processing. Logogens are therefore ahistoric, abstract representations of words which respond equally to words regardless of the form in which they are encountered. This insensitivity of logogens to surface form has come under particular scrutiny (see Section 1.3).

Other models of word recognition have also incorporated sets of abstract word recognition units (e.g. Becker, 1976; 1980; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1982). Similar systems of abstract representations have been proposed to underlie recognition of faces and objects as well as words (e.g. Bruce, Burton, & Craw, 1992). Such abstract representational systems are rooted in models of cognition which emphasise abstraction of commonality across instances, resulting in the formation of prototypes, schemata or mental models (e.g. Carr & Pollatsek, 1985; Johnson-Laird, 1983; Posner & Keele, 1968; Rosch, 1978).

1.2.2 Processing models of memory

Systems models have been much criticised by processing theorists (e.g. Blaxton, 1989; Jacoby, 1983b; Kolers & Roediger, 1984; McKoon, Ratcliff, & Dell, 1986; Ratcliff, Hockley, & McKoon, 1985; Roediger, 1990). These critics argue that performance on different memory tests results from a single system having different modes of processing. Memory is demonstrated to the extent that the processing accorded an item is a recapitulation of the processing accorded to an earlier presented item. Since any detail of an encounter with an item will change the way an item is processed, then the details of the encounter will be encoded. Thus memory effects should be sensitive to differences in surface form and presentation conditions across encounters. This sensitivity to surface form should be reflected in an attenuation of the priming effects observed when the same word is presented in a different format on different occasions. This prediction contrasts with that made by 'abstractionist' accounts in which priming effects are mediated by a representation which is insensitive to changes in surface form. The emphasis of process-based models on specific prior occurrences of an event is echoed in models of skill learning, attention and automaticity (e.g. Brooks, 1978; Logan, 1988; 1990; Neumann, 1984).

Processing models of memory have been particularly advocated by Jacoby and his colleagues, (Jacoby, 1983a; 1983b; 1991; Jacoby & Dallas, 1981; Jacoby, et al., 1993) and by Roediger and his colleagues (Roediger, 1990; Roediger, et al., 1989; Roediger & Blaxton, 1987; Weldon, 1991). These authors have drawn heavily on the idea of 'transfer appropriate processing' proposed by Morris, Bransford and Franks (1977), and on the earlier work of Kolers (e.g. Kolers, 1975).

Jacoby (1991; Jacoby, Toth, Yonelinas, & Debner, 1994) has distinguished between unconscious, automatic uses of memory and intentional uses of memory. Unconscious uses of memory are fast acting and not subject to conscious control. Since tasks are not process-pure the contribution of automatic and intentional memory to the performance of a task must be assessed. Jacoby (1991; Yonelinas & Jacoby, 1995) has proposed that the process dissociation procedure allows an assessment of the relative contribution of automatic and intentional uses of memory in task performance.

The attributes that Jacoby has ascribed to automatic processing are those which have been ascribed to lexical processing (e.g. Marcel, 1980). Early processing models did not acknowledge a specifically lexical level of analysis, but Weldon (1991; 1993, see also Roediger & Srinivas, 1993) has argued that 'access to a unitised lexical representation is fundamental in obtaining priming on the word fragment and perceptual identification tests' (Weldon, 1991 p. 538). Toth, Reingold and Jacoby (1994) also suggest that there may be a lexical contribution to performance on indirect tasks. They argue that Hayman and Jacoby (1989) showed that lexical priming occurs if a word is processed as a word at study. Toth et al (1994) see lexical processing as a form of conceptual processing rather than being distinct from perceptual and conceptual processes (cf. Weldon, 1991).

Although 'systems' and 'processing' accounts of memory have been seen as being mutually incompatible, there have been attempts to reconcile the two approaches (e.g. Hayman & Rickards, 1995; Roediger & Srinivas, 1993; Schacter, 1990; 1992). Recently developed 'connectionist' models of representation (e.g. Plaut & Shallice, 1993; Seidenberg & McClelland, 1989) have also incorporated aspects of both approaches.

1.2.3 Isolating systems and processes

The nature of repetition effects in direct and indirect tasks have been used to make claims concerning the nature of memory systems and/or processes, particularly those concerned with lexical memory. For these claims to be justified experiments must be designed so that the repetition effects reflect changes in the desired system or process. Those researchers interested in lexical memory have sought to distinguish a component of a repetition effect resulting from a change in a lexical representation from components due to perceptual or conceptual processes, and from components resulting from conscious recollection of a prior encounter (e.g.

Monsell, 1985). In Sections 1.4 to 1.11, I selectively review studies using a variety of experimental manipulations thought to be sensitive to one or more of these different components.

1.3 Changes of presentation format and the word repetition effect

Models based upon abstract ahistoric representations predict that there should be no differences in the magnitude of repetition effects with changes in format. This prediction contrasts with that made by processing accounts which suggest that the magnitude of the repetition effects observed will decrease as changes in format across presentations, and hence differences in processing, become more pronounced. Jacoby and Dallas (1981) argued that an attenuation of a repetition effect as a result of changing the modality of stimulus presentation from visual to auditory, or vice versa, would be particularly problematic for abtractionist models. I therefore begin by describing the experiments which have investigated the effects of such modality changes.

1.3.1 Repetition across visual and auditory modalities

In the original formulation of the logogen model of word recognition a single set of logogens could be activated by input from either the visual or auditory modality. If repetition priming effects are entirely a product of changes in the activation of logogens, then the repetition effects should be as great when a word is repeated in the same modality as when a word is repeated across modality. The results of a number of studies using a variety of tasks suggest that this is not the case.

Winnick and Daniel (1970) showed that the repetition effects on a perceptual identification task were sensitive to the modality of presentation. While repetition effects in the identification task were obtained when a word was presented at study in its printed form, there was no increase in the probability of identifying a repeated word when it had earlier been generated by subjects in response to a printed definition. This study however confounds the modality of the encounter with whether the word was being comprehended or produced.

A large number of studies have examined the sensitivity of the perceptual identification task to changes in modality between study and test presentations of a word. (e.g. Clarke & Morton, 1983; Hashtroudi, et al., 1988; Jacoby & Dallas, 1981, experiment 6; Light, et al., 1992; Rajaram, 1993; Weldon, 1991). Although these studies have generally failed to find reliable across-modal priming, some studies have demonstrated reliable effects (e.g. Clarke & Morton, 1983), whilst in others the across-modal effect was up to 40% of the magnitude of the within-modality effect (e.g. Rajaram, 1993).

The absence of reliable across-modality effects in perceptual identification suggest that this task is mainly sensitive to overlap of visual form. The occasionally reliable across-modal effect may indicate that there is a modality independent component, but Jacoby and Dallas (1981) argue that in one study which demonstrated across-modality effects (Lee, Tzeng, Garro, & Hung, 1978), these effects may have arisen because an extended study period allowed conceptual processing of the words.

Across-modality priming has also been investigated in the word stem completion task (e.g. Basilli, Smith, & MacLeod, 1989; Craik, Moscovitch, & McDowd, 1994; Graf, et al., 1985; Jacoby, et al., 1993; Rajaram, 1993). In each of these studies, there were reliable effects of across- and within-modality repetition but with the within-modality effects being reliably greater than the across-modality effects. A similar pattern of effects was reported for the word fragment completion task (Craik, et al., 1994; Rajaram, 1993; Roediger & Blaxton, 1987; Weldon, 1991).

Studies by Kirsner and Smith (1974) and by Monsell (1985) have investigated within- and across- modality repetition effects in the LDT. Kirsner and Smith (1974) found reliable effects of both within- and across-modality repetition for words but the within-modality effects were greater than the across modality effects. For non-words there were reliable effects of within-modality repetition but not of across modality repetition. Monsell (1985) found that when words were presented visually in a LDT there were reliable repetition priming effects only for words which had originally been seen. In contrast when the LDT was conducted in the auditory modality there were reliable priming effects irrespective of the modality of the first encounter. The effects in the within modality conditions were reliably greater than the priming effects in the across modality condition.

Roediger and Blaxton (1987) reviewed the effects of manipulations of surface similarity on the magnitude of priming effects. They noted the reduction in the priming effect caused by changes of surface form and argued that this reduction indicated the importance of surface features in eliciting repetition effects. However for changes of auditory and visual modality, the magnitude of the across-modal effects were some 60% of the magnitude of the within-modality effects (see also Brown, Neblett, Jones, & Mitchell, 1991 for other estimates of the relative magnitude of across-modal effects). It might be equally appropriate therefore to consider reasons why the across-modal effect remained at a relatively high level.

Morton (1979; Morton & Patterson, 1980) amended the logogen model to account for the lack of equivalence of within and across modal effects. This revised model incorporated separate logogens for words encountered in visual and auditory modalities. Under this amended logogen model it is the modality specific component that reflects the operation of a lexicon of modality specific word forms. Although not designed to account for modality non-specific effects, such effects could be mediated through links between each logogen system and the cognitive system.

These modality non-specific processes may include processing which allows for the conscious recollection of repeating stimuli (Jacoby, et al., 1993). Such a 'conceptual' account of modality independent effects contrast with the accounts provided by Monsell (1985) and Kirsner et al (1989), neither of which invoke conceptual processing to account for modality independent repetition effects.

Kirsner (Kirsner, et al., 1989; Kirsner & Smith., 1974) has argued that the repetition effect has two components. A modality specific component which reflected perceptual processing prior to a 'lexical' level of representation, whilst a modality non-specific component reflected changes to an amodal lexical representation. Whilst both components contribute to the within-modality effect, only the modality non-specific component contributes to the across-modality effect. The within-modality effect results from changes to event-specific perceptual processing , whilst across-modality effects arise from event specific mappings between processes involved with the perception and production of words.

Monsell (1985) proposed separate logogen systems for visual and auditory modalities, as well as for perception and production. Across-modality effects occur because of links between logogen systems. Although such indirect activation passing across these links facilitates subsequent word recognition, it does so to a lesser degree than does direct activation of a logogen. The links between visual and auditory input lexica are asymmetric. Whilst activity in the visual input logogen system results in significant activity in the auditory input logogen system, activity in the auditory input lexicon produces little activity in the visual input lexicon. This asymmetry accounts for why across-modal priming effects are greater when the first presentation is visual and the second presentation is auditory than vice versa.

Models based on abstract representations can thus account for the modality-dependence of repetition effects by making the 'unit of analysis' more specific, but these modified models are no longer based upon truly abstract representations. Activity within a system of auditory input logogens, for example, provides information concerning the likely modality of input. Nonetheless the division of lexical representations by modality can be defended as the end result of the different sensory mechanisms and neural pathways through which spoken and written language is apprehended, and as a reflection of relatively recent development of language in a written form compared to the considerably more ancient spoken form. Thus there seems to be good reason for visual and spoken language to have a different representational basis (but see Bradley & Forster, 1987). If so, then the claim that the sensitivity of repetition effects to modality counts against an abstractionist view of lexical representation is weakened. Greater difficulty might be caused for the abtractionist position if a diminution of the repetition effect were brought about by changes in the format of stimulus presentation which could not be parsimoniously accounted for by a further sub-division of a system of abstract representations. A number of studies have attempted to demonstrate such effects.

1.3.2 Manipulations of visual format

A number of studies have varied the physical appearance of visually presented words between a first and a repeated presentation. Thus Scarborough et al (1977) found equivalent facilitation in the LDT when the letter case of the first and second presentations was in a different letter case as when they were in the same case. Clarke and Morton (1983) investigated the effects of format change in a perceptual identification task. Since this task has been thought to be particularly sensitive to perceptual processing, it may have proved to be sensitive to changes of visual form. Clarke and Morton (1983) found an equivalent enhancement of performance in a perceptual identification task when the first presentation of a word was in a cursive script and the second was printed text than they did when both presentations were in printed text.

A number of other studies investigating the sensitivity of repetition effects to changes in surface form have used the perceptual identification task, or variants of it (Feustel, Shiffrin, & Salasoo, 1983; Graf & Ryan, 1990; Jacoby & Hayman, 1987; Jacoby & Witherspoon, 1982; Standen, Kirsner & Dunn, cited in Kirsner, et al., 1983). As with auditory to visual across-modal effects, these studies have generally found that a change in format of presentation reduces the size of the repetition effect. Nonetheless the magnitude of the across-format effects may be some 70% (Jacoby & Hayman, 1987; Jacoby & Witherspoon, 1982) or 50% (Graf & Ryan, 1990) of the magnitude of the same-format effect.

Levy and Kirsner (1989) and Carr, Brown and Charalambous (1989) investigated the effects of changing the format of presentation on the time required to read a prose passage. Both studies suggested that this measure was insensitive to changes in presentation format, a result that is consistent with an abstractionist position. However Carr et al (1989, experiment 3) also found a similar effect with texts made up largely of nonsense words. Such a result is potentially problematic for an abstractionist view such as the logogen model since non-words have no pre-existing representations (see Section 1.6).

Masson (1986, experiment 2) required subjects to read word triplets, the constituent letters of which were mirror reversed and presented in either upper or lower case depending upon the identity of the letter. Subsequently subjects read words which were either repeated from the training phase or were words new to the experiment. Old words were either presented in a visually identical format to that in which they had been presented previously, or in a format in which letters that had been presented in lower case in the training phase were now presented in upper case and *vice versa*. Repeated words in the same format and different format conditions each showed reliable priming effects, but the magnitude of the effect in the case of the visually identical condition was greater than that in the visually non-identical condition. Masson (1986) argued that there were form-specific and form non-specific components to the repetition effect with these components acting independently of one another. Woltz (1990) studied the effects of changes in surface form on repetition effects in a task in which subjects judged whether or not pairs of simultaneously presented words were synonyms. He found that whilst changes in letter-case from study to test did result in a reduction in repetition effects, this reduction was only some 15% of the magnitude of the repetition effect.

In summary, changes in the visual form of items across encounters have a similar effect as does a change in the modality of presentation. When the format changes across encounters, the magnitude of the effects is reduced but the repetition effect is still relatively large and usually statistically reliable. This is the case even in the perceptual identification task; a task which is thought to be particularly sensitive to changes in perceptual processing. Furthermore in some tasks, e.g. the LDT, there is little evidence for any reduction in the magnitude of the effect as a result of changes in visual format. Word repetition effects therefore seem to reflect both format specific and format non-specific levels of processing. The conclusion that there are multiple components to repetition effects is consistent with the results of studies which have investigated the effects of the repetition of perceptually degraded stimuli to which I turn next.

1.4 Word repetition, stimulus degradation and word frequency

A number of studies have compared the effects of repetition on visually degraded and undegraded stimuli. Visual stimuli have typically been degraded either by the addition of visual noise (e.g. Besner & Swan, 1982), by contrast reduction (Norris, 1984) or by removing information from the stimulus display (Holcomb, 1993). This manipulation has generally been held to slow the rate at which information is extracted from a stimulus (e.g. Becker & Killion, 1977; Meyer, Schvaneveldt, & Ruddy, 1974; Neely, 1991). If repetition effects depend upon such perceptual processing, then according to 'additive factors' logic (Sternberg, 1969), repetition and stimulus degradation should produce interactive effects.

Besner and Swan (1982) and Norris (1984) each investigated the effects of repetition of degraded stimuli in a LDT. Words and non-words were presented under both clear and degraded conditions. The interaction between repetition and degradation was reliable for both words and non-words. In each case the effects of degradation were greater on items presented for the first time than for items presented for the second time.

Scarborough et al (1977) found that low frequency words benefited from repetition more than did high frequency words. This interaction between repetition and frequency is highly robust and has been found in a variety of experimental tasks. Such frequency effects have been interpreted as arising at a lexical level of representation (Scarborough, et al., 1977). This claim has been both challenged (Balota & Chumbley, 1984; 1985; Forster & Davis, 1984) and defended (McRae, Jared, & Seidenberg, 1990; Monsell, 1990; Monsell, Doyle, & Haggard, 1989). If frequency effects are a product of lexical processing, and repetition and frequency interact then, according to additive factors, at least one component of the repetition effect should also result from lexical processing. Furthermore if degradation also effects lexical processing, then this factor should interact not only with repetition, but also with frequency. Such an interaction was reported by Norris (1984, but see Stanners, Jastrzembski, & Westbrook, 1975, and Becker & Killion, 1977, for additive effects of degradation and frequency).

Besner and Swan (1982) argued that there were two components of the repetition effect. They suggested that one component reflected differences in threshold or activation levels within a system of abstract representations. Because the representations corresponding to unrepeated words were further from their thresholds than were the representations corresponding to repeated words, manipulations such as visual degradation, which slow the accumulation of perceptual evidence by a word recognition unit, would have more of an effect on unrepeated words than on repeated words. For visually degraded stimuli such word recognition units constitute an 'orthographic input' lexicon (Besner & Smith, 1992; Borowsky & Besner, 1991; 1993).

This view of degradation and word repetition affecting primarily an encoding stage of word recognition has been challenged by Den Heyer and Benson (1988) and by Whittlesea and Jacoby (1990). Den Heyer and Benson (1988) found that degradation interacted with repetition, but the interaction between semantic priming and degradation was not reliable. Den Heyer and Benson (1988) argued that, although part of the repetition effect may lie in a lexicon of word forms, the effects of degradation and repetition were exercised at a late stage in the processing of a word in the LDT which may involve episodic memory. Whittlesea and Jacoby (1990) also favoured an episodic account for the effects of stimulus degradation. They argued that prime and target items in priming experiments typically formed a 'compound cue' (Ratcliff, 1978). According to the compound cue hypothesis, such cues are maintained in short-term memory and matched against representations retrieved from long-term memory. Whittlesea and Jacoby (1990) argued that the formation of a compound cue would occur more for degraded stimuli than clearly visible stimuli because the perception of degraded stimuli would rely more upon the context in which the item occurred. Repetition effects were held to reflect the greater ease with which representations could be retrieved from long-term memory when the compound cue was formed from the same item compared to when it was formed from different items.

To summarise: Effects of frequency and visual degradation have been used to determine the processing locus (or loci) at which item repetition has its effect. Although the results of such studies are not consistent, Besner and his colleagues have identified two components of repetition effects, one of which, they argued, reflects changes in a lexicon of word forms. The second component may reflect processes involved in episodic memory.

1.5 Conceptual processing and repetition priming

A number of approaches have been taken in an attempt to determine the nature of the component of the repetition effect which appears to be independent of the surface form of an item. This component may reflect the repetition of conceptual processing and a number of experimental paradigms have been used in an attempt to assess this possibility.

1.5.1 Repetition effects across languages

A number of studies have investigated the effects of word repetition across languages (e.g. Brown, Sharma, & Kirsner, 1984; Cristoffanini, Kirsner, & Milech, 1986; see de Groot & Nas, 1991 for a review). If a repetition effect is observed when the first encounter with a word is in language A and the second encounter is in language B, then this effect may be accounted for either by proposing that the words share a conceptual representation and the repetition effect is mediated by such a representation, or that the lexical representations of the word in each language are strongly linked and that the repetition effect is mediated by such a link.

Cristoffanini et al (1986) investigated across-language repetition effects in English and Spanish using the naming and lexical decision tasks. Some words were 'non-cognates' being formally different in the two languages (e.g. 'panaderia' - 'bakery'), whilst others were 'cognates' which were formally as well as semantically similar across the two languages (e.g. 'succion' - 'suction'). Whilst there was no evidence of across-language priming effects for the non-cognates, the cognate forms produced as great a priming effect as did within-language repetition. The absence of repetition effects with the non-cognates suggests that repetition of conceptual information is not a sufficient condition for eliciting repetition effects.

De Groot and Nas (1991) investigated the effects of repetition priming and semantic priming between Dutch and English cognate and non-cognate forms using either masked (see Section 1.8) or unmasked primes. They found that there were reliable masked repetition priming effects for cognate and for non-cognate words, but that the semantic priming effect for non-cognate words was reliable only in the unmasked condition. De Groot and Nas (1991) argued that the masked repetition effect reflected links between lexical representations. However, the unmasked repetition effect was some three times the magnitude of the masked effect, suggesting that this lexical mechanism may not be responsible for the greater part of the repetition effect.

1.5.2 Repetition effects with pictures

A number of studies have reported the effects on performance of an indirect test resulting from a prior encounter with a picture (Brown, et al., 1991; Durso & Johnson, 1980; Scarborough, Gerard, & Cortese, 1979; Vanderwart, 1984; Weldon, 1991; 1993; Weldon & Jackson-Barrett, 1993; Weldon, Roediger, Beitel, & Johnston, 1995; Weldon & Roediger, 1987).

Generally, priming effects are smaller with picture primes than with word primes, or they may be absent altogether (see for example the studies by Weldon and her colleagues). Weldon and Jackson-Barrett (1993) argued that picture priming effects could largely be accounted for as reflecting the use of verbal labels to name the pictures. Even when conceptual processing is involved in picture-word priming, such processing is slower to have an effect than perceptual and lexical processing (see also Weldon, 1993). Although Vanderwart (1984) found larger effects with picture primes than with word primes, the magnitude of the word priming effects may have been constrained because of a floor effect. Also Brown et al (1991) have argued that because picture-word priming effects were evident only when picture and word prime types were varied across subjects, or blocked within subjects, across-form effects are unlikely to be mediated by automatic processing.

The results of these studies suggests that prior conceptual processing as elicited by the naming of a picture is not sufficient to produce reliable priming effects on typical indirect, largely data-driven tasks. Where effects are evident they may be mediated through lexical representations invoked as a result of subjects applying verbal labels to the pictures. Where conceptual processing is implicated in picture-word priming, its effects are short-lived and relatively slow to exert an effect.

1.5.3 Repetition effects with homographic and polysemous words

Masson and Freedman (1990) and Bainbridge, Lewandowsky and Kirsner (1993) reported priming effects with words having multiple meanings. Such words allow an examination of the effects of a repeated encounter with a particular word form when the conceptual processing accorded the word differs across encounters.

Masson and Freedman (1990, experiment 2) demonstrated reliable repetition effects when homographs were repeated with either an identical word (e.g. money - BANK followed by money - BANK), or with a different word that was consistent with same meaning as had been suggested on the first presentation of the word (e.g. light - BEAM followed by laser - BEAM). The 'identical' condition produced a greater effect than the 'same meaning' condition. In contrast, there was no reliable effect when a homograph was repeated, but where the suggested interpretation differed across encounters (e.g steel - BAR followed by tavern - BAR). Masson and Freedman (1990) argued that repetition effects arose as a result of the integration of a representation of the word form and a particular meaning into a context-specific interpretation of a word.

The empirical basis of this claim can be questioned. For one sub-set of experimental items, the 'different meaning' effect was some 70% of the magnitude of the the 'same meaning' effect, but the reliability of this 'different meaning' effect alone was not reported. Furthermore the larger 'same meaning' effect in comparison with the 'different meaning' condition depends upon the collapsing together of identical and 'same meaning' conditions. But because repetition of the context word was a completely reliable predictor of the identity of the target word, the magnitude of the identical repetition effect may have been inflated by subjects predicting the occurrence of words in the identical repetition condition. This would then also have inflated the difference between the 'different meaning' condition and the collapsed same and identical meaning conditions.

Bainbridge et al (1993) required subjects to make lexical decisions to polysemous words that were preceded by a sentence 'frame' that provided a context that was consistent with one of the word's senses. They found that changing the sentence frame reduced the magnitude of the repetition effects for items with many meanings by 97%, but a change in sentence frame reduced the magnitude of the repetition effect for the items with few meanings by only 14%.

Bainbridge et al (1993) argued that effects of context on repetition priming effects are a consequence of a change in the perceived sense of the word brought about by the context, rather than the change of context itself. Repetition priming effects arose, at least in part, from the activation of the meaning of a word, with the particular meaning activated dependent upon the context in which the word is encountered.

In this section two studies were considered. Each of these studies has emphasised the importance of conceptual processes in repetition effects. Although the study by Bainbridge et al (1993) provides some evidence for the effects of conceptual processing on repetition effects, these effects may be dependent upon the use of sentence frames. The study reported by Masson and Freedman (1990) does not provide convincing evidence that repetition effects reflect conceptual processing. Studies which have investigated the joint effects of semantic and repetition priming further question a conceptual processing account of repetition effects.

1.5.4 Repetition effects and semantic priming

When a word presented in a LDT has been preceded by a semantically related word, then a correct response is generally made more quickly than if it had been preceded by a semantically unrelated word (Meyer & Schvaneveldt, 1971, see Neely, 1991, for a review). It has been argued that such semantic priming effects reflect the conjoint effects of three different mechanisms (Neely, Keefe, & Ross, 1989; Neely, 1991). These three mechanisms are automatic spreading activation (ASA), prospective prime-generated expectancies and retrospective semantic matching. Each mechanism is thought to be sensitive to different variables. Since similar mechanisms have been proposed to account for other types of priming described in later sections, I will briefly describe each in turn.

ASA is a mechanism which, it is argued, operates automatically between representations corresponding to related words. As its name implies this mechanism is thought to be independent of subjects' intention or awareness and can be demonstrated even in circumstances where subjects are unaware of the prime word. Although this mechanism has typically been used to account for semantic priming effects, analogous mechanisms have also been used to account for priming effects between formally (see Section 1.9) and morphologically (see Section 1.10) related words.

In contrast the expectancy and retrospective matching mechanisms are under the strategic control of subjects. As acknowledged by Neely (1991), the expectancy mechanism he proposes has much in common with that suggested by Becker (1985). When a prime word is presented, this expectancy mechanism constructs 'expectancy sets'. These sets contain word nodes corresponding to words which are visually and/or semantically similar to the prime word. If a subsequently presented target word is represented by a node within an expectancy set then it will be recognised more quickly since the contents of the expectancy sets are searched first. In the model, expectancy, like ASA, operates upon a lexicon of word nodes. The degree to which an expectancy mechanism operates is dependent upon the proportion of related items that are encountered. Where there are few related words in the experimental lists then a particular word is unlikely to be in the expectancy set established by its predecessor. Under these circumstances, subjects may strategically reduce the extent to which an expectancy mechanism is engaged.

The third mechanism, retrospective matching, occurs after the word has been identified and depends upon the detection of a relation between prime and target items. In a typical priming experiment using a LDT task, the detection of a relation between prime and target items is sufficient for a 'word' response to be made. On the other hand the absence of a relation may mean that the target word is an unrelated word or a non-word. The additional time required to resolve this ambiguity and respond to unrelated words leads to a longer RTs to unrelated words than to related words. As the proportion of non-words increases, then the absence of a prime-target relation biases a non-word response and further delays correct responses to unrelated words and thus results in an increase in the priming effect.

A number of studies have investigated the relationship between such semantic priming effects and repetition priming effects. If these two priming effects have interactive effects then this would suggest that repetition effects depend, at least partially, on conceptual processing.

Den Heyer, Goring and Dannenbring (1985) preceded a target word by a semantically related word, a semantically unrelated word or a 'neutral' display. Each prime-probe word pair was presented three times and subjects made lexical decisions on each word. The effects of repetition and of semantic priming were both reliable, but the interaction between them was not. Den Heyer et al (1985) suggested that repetition and semantic priming affect different stages in the processing of a word. If semantic priming effects reflect conceptual processing, then word repetition effects reflect changes to processes occurring either before or after such conceptual processing. An additive relationship between repetition and semantic priming has also been reported by Wilding (1986). Dugunoglu (1988) found additivity even when the priming effects were made larger by stimulus degradation, thereby making it more likely that an interaction would be observed, and when the task was changed to word naming, a task thought to be less influenced by post-lexical decision processes which may have obscured an interactive effect (Balota & Chumbley, 1984; 1985).

A number of studies have compared the effects of manipulations of lag on repetition and semantic priming. Dannenbring and Briand (1982) found reliable repetition effects in the LDT at lags of up to 16 intervening items, but a semantic priming effect was reliable only at lag 0. Using a semantic comparison task, Woltz (1990, experiment 2) reported reliable repetition priming effects when the lag was 1, 2, 5 or 15 trials, but a semantic priming effect was reliable only at the two shorter lags. Henderson, Wallis and Knight (1984) did not directly compare the longevity of semantic and repetition priming but did find reliable semantic priming effects when the interval between prime and probe was 1 second but not when it was 4 seconds.

Den Heyer and Benson (1988) did find an interaction between repetition and semantic priming effects. Using the LDT and lags of 0, 1, 3, or 7 intervening items, Den Heyer and Benson (1988) observed a reliable interaction which was equivalent at each of the 4 lags. The repetition effect declined over the 4 lags by approximately one third of its initial magnitude, whereas the semantic priming effect declined to a lesser degree. Den Heyer and Benson (1988) suggest that the degree to which repetition and semantic priming effects effect similar processes depends upon the lag between the related or repeating items.

Den Heyer and Benson (1988 see also Forster & Davis, 1984; Monsell, 1985; Ratcliff, et al., 1985) suggested that the repetition effect could be fractionated into a number of components. They argued that the absence of an additive relationship between repetition and semantic priming at relatively short lags supported the view that there was a long term repetition effect mediated by episodic memory. In addition they suggested that an intermediate, lexical, component was responsible for the interaction between repetition and semantic priming effects with semantic priming effects resulting from changes in the states of lexical representations. Finally, a 'sensory repetition effect' was responsible for the initially larger repetition effect.

Each of these components may contribute to the repetition effect under a given set of conditions. However, the additive relationship between repetition and semantic priming found by Den Heyer et al (1985), Wilding (1986) and by Durgunoglu (1988), and the difference in the the effects of inter-item lag on repetition and semantic priming reported by Dannenbring and

Briand (1982) and by Woltz (1990) suggests that conceptual processes contribute little and/or infrequently to word repetition effects. Although this conclusion contrasts with that reached by Masson and Freedman (1990) and by Bainbridge et al (1993), these studies do not provide unequivocal support for a conceptual locus for repetition effects with single words.

1.6 Repetition priming effects with novel stimuli

If repetition effects on indirect tasks reflect changes in the state of pre-existing lexical representations, then such effects should be reduced or absent if the repeating stimuli are 'novel', having no pre-existing representation. These predictions have been tested using a number of different types of novel information in repetition priming experiments. The most frequently used form of novel item are orthographically legal and illegal non-words, but a number of important studies have employed pairs of previously unassociated words.

1.6.1 Repetition effects with previously unassociated words

Typically in studies using previously unassociated words, a lexical decision is made to a word paired with a semantically unrelated word with which it either had, or had not, been previously studied. This pairing of words not previously associated constitutes a novel stimulus. If lexical decisions to words presented with the same word with which they had been previously studied are facilitated compared to lexical decisions to words presented in the context of a different word, then this would constitute evidence that such priming effects were not solely mediated by abstract context-free representations

Studies using this paradigm have produced contrasting results. In two studies McKoon and Ratcliff (1979; 1986) found evidence of priming effects for such new associations and have accounted for such effects as a reflection of episodic memory, but Carroll and Kirsner (1982) did not demonstrate priming effects with new associations. Neely and Durgunoglu (1985, see also Durgunoglu & Neely, 1987) argued that episodic information will be used in the performance of the experimental task to the extent that it is useful. If only words are repeated in a LDT so that repetition is confounded with lexicality, then this creates 'conditions under which an episodic memory task (is) masquerading as a lexical decision task' (Neely & Durgonuglu, 1985, p. 485).

Graf and Schacter (1985) investigated memory for new associations in a stem completion task. They found a priming effect only when the word pair was studied under 'elaborative' study conditions. They argued that the priming effect with new associations was a consequence of a different mechanism than are priming effects with single words which are not generally dependent upon encoding conditions (Graf & Mandler, 1984; Jacoby & Dallas, 1981). Although the elaboration dependence of the priming effect with new associations may suggest that this effect was dependent upon episodic memory, Graf and Schacter (1985) also found that amnesic patients showed a priming effect with new associations, suggesting that the effect was unlikely to have been mediated by episodic memory. However on the basis of subsequent investigations (e.g. Schacter & Graf, 1986; Shimamura & Squire, 1989), Schacter et al (1993) argued that the case for priming effects with new associations in memory impaired patients was, at best, unproven.

Schacter and his colleagues have performed a number of experiments involving the repetition of pictures of structurally possible and impossible objects (e.g. Schacter, Cooper, Delaney, Peterson, & Tharan, 1991). Only for the structurally possible objects was there a reliable repetition effect. Schacter argues that these results indicate that repetition effects are not based upon episodic memory. They suggest instead that these effects reflect the operation of a PRS concerned with the recognition of visual objects.

The results of these studies provide conflicting evidence concerning the basis of repetition effects with novel word pairings. A number of studies however suggest that these effects reflect the workings of episodic memory rather than changes in the states of abstract representations.

1.6.2 Repetition effects with non-words

A number of studies of non-word repetition effects using the LDT appeared to support an abstractionist view of repetition effects. However the status of repetition effects with such novel stimuli has been controversial and may depend upon the task which subjects are required to perform. Forbach, Stanners and Hochhaus (1974) using a LDT found no evidence of non-word repetition effects. On the other hand, a number of studies have all demonstrated reliable effects of non-word repetition in the LDT (Bentin & Moscovitch, 1988; Kirsner & Smith, 1974; Monsell, 1985; Scarborough, et al., 1977). However, in each case, the effects of non-word repetition differed qualitatively from the repetition effects seen with words. As described further in Section 1.8, words and non-words respond differently to increases in the interval between prime and probe encounters. Differences in repetition effects between non-words and words suggests that the two effects result from at least partially different mechanisms.

The interpretation of results of experiments using the LDT was called into question by Feustel et al (1983), who argued that the difference between word and non-word repetition effects in the LDT could result from a confounding of the lexical status of the stimulus and the response required. When a non-word is repeated, any episodic memory of its prior occurrence would tend to inhibit the making of a non-word response because the stimulus would be familiar, and therefore more word-like. This inhibition would offset any facilitatory effect arising from repetition, and might result in the absence of a repetition priming effect. Feustel et al (1983) suggested that in a task in which non-words were not subject to this inhibitory effect, non-word repetition priming effects would be evident.

Feustel et al (1983) used a perceptual identification task, a task with no response confound, to show that although identification thresholds were higher for non-words than for words, the benefit resulting from repetition was equivalent for the two stimulus types. Feustel et al (1983) argued that the differences between the recognition thresholds for words and non-words reflected the availability of pre-existing unitised abstract representations of words which were not available for non-words. In contrast, the repetition effects for non-words, and part of the effect with words, reflected the influence of episodic memories which were available equally for both stimulus types.

Dorfman (1994) has challenged this episodic account of non-word repetition effects. She compared the magnitude of the priming effects seen with non-words having morphological or syllabic structure with non-words having no such structure. She found that only non-words having morphemic or syllabic structure gave rise to reliable priming effects. Dorfman (1994) argued that non-word priming effects are dependent upon the use of abstract pre-existing representations rather than on the formation of new episodic representations. These pre-existing representations are of sublexical components such as syllables and morphemes rather than of words.

On their first enounter with a non-word subjects in the study reported by Rajaram and Neely (1992) either tried to remember the non-word for later recall or had to pronounce it. There were reliable repetition effects for non-words in a subsequent LDT for both study tasks. Rajaram and Neely (1992) suggested that performance of the LDT was facilitated to the degree that subjects constructing temporary 'lexical' representations of the non-words in the two tasks.

Bowers (1993) argued that if similar priming effects were found with illegal non-words to those found with legal non-words, then this pattern of effects would support the view that priming effects were not mediated by pre-existing lexical or sub-lexical representations. This was because illegal non-words do not contain letter clusters typically found in English words and hence would not engage pre-existing sub-lexical representations.

Bowers (1993) compared performance on a perceptual identification task and a recognition task for legal and illegal non-words which had been previously studied in either a structural encoding task or a pronounciation task. Reliable priming effects were found for both the legal and illegal non-words. Bowers (1993) argued that the reliable effect found for illegal non-words indicated that priming effects in perceptual identification tasks were not dependent upon pre-existing lexical representations. Bowers (1993) concluded that his results supported what he described as an 'acquisition-based' account of priming effects; an account in which priming effects were mediated by memory representations acquired in a single learning episode.

Bowers' interpretation of his results can be challenged. Performance on the perceptual identification task with illegal non-words was not clearly dissociated from performance on the recognition memory task. The magnitude of the priming effect in the pronunciation study task was twice that in the structural study task, a result which contrasts with the dissociation found by Bowers for legal non-words and which is typically found for real words. The difference in the pattern of performance for legal and illegal non-words in the perceptual identification and recognition memory tasks suggests that different mechanisms were underlying the effects for the two types of stimuli. As Bowers (1993) acknowledges, it is possible that the priming effects with words and legal non-words were mediated by pre-existing sub-lexical representations.

The nature of the processes underlying non-word priming effects, and the relation between word and non-word priming, has also been investigated by Rueckl (1990; Rueckl & Olds, 1993). Rueckl (1990) found a reliable repetition priming effect for words and legal non-words in a perceptual identification task. In addition, Rueckl (1990) found that when words or non-words were preceded by an orthographically similar item of the same lexical status, reliable priming effects were also obtained, but were smaller than were the effects resulting from repetition. On the other hand, repetition priming effects seen with words were differentiated from the repetition effects seen with non-words, and from the orthographic priming effects seen with both words and non-words, by virtue of their response to multiple presentations of the prime. In contrast to the effects seen with words, for non-words three presentations of the prime did not result in a larger priming effect than did a single presentation (see also Light, LaVoie, & Kennison, 1995).

Reuckl (1990) suggested that non-word repetition and orthographic similarity effects resulted from interactions between orthographic representations, whilst the benefits of multiple repetitions for words arose because of a strengthening of the link between orthographic and semantic representations. Such an orthographic-semantic 'co-activation' effect would not normally occur for non-words because of the absence of a corresponding semantic representation. Nor would such an effect occur between orthographically similar words since strengthening the orthographic-semantic link for the prime word would not aid the subsequent recognition of the probe word. Studies on the effects of the repetition of non-words to which arbitrary meanings have been assigned have also been reported by Whittlesea and Cantwell (1987) and by Rueckl and Olds (1993). The results of these studies have also supported the view that repetition effects may be mediated by links between orthographic and semantic representations.

However, an incremental priming effect for words and the absence of such an effect for non-words was not found by Whitlow and Cebollero (1989 see also Soloman & Postman, 1952). Whitlow and Cebollero found that it was non-words that gave rise to an incremental priming effect with additional study presentations. In contrast, there was either no effect, or a much reduced effect, as a result of the multiple repetition of real words. Whitlow and Cebollero (1989) argued that the differences between the two types of stimuli reflected the effect of the presence of a pre-existing unified representation for words which was not available for non-words. They suggested that the constant priming effects for words across multiple presentations reflected the activation of lexical nodes, whilst the incremental effects for non-words reflected a process of 'codification' (Salasoo, Shiffrin, & Feustel, 1985) thought to be involved in building new, relatively permanent representations. The reasons for the contrast between the results reported by Whitlow and Cebollero (1989) and Rueckl (1990) are not clear, but the differences between the results obtained with words and non-words within each study suggest that these two types of item are processed in different ways. This is consistent with there being a level of representation involved in word but not non-word repetition effects. Such an effect may involve lexical or semantic processing.

Non-word repetition priming effects have also been investigated under conditions in which it has been claimed that the contribution of episodic processes is reduced. Generally, one of two approaches have been taken. In the first, subjects perform an indirect task under conditions of divided attention. Such conditions are generally held to prevent elaborative encoding and thus prevent subsequent episodic retrieval (e.g. Jacoby, et al., 1989). The second approach involves the investigation of non-word priming effects in memory-impaired patients.

Smith and Oscar-Berman (1990) compared repetition under conditions of full and divided attention. When the data were normalised to equate performance across the two attention conditions, the shift from full to divided attention reduced the magnitude of the repetition effect for both words and non-words. The repetition effect on reaction times was still reliable for the words but not for the non-words. A reliable non-word repetition effect in the divided attention condition was evident however in the accuracy data. Subjects were more likely to misclassify repeating non-words as real words than to misclassify non-words appearing for the first time. Smith and Oscar-Berman (1990) found that this tendency to misclassify repeating non-words was also evident in a group of amnesic patients who also showed a repetition effect on reaction times for words but not for non-words. Smith and Oscar-Berman (1990) suggested that the reduced, but still reliable, priming effects for words under conditions of divided attention supported the view that repetition effects were a product of (at least) two different factors, one being dependent upon conscious attention, and one which was evident even under 'resource limited' conditions. The absence of this latter effect for non-words suggests that it may be specific to stimuli having unitised pre-existing lexical representations.

Repetition priming effects for non-words have been extensively studied by Cermak and his colleagues, particularly in amnesic patients suffering from Korsakoff's syndrome (e.g. Cermak, et al., 1985; Cermak, Verfaille, Milberg, Lettourneau, & Blackford, 1991; Verfaille, Cermak, Letourneau, & Zuffante, 1991). Cermak et al (1985) found that control subjects showed priming effects in a perceptual identification task for both words and non-words. On the other hand amnesic patients showed reliable priming effects for real words, but there was no such priming effect for non-words.

In a subsequent re-analysis of these results, Cermak et al (1991) suggested that when the priming effects were analysed as a proportion of the baseline score, the priming effects for non-words in the amnesic subjects were reliable, although smaller than the effects seen in the control subjects. They also suggested that, because these effects were dependent upon the structure of the word lists used in the experiment, priming effects with these stimuli do not occur automatically. Rather the availability of a unitised code for the non-word in respect of either its pronunciation or the meaning of the corresponding word must be salient before the priming effects are observed.

Cermak et al (1985) argued that the absence of priming effects for non-words in amnesic patients resulted from their inability to use episodic information to enhance their performance, and from the lack of pre-existing representations of the non-words which could mediate priming effects. For words, priming effects were observed because of the availability of a pre-existing representation. For the control subjects both the creation of episodic representations, and changes in abstract pre-existing representations may facilitate performance for words. However, only the former process would be available to enhance identification of the non-words. The non-word priming effects in amnesics demonstrated by Cermak et al (1991) may be accounted for either in terms of the priming of sub-lexical constituents as suggested by Dorfman (1994), or as reflecting preserved explicit memory in the amnesic patients.

Musen and Squire (1991) have also demonstrated reliable priming effects for words and non-words. In their study amnesic patients were required to read lists of words and non-words as quickly as possible; a task which Musen and Squire (1991) argued would only minimally invoke episodic memory. Priming effects persisted even when 10 minutes intervened between the two presentations of the stimuli lists. Musen and Squire (1991) argued that the priming effects they observed were unlikely to be due to processes concerned with episodic memory, but because the effects for the putatively novel non-word stimuli were as large, or larger, than were the effects with words, they also argued that the effects were not mediated by pre-existing representations. Rather, Musen and Squire (1991) argued that the priming effects were a reflection of changes in a perceptual representation system concerned with word recognition. This interpretation is however dependent upon accepting that orthographically legal non-words are genuinely novel stimuli, a claim that, as described above, has been questioned.

To summarise the results of studies which have used non-words as stimuli: The absence of priming effects for non-words in the LDT cannot be taken as evidence of the importance of pre-existing lexical representations in repetition effects. This is because of the response confound involved in this task. Although demonstrations of reliable non-word priming effects indicate that repetition effects may depend upon episodic memory for particular prior occurrences, such demonstrations cannot be taken as strong evidence for the involvement of such episodic processes in repetition effects. This is because orthographically legal non-words cannot be seen as genuinely novel stimuli. Repetition effects with these stimuli may reflect processes that involve pre-existing sub-lexical representations. Dissociative effects seen with words and non-words may reflect lexical processes engaged by words but not non-words. The addition of conceptual information enhances repetition effects with stimuli which have no prior unitised representations such as non-words. However, this does not necessarily mean that conceptual processes play a role in repetition effects with stimuli which do have such pre-existing unitised representations, e.g words.

1.7 Repetition effects and inter-item lag.

The effect on repetition effects of varying the lag between the first and second encounters with an item has been extensively investigated. Using a LDT, Scarborough et al (1977) found that repetition effects for words were greatest when the probe encounter immediately followed the prime encounter, but they found reliable repetition effects of approximately equal magnitude as the lag between the two encounters increased to either 15 intervening items or 48 hours. In contrast the repetition priming effect with non-words decreased steadily as the lag increased. Performance on an explicit recognition memory task also declined as the lag increased from 0 to 31 intervening items. Scarborough et al (1977) suggested that the direct and indirect tasks were sensitive to different forms of memory. Since the effects in the LDT task were sensitive to word frequency, a variable thought to affect lexical memory, they suggested that the persistent effects of repetition could be seen as a result of changes in lexical memory. Monsell (1985, experiment 2) also demonstrated that in the LDT, immediate repetition gave rise to a large effect, but at lags of between 2 and 4 intervening items there was a smaller but highly reliable effect that was absent with non-words. Because of the failure to find this persistent effect with non-words he suggested that this was a lexical effect. Monsell (1985, experiment 3) found a reliable repetition effect for words that was equal in magnitude between lags 3 and 31.

Ratcliff, Hockley and McKoon (1985) also found that when one item intervened between prime and probe items the priming effect was smaller than when repetition was immediate. However there was no further decrease in the size of the priming effects as the lag increased to 16 intervening items. The repetition of non-words produced a statistically non-significant effect, even with immediate repetition. Performance in a recognition memory task declined gradually and continually over a range of lags.

These results, as well as those reported by Scarborough et al (1977), were interpreted by Ratcliff et al (1985) as providing support for a view of repetition effects reflecting the action of, at least, two processes; one responsible for the short term priming effect seen with immediate repetition, and a second responsible for the more persistent repetition effect. Notwithstanding the apparent differences between the rate at which the effects of repetition in the LDT, and performance on the direct test of recognition memory, decayed, Ratcliff et al (1985) argued that the same processes may underlie performance on the two tasks. They suggested that the gradual decline over lags in the recognition task was a reflection of the different responses required in the recognition task for the first and second presentations of words (Hockley, 1982, cited in Ratcliff et al, 1985).

Bentin and Moscovitch (1988) compared performance on a LDT when words and non-words were repeated with a lag between first and second presentations of either 0, 4 or 15 intervening items. For both words and non-words repetition effects were greater at a lag of 0 than at the longer lags. Whilst for words the repetition effects were still reliable at the longer lags, this was not the case for non-words. Bentin and Moscovitch (1988) argued that one reason for the advantage enjoyed by words over non-words at the longer lags was because such priming effects depended on elaborative encoding. Whilst words possess unitised pre-existing representations which could serve as a basis for such encoding, this was not the case for non-words. In a second experiment subjects performed a task which required them to compare the identities of the first and last letters of the word or non-word. Whilst there was again a large priming effect for words and non-words at zero lag, the effect at the longer lags was not significant for either words or non-words. Bentin and Moscovitch (1988) argued that the absence of a persistent repetition effect was a consequence of this task not requiring lexical processing, whilst the short term effect reflected memory for the response that had been made on the previous trial.

Jacoby and Dallas (1981, experiment 5) investigated the effect of increasing the interval between a study encounter and a perceptual identification test. The interval between study and test was immediate, 15 minutes or 24 hours. There was a reliable priming effect that was equivalent at all three retention intervals. In contrast, performance on a test of recognition memory over the same study-test intervals declined monotonically over the three retention intervals. Reliable priming effects in an identification task were also reported by Feustel et al (1983), by Jacoby (1983a) and by Hashtroudi et al (1988). Whilst in the studies by Feustel et al (1983) and Hashtroudi et al (1988) the priming effects were equivalent regardless of the interval between study and test, Jacoby (1983a) found that the repetition effects were smaller when the study-test interval was 24 hours than when the test immediately followed the study phase. In contrast to the apparent persistent effects with the LDT and perceptual identification, Graf and Mandler (1984) report that priming effects in a word fragment completion task last approximately 2 hours.

With both perceptual identification and lexical decision tasks, repetition effects have been demonstrated over a wide range of lags between prime and probe items. In the LDT, the difference between the magnitude of the repetition effects found at short lags and the magnitude of the effects at long lags has been taken as evidence that there at least two components to the repetition effect. A short term component may reflect the influence of an episodic memory, possibly for the nature of the response or decision that had been made to an item on a previous encounter. The long term component has been taken as a reflection of changes in lexical processing as a result of a previous encounter with an item. Jacoby (1983a) has argued that long term repetition priming is incompatible with models based on lexical activation, on the grounds that such persistent activation would result in a lexicon becoming 'overheated'. This claim has been rejected by Monsell (1985). Nonetheless the view that persistent priming effects are lexical in nature has also been challenged by studies which have manipulated the lag between prime and probe items when subjects are unable to consciously identify the prime item.

1.8 Repetition priming effects with masked primes

Variations in inter-item lag were used by Forster and Davis (1984) to distinguish different components of the repetition effect. However they combined this manipulation of lag with a 'masked priming' paradigm. Masked priming is generally held to prevent conscious identification of the prime without preventing it being processed perceptually and possibly semantically (Marcel, 1983). When the prime cannot be consciously identified, then this is thought to eliminate that component of the repetition effect due to episodic memory. Typically in a 'masked priming' experiment a briefly presented prime item is preceded and followed by a 'visual mask', the components of which critically have a similar spatial frequency to the letters making up the prime item and are, at least, co-extensive with it. The probe word is presented after this masked prime display (see Allport, 1977; Dixon, 1971; Holender, 1986, and accompanying commentaries; Marcel, 1983; Merikle, 1982; for a discussion of masked priming paradigms).

The first study to use a masked repetition priming paradigm to minimise the effects of episodic memory was by Evett and Humphreys (1981). They showed that masked repetition priming enhanced the rate at which subjects identified briefly presented target words. Humphreys, Besner and Quinlan (1988) demonstrated that compared to a 'neutral' prime consisting of a row of X's, the masked priming effect in perceptual identification was abolished by the introduction of 7 intervening items

Forster and Davis (1984) used a masked repetition paradigm with the LDT. Previous reports (e.g. Scarborough, et al., 1977) had shown what Forster and Davis (1984) referred to as the 'frequency attenuation effect'; the difference in lexical decision latencies between low and high frequency words was much reduced or absent when words were repeated. Forster and Davis (1984) investigated whether a similar frequency attenuation effect would occur when the first occurrence of the word was masked. They argued that such masking would mean that either there would be no episodic trace of the prime or any such trace that was formed would be relatively inaccessible and any priming effects observed could reasonably be ascribed to processes involved in word recognition.

Forster and Davis (1984) found reliable masked repetition priming effects for both high and low frequency words. Critically however, the magnitude of the effects was approximately equivalent for words in each frequency class. Thus under conditions of masked priming the frequency attenuation effect was absent. The masked priming effect was still reliable when up to 3 items intervened between prime and probe words, but not when 17 items intervened. Segui and Grainger (1990, experiment 4) and Sereno (1991, experiments 1 and 2) also found no frequency attenuation effect under masked priming conditions.

Forster and Davis (1984, see also Forster, 1987) argued that the masked priming effects reflected lexical processing, with these effects persisting over only a few intervening experimental trials. Repetition effects with unmasked primes were considerably longer lasting and reflected the involvement of episodic memory in these effects. As with other experimental manipulations, masked priming appears to reveal a number of components to word repetition effect. One of these components may reflect lexical processes. Another experimental paradigm which has also been used to argue for a lexical level of processing has investigated the effects of preceding words and non-words with orthographically and/or phonologically, i.e. 'formally', similar items.

1.9 The effects of formal similarity on word recognition

A considerable literature has now developed concerning the degree to which different aspects of a printed word contribute to its recognition. Although much attention has been devoted to the effects of morphological structure (see Section 1.11), the effects of orthographic structure have also been examined.

A number of proposals have been put forward as to the way in which words may be segmented on the basis of their orthography into sub-lexical components. On such proposal advocates 'onset' and 'body' (Patterson & Morton, 1985) or 'orthographic rime' (e.g Bowey, 1990) segments. The 'onset' consists of the inital consonant cluster and the 'body' or 'orthographic rime' consists of the letters remaining once the initial consonant cluster of a syllable has been removed. The 'anti-body' has been defined as the initial consonant cluster together with the following vowel(s), whilst the Basic Orthographic Syllable Structure (BOSS; Taft, 1979a) refers to the letters up to, and including, the orthotactically legal consonant cluster following the first vowel of the root morpheme of a word (e.g. 'seg' in 'segment'). Much of this interest in sub-lexical orthography has been in relation to the issue of the mechanism(s) by which a phonological representation is derived from an orthographic one by means of sub-lexical orthographic to phonological correspondences (see Glushko, 1979; Humphreys & Evett, 1985; Kay & Bishop, 1987; Patterson & Morton, 1985; Seidenberg, Walters, Barnes, & Tanenhaus, 1984; Taraban & McClelland, 1987). Whilst it has also been argued that representations of sub-lexical letter clusters are involved in accessing orthographic representations of whole words (e.g. Treiman & Chafetz, 1987), there has not been universal acceptance that these sub-lexical divisions are functionally significant (e.g. Seidenberg & McClelland, 1989 but see Rapp, 1992).

Much of the evidence for the functional significance of sub-lexical orthography has come from priming experiments in which prime and probe items are formally similar to each other. For present purposes these studies are relevant for two reasons. Firstly, formal priming effects have been interpreted as a partial reflection of the action of inhibitory connections between representations of word forms in an orthographic lexicon and thus provide further evidence of the existence of such a lexicon. Secondly, since regular morphologically related words tend also to be formally similar, the effects of formal and morphological similarity are generally confounded. Effects of formal similarity must therefore be understood before effects of morphological similarity can be correctly interpreted.

Initial studies by Meyer et al (1974) and by Shulman, Hornak and Sanders (1978) found that presenting two words orthographically and phonologically similar to each other (e.g. 'bribe' - 'tribe') resulted in a facilitatory effect in a LDT compared to word pairs which were were orthographically similar but phonologically dissimilar (e.g. 'touch' - 'couch') or word pairs which were dissimilar with respect to both orthography and phonology. Shulman et al (1978) also demonstrated reliable facilitatory effects with words which were only orthographically similar (e.g. 'youth' - 'south'; see also Hillinger, 1980). Lima and Pollatsek (1983, experiment 2) preceded words in a LDT with formal primes. A facilitatory effect on LDT latencies was greater when the overlap between prime and probe was at the beginning of the word than when the overlap between prime and probe words was at the end of the words.

Humphreys and his colleagues have consistently found facilitatory effects in experiments using masked formal priming on a word identification task. (Evett & Humphreys, 1981; Humphreys, 1985; Humphreys, Evett, Quinlan, & Besner, 1987; Humphreys, Evett, & Quinlan, 1990). Evett and Humphreys (1981) demonstrated reliable word repetition and semantic masked priming effects, as well as reliable masked priming effects due to formal similarity between prime and probe items. This formal similarity effect was equivalent whether the prime and target words were orthographically and phonologically similar (e.g. 'tile' and 'file'), or were only orthographically similar (e.g. 'couch' and 'touch'). These priming effects occurred despite subjects being unable to detect the prime word. Humphreys et al (1987) also found that the identification of probe words was facilitated by the prior presentation of a formally similar masked non-word prime (e.g. 'lert' - 'lost') or word (e.g. 'list' - 'lost'). However, when the prime items were clearly visible, there were no reliable priming effects between formally similar words.

Using a LDT, Sereno (1991) has demonstrated facilitatory effects of masked non-word priming whilst with the same task Napps and Fowler (1987) found that there were facilitatory formal priming effects between word pairs such as 'rib' and 'ribbon'. These effects were reliable, using

SOAs of between 350 ms and 1650 ms, when the proportion of related words was 75%, but not 25%, of the total. Nor were there reliable effects of formal priming at the lower proportion when the lag between prime and probe word was between 1 and 10 items.

Forster and his colleagues (Forster, 1987; Forster & Taft, 1994; Forster & Davis, 1984; Forster & Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987) have reported a number of experiments which investigate the processes involved in formal priming effects and their relation to repetition priming effects. Forster and Davis (1984) in their study of masked priming effects in the LDT found neither facilitation nor inhibition when a four-letter word was preceded by one formally similar to it (e.g. 'lack' then 'luck'). However Forster (1987) found facilitatory effects from both word and non-word primes on word probes in a LDT using words having eight or more letters. A similar difference between the priming effects seen for short and long words was demonstrated by Forster et al (1987). Forster argued that the critical difference between words of different lengths was that shorter words often come from a more densely populated 'neighbourhood' than do longer words.

A lexical neighbourhood of a word has been defined as the set of words that can be produced by changing one letter of that word (Coltheart, Besner, Jonassen, & Davelaar, 1977). Such a definition entails that lexical neighbours are of the same length in letters, but this may not be a necessary condition. Lexical neighbourhoods may differ in their size or 'density', i.e. how many neighbours does a word have, and the relative frequency of words in the neighbourhood, i.e. their 'neighbourhood frequency'.

The consequences for word recognition of neighbourhood size and neighbourhood frequency have been extensively investigated by Grainger and his colleagues (Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; Grainger & Segui, 1990) and by Andrews (1989; 1992). Briefly, the outcome of these studies suggests that response latencies in tasks such as the LDT are sensitive to characteristics of the lexical neighbourhood. Although it has been argued by Andrews (1989; 1992) as well as by Forster (1987) that neighbourhood size is the critical variable, Grainger has maintained that the relative frequency of lexical neighbours is the critical variable. He has argued that demonstrations of the effects of neighbourhood size have confounded size and neighbourhood frequency since, unless controlled for, dense neighbourhoods will generally contain a neighbour which is of higher frequency than is the probe word. Demonstrations of effects of word frequency have also typically confounded word and neighbourhood frequency, but Grainger and Segui (1990) demonstrated that effects of word frequency could be found even when neighbourhood frequency was held constant.

Forster (1987) showed that the magnitude of the formal priming effect was not dependent on the neighbourhood density of the prime word, but was dependent upon the neighbourhood density of the probe word. He suggested that when probe (and prime) words are from a low-density neighbourhood then facilitation will occur, but when probe (and prime) words come from high density neighbourhood then inhibitory effects will be found (see Forster, et al., 1987, experiment 6). Forster and Davis (1991) showed similar effects of neighbourhood density using the naming task. Lima and Pollatsek (1983) found facilitatory priming effects when primes were equivalent to the root morphemes of the probe, but inhibitory priming effects when the prime constituted the BOSS of the probe word. There have been a number of other reports of inhibitory effects of formal priming.

Fowler, Wolford, Slade and Tassinary (1981) reported that orthographically similar, but phonologically dissimilar primes resulted in inhibitory effects on LDT latencies. This was the case for both masked and unmasked primes. Henderson, Wallis and Knight (1984) found inhibitory formal priming effects when the interval between prime and probe word was either 1s or 4s. Colombo (1986, experiment 2) preceded Italian words with formally similar words using an SOA of 320 ms. She found an inhibitory priming effect for high but not for low frequency probe words compared to words preceded by an unrelated prime. Lexical decisions to low frequency probes were either facilitated or inhibited but to a lesser degree than was found with high frequency probe words. Laudanna, Badecker and Caramazza (1989) found significant inhibitory effects on response latencies in a 'double' LDT when two words were formally similar in their initial segment. Using Italian words these effects were observed when the overlapping segment did and did not, constitute the initial morpheme of both words.

Using an SOA of 350 ms, Segui and Grainger (1990) found a reliable inhibitory priming effect in the LDT only when the prime was a word of lower frequency than the probe word. In contrast, there was a small and non-significant facilitatory priming effect when the prime was a word of higher frequency than the target. Grainger (1990, experiment 2), also using the LDT, found equivalent inhibitory formal priming effects on high frequency probe words from low and medium frequency prime words.

Drews and Zwitserlood (1995) used a LDT with German words which overlapped formally on all but the last one or two letters. When primes and probes were separated by 8 to 12 items a non-significant inhibitory formal priming effect was observed. However when the SOA between word primes and probes was reduced to 300 ms, reliable inhibitory formal priming effects were observed for probe words, but not for probe non-words. In contrast non-word primes produced non-significant facilitatory effects on LDT latencies with words.

Drews and Zwitserlood (1995) also found that formal priming with word primes and probes resulted in a reliable inhibitory effect even when the primes were masked. LDT latencies for words primed by non-word primes did not differ from a control condition. In the same experiment there were reliable facilitatory effects of both repetition and morphological priming. Segui and Grainger (1990) investigated the effects of masked priming in the LDT using orthographically similar words which differed in their relative word frequencies. When primes orthographically similar to a probe word were masked to prevent their identification, then a large inhibitory effect was observed when the prime was of higher frequency than the probe word, and a facilitatory (experiment 2) or a small inhibitory (experiment 3) effect was observed when the prime had a lower frequency than did the probe word. Grainger, Cole and Segui (1991) assessed the effects of formal priming in the LDT as part of their investigation into morphological priming effects. The formal similarity between words occurred either at the beginning or at the end of the words and the probe words were either of approximately the same frequency as the targets or were of lower frequency. In general Grainger et al (1991) found inhibitory effects of formal similarity between words. These effects were greatest when the prime word was of higher frequency than the probe word and when the overlap between words was at the beginning of the word.

Drews and Zwitserlood (1995) and Grainger and his colleagues (e.g Ferrand & Grainger, 1992; Grainger, 1992) have suggested that the different pattern of effects seen with masked and unmasked primes, and with words and non-word primes, reflects the different amounts of activation and inhibition passing between sub-lexical and lexical representations of word forms. Grainger and Jacobs (1993) have accounted for these effects in a modified version of McClelland and Rumelhart's (1981) interactive activation model in which facilitatory connections occur between sub-lexical and lexical levels, whilst there are inhibitory connections between representations within each level (see also Rueckl, 1990).

Under the model unmasked low frequency primes produce inhibitory formal priming effects because of the need to dampen the activation of a higher frequency neighbour. In contrast high frequency primes will not produce inhibitory effects because the identification of the prime will be relatively easy and will not involve the inhibition of a low frequency word. Such high frequency primes will either have little effect or will produce a facilitatory effect due to the consistency of sub-lexical orthography between prime and probe words. When low frequency words are masked to prevent identification, then this will produce little activation at a lexical level so there will be little inhibition brought to bear upon the representations of target words. With masked high frequency words, an inhibitory effect is observed on the LDT latencies for lower frequency probe words. This may be due to the weak activation resulting from the masked presentation adding to the high resting activation state of a high frequency word, to inhibit low frequency word neighbours.

Grainger (1992) has suggested that inhibitory priming effects tend to be found when primes are words. This is especially so for high frequency words, or when the prime duration increases. Under these conditions the activation of lexical units increases and there is a consequent increase of intra-level inhibition between lexical representations. In contrast, facilitatory effects are obtained to the degree that prime items activate sub-lexical but not lexical representations.

This may be a result of the primes being non-words, or being heavily masked low frequency words, or of the SOA between prime and probe being short.

Humphreys et al (1990) suggest orthographic priming effects may reflect processing at any stage from the representation of individual letters to whole words. Humphreys et al (1988) suggested that differences between masked and unmasked priming effects were due to prime and probe words being perceived as a single event in the masked priming paradigm, but as distinct events in the unmasked paradigm. As a result whereas in the masked priming paradigm processing engaged by orthographically similar prime and probe items was consistent and co-operative, in the unmasked paradigm the processing of orthographically similar prime and probe engaged competitive processes. Humphreys (1985) has interpreted these effects within the two-process theory of attention (Posner & Snyder, 1975). Demonstrations of inhibitory effects between words have been interpreted by Humphreys (1985) as a consequence of non-automatic processes engaged when the presentation of unmasked stimuli are perceived as separate events, whilst facilitatory effects are a consequence of automatic processing. However demonstrations of inhibitory effects using masked primes led Humphreys (1985) to argue that masked priming also engaged non-automatic processes.

1.9.1 Position of overlap and formal similarity effects

A number of studies have investigated the degree to which formal priming effects depend upon the location in the prime and probe items of the region of formal overlap. Lima and Pollatsek (1983) found that whilst lexical decisions were facilitated by prior exposure to the beginning of a word (e.g. either 'burd' or' bur' from the word 'burden'), there was no reliable priming effect as a result of prior exposure of the ends of words (e.g. 'den' or 'en'). Bowey (1993; 1990) investigated the nature of priming effects with orthographic units in a word naming task. Bowey (1990) found that word naming was facilitated when the primes constituted onset and orthographic rime units, but no facilitation was found when the primes consisted of orthographic fragments which did not constitute such subsyllabic units.

Taft (1992) argued that the recognition of polysyllabic words involved a representation of the 'body of the BOSS' or BOB (e.g. 'ead' in 'meadow'). Naming responses were more consistent with the pronunciation of the BOB than with the word itself, the first syllable of the word or the initial vowel. However Taft (1992) suggested that the BOB was not the only sub-lexical representation involved in word recognition. Rather it was just one of a number of sub-lexical orthographic units which could be represented in an interactive model of word recognition. Forster and Taft (1994) showed that facilitatory priming effects could be found with 4 letter words from dense neighbourhoods (cf. Forster, et al., 1987). However these effects were found when a non-word prime and a word probe shared a 'body' having a low frequency of occurrence (e.g. 'perd' - 'herd') but not when the shared body had a high frequency of occurrence (e.g. 'feep'

- 'weep'). Reliable facilitatory effects were also found where prime and probe shared a low frequency anti-body (e.g. 'prute' - 'prune') but not where they shared a high frequency anti-body (e.g. 'prite' - 'prize'). Reliable formal priming effects were found between non-word primes and word probes in which the body of the word was disrupted (e.g. 'drice' - 'drive'). There was no reliable facilitation when a non-word prime and a word probe shared an onset ('hord' - 'herd').

Grainger and Jacobs (1993) found that in a masked priming paradigm there was also a larger facilitatory formal priming effect when prime and probe words shared initial letters than final letters. They argued that the initial segment of a word did not have a privileged status in word recognition. Rather, they suggested that the letters in the final positions of words were found in those positions more often than letters in the initial positions of words. Therefore more words will be activated by primes which share word final letters with the probe than by primes which share word initial letters with the probe. As a consequence more lexical inhibition will be brought to bear on the representation of the probe word when the prime and probe share final letters than when they share intial letters. When formal priming effects were determined for prime and probe pairs which overlapped at the beginning or at the end of words, but in which the letter frequencies were equated, then equivalent effects were found in the word-final and word-initial condition.

Using the masked priming and perceptual identification paradigm, Humphreys et al (1990) found facilitatory formal priming effects that were non-linear. The benefit of there being three letters in common was greater than three times the benefit of having a single letter in common. These priming effects were greater when prime and probe words had the same initial and final letters than when they had the two medial letters in common. The priming effect depended upon letters maintaining their relative, but not specific, positions within a word. Jordan (1986) reported facilitatory formal priming effects in the LDT using word pairs such as 'demon' and 'monarch', again suggesting that formal priming effects do not depend upon the absolute positions of letters within an item being maintained from prime to probe item.

1.9.2 Orthographic and phonological similarity and formal priming effects

The relationship between representations of the orthography and phonology of a word has received much attention in the literature on word recognition. Initially this interest was focussed on the question of whether phonological mediation in word recognition was mandatory (e.g. Baron, 1973; Rubinstein, Lewis, & Rubinstein, 1971). Although this debate is still being conducted (Lukatela & Turvey, 1995a; Lukatela & Turvey, 1995b; McRae, et al., 1990; Van Orden, 1987), attention has shifted towards questions of how information available from orthographic and phonological representations is integrated during processes of word recognition (e.g. Paap, et al., 1982; Seidenberg, et al., 1984).

A number of studies by Perfetti and his colleagues (Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Perfetti & Zhang, 1991) investigating the disruptive effects of backward masking suggest that both graphemic and phonological similarity facilitate word recognition. They found that the identification of a briefly presented word was enhanced when the word was immediately followed by an orthographically or phonologically similar non-word mask compared to when the mask was neither orthographically or phonologically similar. Furthermore a homophonic mask had a larger effect than a merely orthographically similar mask. This favours the view that both orthographic and phonological information become available during the process of word identification. Perfetti and Bell (1991) report that effects of phonological similarity can be observed when the SOA between word and non-word mask is greater than 45 ms.

The contributions of orthographic and phonological similarity to formal priming effects has also been the subject of study (e.g. Ferrand & Grainger, 1992; Ferrand & Grainger, 1994; Ferrand, Grainger, & Segui, 1994; Humphreys, Evett, & Taylor, 1982; Taraban & McClelland, 1987). Humphreys, Evett and Taylor (1982) using the masked priming paradigm found that performance on a word identification task was enhanced by homophones of the probe word (e.g. 'flee' vs 'flea'), but not by pseudohomophones (i.e. non-words homophonous with the probe, 'brane' - 'brain'). They argued that these phonological effects were likely to affect post-lexical processes. However, as Perfetti and Bell (1991) note, the absence of effects with the non-words may have been due to the SOA between prime and probe being too short (less than 45 ms).

Ferrand and Grainger (1992) using masked primes compared the priming effects on LDT latencies resulting from non-word primes that were homophonic with a probe word, from non-word primes that were orthographically, but not phonologically similar, to a probe word, and from non-word primes that were neither orthographically and phonologically similar to the probe word. When the SOA between prime and probe was 64 ms, then there were facilitatory effects of a homophonic non-word prime, but no effect of primes that were only orthographically similar. In contrast when the SOA was reduced to 32 ms, there were reliable facilitatory effects of both homophonic and orthographically similar non-word primes. Ferrand and Grainger (1992) argued that orthographic priming at short SOAs was due to facilitatory connections between sub-lexical and lexical repesentations, whilst at longer SOAs sufficient inhibition between lexical representations had developed to offset this facilitation. Effects of phonological similarity however were slower to exert an effect so that between level facilitation for homophone primes was still evident at the longer SOA (see also Ferrand & Grainger, 1994; Ferrand, et al., 1994).

The results of these studies demonstrate that it is likely that both orthographic and phonological similarity between words enhances the process of word recognition. However the processing of orthography and phonology occurs at different rates, with orthographic information becoming available somewhat earlier than phonological information.

Overall the studies reviewed in this section on the effects of formal similarity on word recognition processes, suggest that the orthographic structure of written words does affect their recognition. Such effects may be facilitatory, occurring under conditions in which the activation of lexical representations is minimised, or inhibitory, being most evident under conditions which favour the activation of lexical representations.

For present purposes these qualitative differences between priming effects are important not only because that may be taken as indicating the functional architecture of a lexical memory, but also because they are relevant to the interpretation of effects seen with morphologically related words. Since these words also tend to formally similar, priming effects with morphologically related words must be interpreted with these effects of formal similarity in mind.

1.10 The recognition of morphologically complex words

This final section presents evidence concerning the sensitivity of tasks involving word recognition to word morphology. The majority of studies investigating the processes and representations involved in word recognition have employed as experimental items words containing a single 'morpheme'. A morpheme has been defined as 'the minimal unit of grammatical analysis' (Lyons, 1968). However, the majority of words in English are morphologically complex, having a number of constituent morphemes, and can be seen as part of a 'family' of morphologically related words. Thus the word 'accept' has amongst its morphological relatives the words 'acceptable', 'accepting', 'acceptance', 'accepts' etc. Demonstrations that these words have some aspects of their representation or processing in common that cannot be ascribed to similarity of pronunciation or of visual appearance or of meaning would suggest that there is a form of representation in which such morphological relationships are encoded. Since such relationships are specific to words, this would support the view that there is a form of representation which is also specific to words.

The functional significance of morphological relationships has recently been questioned. In some connectionist models of word recognition (e.g. Seidenberg & McClelland, 1989), the apparent effects of morphological relationship have been ascribed to orthographic regularities between morphologically related words. However the ability of such 'orthographic' models to account for morphological priming effects has been questioned (e.g. Rapp, 1992; Laudanna, Burani & Cermele, 1994), whilst the need for models of word recognition to take account of the distinctions made by linguists between different types of word has also been emphasised (e.g. Henderson, 1985; 1989; Laudanna, Badecker, & Caramazza, 1992; Sandra, 1994). Particular attention has been paid to the attempts to demonstrate differences in the representation of inflectionally and derivationally related words (for meanings of these terms see Section 1.11.1 below), and to demonstrate effects of morphological similarity between morphologically related words which are not also formally similar (e.g. 'speak' and 'spoke'). Such effects would provide evidence in favour of a specifically morphological level of representation or process.

Before describing the empirical work which has investigated the psychological reality of morphological relations between words, I will briefly outline the way that the morphological structure of English words has been described. This outline is based on the discussion of word morphology in Aronoff (1976), Lyons (1968), Matthews (1974) and Bybee (1985).

1.10.1 Morphological structure in English

In English, morphemes may be 'bound' or 'free'. A 'free morpheme', e.g. {accept}[1], may occur independently of any other morpheme (e.g. as the word 'accept'), or may occur in conjunction with one or more bound morphemes (e.g. 'unacceptable'). In contrast, bound morphemes, e.g. {-ment}, may occur only in conjunction with a free morpheme. In contrast, in Italian all morphemes are bound forms; all words being composed of a root morpheme together with one or more affixes. Different languages vary in the degree to which words can be sub-divided into constituent morphemes. In 'isolating' languages such as Vietnamese, words tend to contain only a single morpheme. In 'aggutinating' languages such as Turkish, words may be composed of a sequence of many morphemes. English occurs as an intermediate type having many monomorphemic and polymorphemic words. With notable exceptions (e.g. {un}, {in}), most bound morphemes in English occur as suffixes (Cutler, Hawkins, & Gilligan, 1985). The morpheme(s) remaining when all derivational and inflectional affixes have been removed is generally described as the 'root' form. When the root constitutes only a single morpheme this may be referred to as the root morpheme. When inflectional, but not derivational, affixes have been removed, then the remainder is generally referred to as the 'stem' of the word.

The morphemic structure of a word is not always phonologically and orthographically transparent. Such suppletive forms include the English past tense form 'went' which combines the free morpheme {go} and the bound morpheme {ed}. In addition to these 'strong' verbs, other suppletive forms in English are the irregular plurals, e.g. 'children', 'mice' etc, and the irregular comparatives and superlatives, e.g. 'better', 'worst'. Nor is morphemic structure always semantically transparent. Words such as 'reproach' and 'approach' may be considered to be morphologically related because in each case the initial letter(s) ('re' and 'a') may be considered to be morphemic on etymological and semantic grounds. Such an analysis requires that the remainder of the word ('proach') also to be consttitute a morpheme, and thus allows these words to be seen as morphological relations.

---

[1] References to abstract morphemes will be identified by the use of {}, references to particular instantiations of a morpheme will be identified by the use of [ ].

Word morphology has been divided into 'inflectional' and 'derivational' morphology. Inflectional morphemes in English are those which mark a word for number (i.e. singular or plural) and tense, aspect and mood. In languages other than English they may also indicate case and gender. Such morphemes are required by the syntax of the sentence and are obligatory. The addition of an inflectional affix to a word generally leaves the meaning of the word and its grammatical class unchanged. In contrast, derivational morphemes allow the creation of new words from existing ones. Thus they allow the creation of adjectives from nouns (e.g. 'functional' from 'function'), nouns from verbs (e.g. 'examination' from 'examine') etc. Typically, they change the meaning and/or the grammatical class of a word to which they are attached; a change which is acknowledged when derivational, but not inflectional, forms are given separate dictionary entries. However derivationally related forms generally retain a semantic relationship. Bybee (1985) suggests that only the obligatoriness criterion provides a reliable way of dividing inflectional and derivational morphology, and that the differences between inflectional and derivational forms are of the same kind as can be found between some inflectional forms. Other morphologically complex words are formed from the compounding of two words. Such compounds may be semantically transparent, e.g. 'blackbird', or semantically opaque, e.g. 'foolscap'.

1.10.2 Experimental investigations of the functional significance of morphological structure

Although attempts have been made to provide a unified account of the representation of morphologically complex words, for a number of reasons this attempt is likely to prove fruitless (see also Burani & Laudanna, 1992; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Laudanna et al, 1994). As noted above, morphologically complex forms can be classed as either inflectional or derivational depending on their functional role, and these differences in function may have consequences for the processing and representation of the two types of word. Secondly, although a considerable amount of work on morphologically complex forms has been done in English, much work has also been carried out in Serbo-Croat and Italian, languages with a considerably richer lexical morphology than English, and in Hebrew, a language in which morphological information is generally represented by infixes, rather than by prefixes or suffixes. There is no *a priori* reason why users of different languages represent morphological information in the same way. Because of this variety in experimental materials, it may be difficult to determine when differences between experimental results reflect differences of theoretical importance, and when such differences reflect variations in the surface form of different languages.

Evidence from a number of sources has been deployed in support of the claim that lexical memory encodes the morphological relationship between words. Some studies which have investigated the influence of morphological structure on lexical memory have considered the pattern of errors produced during natural speech (e.g. Fromkin, 1973; Garrett, 1982), whilst others have investigated deficits in the processing of morphologically complex words after neurological damage (e.g. Caramazza, Miceli, Silveri, & Laudanna, 1985; Funnell, 1987; Miceli & Carammaza, 1988; Miceli, Silveri, Romani, & Carammaza, 1989; Morton & Patterson, 1980; Patterson, 1980; Tyler, Behrens, Cobb, & Marslen-Wilson, 1990; Tyler & Cobb, 1987).

Experimental investigations of the effects of morphology have employed a variety of experimental paradigms with normal subjects. A number of studies have investigated morphological effects in spoken word comprehension, (e.g. Emmorey, 1989; Jarvella & Meijers, 1983; Kempley & Morton, 1982; Schriefers, Zwitserlood, & Roelofs, 1991). Others have investigated the importance of morphemic and non-morphemic units in word recognition (Beauvillain, 1994), the differential ease with which letter clusters can be extracted from words which are morphologically complex (e.g. 'drummer') and words which only appear to be morphologically complex (e.g. 'summer'; Feldman, 1991; 1994), the probability of detecting a given letter in morphologically complex words (e.g. Drewnowski & Healy, 1980; Gibson & Guinet, 1971), and the phenomena of ' illusory conjunctions' (Prinzmetal, Hoffman, & Vest, 1991) and 'repetition blindness' (Bavelier, Prasadam, & Segui, 1994). These studies have made important contributions to our understanding of the influence of morphological complexity. Nonetheless, I will focus on those studies which have employed a variant of three particular experimental paradigms involving the visual presentation of words and non-words to normal subjects. These studies are most relevant to the the initial experiments reported here which also present words visually to normal subjects.

The first paradigm I consider investigates the degree to which response latencies are determined by not only the frequency of whole words but also by the frequency of their constituent morphemes, the second paradigm examines the speed with which subjects can identify as words (or as non-words) items of differing morphological complexity, whilst the third paradigm explores the nature of the priming effects between morphologically related words.

These empirical studies have been performed against a background of two general models of the representations and processes involved in the recognition of morphologically complex words. One class of model assumes that morphologically complex words are represented in a morphologically 'decomposed' form. Generally such models propose that the representation of morphologically complex words consists of a representation of the root or stem morpheme together with a representation of the way in which this 'base' form combines with other morphemes. This form of representation can be contrasted with models in which words are separately, but non-independently, represented as whole words. In these models, the connections between words mean that the activation of the representation of one word will result in the activation of its morphological relatives. Investigations of morphological effects in word recognition have addressed two questions, explicitly articulated by Henderson, Wallis and Knight (1984) and by Laudanna and Burani (1985). Firstly, can morphological relationships be shown experimentally to have functional significance? Secondly, if so, then at what point in the processing of a word does information concerning morphological structure become available, i.e. how are morphological relationships encoded?

1.10.2.1 Morpheme frequency and word frequency

As noted in Section 1.4, the time required to respond to a word in a LDT has been shown to be sensitive to the frequency with which that word occurs in the language. A number of studies have investigated the degree to which the frequency of the morphemes constituting a word, as well as the frequency of the word itself, contribute to determining performance in tasks such as the LDT. If 'morpheme frequency' were found to partially determine LDT latencies, then this would suggest, firstly, that a word is analysed into its constituent morphemes during the process of word recognition, and secondly that the recognition of words which had a common morpheme utilised a shared representation of that morpheme. Although the frequency of occurrence of a whole word and the frequency of the morphemes constituting that word are highly correlated, it is possible to select word sets for which these measures are uncorrelated. A number of studies have investigated the effects of these different frequency measures (Bradley, 1980; Burani & Carammaza, 1988; Katz, Rexer, & Lukatela, 1991; Kelliher & Henderson, 1990; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Taft, 1979a). In general these studies have shown that response latencies in the LDT are sensitive to both morpheme frequency and word frequency.

Demonstrations that decision latencies in tasks such as the LDT depend upon the frequency of the morphemes constituting a word support the view that the processes involved in word recognition are sensitive to the morphological structure of words. Effects of both morpheme and whole word frequency implicate representations of the word as a whole and representations of its constituent morphemes in word recognition. However these results shed little light on the possible mechanisms by which word recognition is affected by morphological complexity. Representations of whole word and of morphemic constituents may be engaged at the same processing locus, or may reflect processing at different stages of word recognition. Results from studies using other experimental paradigms have claimed to address questions concerning the mechanism through which word morphology exerts its influence.

1.10.2.2 Manipulations of the morphographic structure of words and non-words

In a number of studies the significance of the morphological structure of words has been investigated by manipulating the ease with which words and non-words of different complexity are recognised. Taft and Forster (1975) compared response latencies in a LDT for non-words such as 'juvenate' and 'pertoire'. Whereas 'juvenate' can be taken to be a morpheme occurring in words such as 'rejuvenate', 'pertoire' cannot be analysed as a legal morpheme. Taft and Forster (1975) argued that if words were represented in a morphologically decomposed form, then 'juvenate' would make contact with a representation in a 'lexicon' of morphemes, but 'pertoire' would not. 'Juvenate' could only be rejected as a word when it had been determined that it could not exist as a free form. In contrast 'pertoire', having no lexical representation, could be rejected as soon as some deadline for finding a lexical entry had been passed. Thus 'juvenate' would be likely to take longer to classify as a non-word than would 'pertoire'.

Taft and Forster (1975) found that response latencies in a LDT to items such as 'juvenate' were indeed longer than latencies to items such as 'pertoire'. This result was taken to support a decompositional model of the lexicon in which prefixes were automatically 'stripped' from words pre-lexically. These experiments formed the basis for the development of the morphographic BOSS model of word recognition (Taft, 1979a; 1979b; 1981; 1985; Taft & Forster, 1976), a model that has since been much criticised (e.g, Jordan, 1986; Lima & Pollatsek, 1983).

The recognition of morphologically complex words was also the subject of the study by Rubin, Becker and Freeman (1979). They found that pseudo-prefixed words (e.g. 'uncle'; 'regent') were recognised more slowly than truly prefixed words (e.g. 'unknown'; 'rebook') only when a large proportion of experimental items were prefixed. Rubin et al (1979) suggested that the morphological decomposition is a strategy which subjects can adopt when appropriate, but that words are more generally recognised as whole words. Manelis and Tharp (1977) also favoured what they described as a 'single-unit' hypothesis. They showed that LDT latencies did not differ when word pairs were either both affixed or both non-affixed suggesting that there was no time cost in the processing of affixed words as might have been supposed from an affix stripping model. However the studies by Rubin et al (1979) and by Manelis and Tharp (1977) have also been the subject of criticism (Taft, 1979b; 1981).

Lukatela, Gligorijevic, Kostic and Turvey (1980) found that lexical decision latencies for nominative singular nouns in Serbo-Croatian were shorter than for two other types of inflection. Lukatela et al (1980) argued that because the three inflected forms were equivalent with respect to morphological complexity, the difference between them could not be due to differences in the degree to which they underwent processes of morphological decomposition during their recognition. Instead they proposed a model based upon logogens in which one particular inflected form of a noun is the focus of a 'satellite' system with the other inflected forms acting as satellites. The logogen of the focal form has a lower threshold than the logogens representing the satellite forms.

Segui and Zubizarreta (1985) also suggested that morphologically related words are represented separately but non-independently. They reported the results of experiments by

Cole, Beauvillain, Pavard, Segui and Zubizarreta which found that suffixed, but not prefixed, words in French were sensitive to the morphological complexity of the preceding words in a word list. Segui and Zubizaretta (1985) argued that the differences between prefixed and suffixed words arose because a parsing mechanism operates from left to right to extract a root morpheme and a suffix if present (see also Beauvillain & Segui, 1992). Detection of a root morpheme activates a 'family' of representations of morphologically related forms and the correct representation is selected by matching the members of the family with a suffix where present. In contrast to the prefix-stripping model of Taft and Forster (1975), the left to right parser does not recognise a prefix and prefixed words are recognised in the same manner as are monomorphemic words.

Bergman, Hudson, and Eling (1988) also suggested that a left-to-right process operated in the recognition of Dutch derivational words. They found that there was only a marginal difference in lexical decision latencies between truly prefixed and non-prefixed words, but that words which begun with a pseudo-prefix attracted significantly slower reaction times. This result supported Taft and Forster's (1975) prefix stripping model. A second experiment failed to show a similar effect with suffixes and pseudo-suffixes (e.g. 'working' vs 'pudding'). Bergman et al (1988) proposed that lexical access depended upon separate representations of root morphemes and affixes which necessitated a process of affix extraction. Within the lexicon itself, at least for derivational forms, all words were separately represented.

Caramazza, Laudanna and Romani (1988) investigated the effects of morphological complexity on the recognition of Italian words in order to test the Augmented Addressed Morphology (AAM) model of Caramazza, Miceli, Silveri and Laudanna (1985). The AAM model proposes that there are recognition units for whole words and for the constituent morphemes of words. These recognition units, on reaching a threshold, activate morphemic representations within a decomposed lexicon. Caramazza et al (1988) constructed four types of non-word: Firstly non-words which consisted of a real root and a real suffix but in which the root and suffix could not be legally combined (an equivalent in English being 'flinged'); secondly non-words consisting of a nonsense root and a nonsense pseudo-suffix (e.g. 'fippeny'); thirdly non-words consisting of a legal root and a nonsense suffix (e.g. 'flingeny'); and finally non-words consisting of a nonsense root with a legal suffix (e.g. 'fipped').

Caramazza et al (1988) argued that the AAM model predicted differences in the ease with which these non-words could be rejected in a LDT. Nonwords such as 'flinged' would be most difficult to reject as real words because only when an attempt was made to integrate two legal morphemes would the identification process fail. In contrast, completely illegal non-words such as 'fippeny' would be easiest to reject because this type of non-word would not activate to threshold either morphemic or whole word recognition units. Non-words with partial morphological structure (e.g. 'fipped', 'flingeny') would be of intermediate difficulty since they would activate only a single recognition unit and a single lexical unit. The results of three experiments were generally consistent with the predictions of the AAM model; performance on the LDT was dependent upon the morphological structure of the non-words.

Feldman (1991, experiment 1) exploited the 'phonological ambiguity' effect in Serbo-Croatian (see Lukatela, et al., 1980). She found that lexical decision and naming latencies for words consisting of a base morpheme and an affix depended upon whether each of the constituent morphemes were ambiguous or unequivocal in their phonology. Feldman (1991) argued that this result supported the view that both morphological constituents were involved in lexical access and was inconsistent with a pre-lexical process of affix stripping.

Laudanna et al. (1994) found that the extent to which lexical decisions to pseudo-prefixed non-words were delayed compared to decisions to non-prefixed non-words depended upon the identity of the prefix. Specifically they found strong positive correlation between lexical decision latencies and the extent to which a given orthographic pattern occurred as a real prefix rather than a pseudo-prefix. Laudanna et al (1994) argued in favour of a decompositional model of word recognition in which morphological decomposition was not obligatory.

The demonstrations of the effects of morphological structure in tasks such as the LDT support the view that word recognition depends upon representations of the morphological structure of words. The majority of studies which have varied the morphological complexity of words have been interpreted within a decompositional model of lexical representation. Under such models affixes may be removed in a pre-lexical process, whilst the 'lexical' representation may be a root or stem morpheme. Models of word recognition which incorporate a process of affix-stripping are being supplanted by those proposing other mechanisms of decomposition. Even the original advocate of the prefix-stripping model has recently suggested an alternative model which, although incorporating an explicit representation of morphological structure, does not involve an explicit operation of prefix-stripping (Taft, 1994, see Section 1.10.2.4).

1.10.2.3 Repetition effects and the representation of morphologically complex words

In this section I will selectively review studies which have employed repetition paradigms to investigate the way lexical memory is sensitive to morphological structure (see Feldman & Andjelkovic, 1992, and Henderson, 1989, for more extensive reviews). In a morphological priming paradigm, a word is preceded by a morphologically related word. For example, the morphologically complex word 'ruinous' might be preceded by its morphological relative 'ruin' (or *vice versa*). The unit repeated therefore is not the whole word but one of the constituent morphemes of the word. According to a decompositional account, 'ruinous' and 'ruin' should contact the representation of the morpheme {ruin}. To the extent that repetition effects reflect solely lexical processes, a prior encounter with the word 'ruinous' will have a similar effect on the perception of 'ruin' as would its repetition. Alternatively, morphological priming effects may arise as a result of a spread of activation between inter-connected representations.

Typically morphological priming effects are assessed by comparing their magnitude and longevity to those of repetition effects. Morphologically related words tend also to be both formally and semantically related. As a result morphological priming effects have also been compared to formal and semantic priming effects. Only effects which cannot be seen as resulting from such formal and semantic similarity can be properly attributed to the effects of morphological similarity between words.

One of the first investigations into the relation between morphologically related words was that of Murrell and Morton (1974). This study attempted to determine whether logogens proposed by Morton (1969; 1979) to underlie word recognition were sensitive to specific words or to morphemes. Murrell and Morton (1974) found that the ability of subjects to identify words in a perceptual identification paradigm was enhanced by having previously seen a word having the same root morpheme, although to a lesser degree than when the word itself had been seen previously. No similar enhancement was found when a word was preceded by a formally similar word.

In two studies Stanners and his colleagues investigated the relationship between a root form and its inflectional relatives. Stanners, Neiser, Hernon and Hall (1979) found that preceding a word by a regular inflectional relative produced as much priming as repeating the word. Irregular inflectional relatives, which tend to be less formally similar than regular forms (e.g. shook - shake), produced a reliable priming effect which was smaller in magnitude than that produced by repetition. Stanners, Neiser and Painton (1979) preceded a target word by two words each of which contained a different morpheme from the target word. Thus the word 'progress' was preceded by the words 'regress' and 'profess'. Stanners et al (1979) found that although there was a reliable priming effect it was not as great as the effect of repetition and argued that the repetition effect was not simply the sum of the morphological priming effects. They argued that recognition of morphologically complex words involves the integration of information from representations of morphemes and of whole words (but see Taft, 1981, for counter-arguments).

Henderson, Wallis and Knight (1984) compared the priming effects observed between various inflectionally and derivationally related suffixed words with those found between semantically or formally related words. Morphological priming resulted in a priming effect which was as great when the interval between the presentation of related items was 4 seconds as when it was 1 second. In contrast the semantic priming effect was abolished at the longer inter-stimulus-interval, whilst formal priming produced an inhibitory effect. Henderson et al (1984) argued that morphological priming was not reducible to semantic or formal priming, but was further evidence in favour of a level of representation in which morphological structure was encoded.

Bentin and Feldman (1990) also argued that morphological priming effects could be distinguished from semantic priming effects on the basis of the longevity of the effects. Using

Hebrew words they found that at lag 0, semantic priming effects were greater than morphological priming effects. However, at a lag of 15 intervening items the morphological effects were equal in magnitude to the effects at lag 0, whilst the semantic effects were no longer reliable.

Stanners et al (1979a) and Henderson et al (1984) identified two possible mechanisms which could account for morphological priming effects. A 'pre-lexical' mechanism, ascribed to Taft and Forster (1975), involves the stripping of prefixes prior to accessing a lexical entry. By this mechanism the same base representation is used in the recognition of morphologically related words. In contrast, in the lexical mechanism, activation spreads through a network of detectors of morphologically related words. As noted by Henderson et al (1984) these two mechanisms may operate in parallel.

Demonstrations of morphological priming effects with irregularly related words are particularly informative because of the decrease in formal similarity between words. In addition to the study by Stanners et al (1979a), there have been a number of reports of the effects of priming by irregular morphological relatives. Laudanna and Burani (1984, cited in Laudanna & Burani, 1985) found that whilst regular inflections produced as big a priming effect as did repetition, priming with irregular forms produced a smaller but still reliable effect.

This pattern of results was replicated in English by Fowler, Napps and Feldman (1985, experiment 1). However Fowler et al (1985) suggested that one reason why the morphological priming effect was smaller than the repetition priming effect was because the repetition effect included a contribution from episodic memory processes. Such an episodic effect would be reduced in the morphological priming condition because the related items were less similar to one another. This problem of the priming effect not being a 'pure' measure of lexical priming effects has been addressed in a number of ways.

Fowler et al (1985) attempted to reduce the influence of episodic memory on the magnitude of the repetition priming effect by increasing the interval between related or repeated items. When this interval was 48 items, non-word repetition effects, which Fowler et al (1985) argued reflected the influence of episodic memory, were abolished. Under these conditions the priming effects with inflectionally and derivationally related words were equivalent, and were as great as the effects of repetition. Fowler et al (1985) also compared the effects of morphological priming using primes which were and were not consistent in their spelling and pronunciation between prime and probe. They found that whereas the effects of morphological priming were smaller than the effects of repetition, whether or not the prime and probe words had consistent spelling and pronunciation had no effect on the magnitude of the morphological priming effect (see also Feldman & Fowler, 1987, experiment 3).

Fowler et al (1985) argued that these results support a model in which morphologically related words have separate representations, or 'nodes', but these nodes are connected to a node representing the stem morpheme (see also Dell, 1986). This model has similarities with the satellite model proposed by Lukatela et al (1980), but differs in having the stem morpheme at the centre rather than the full nominative form. This difference between models may reflect only the differences in the languages being represented rather than being theoretically significant.

Feldman and Fowler (1987) demonstrated that inflected forms in Serbo-Croatian had as great a priming effect on the nominative singular base form as did repetition of the base form. This result was taken to support a satellite model in which the representation of the base-form is activated upon presentation of any of the satellites forms. However in a second experiment Feldman and Fowler (1987) showed that not all 'oblique' (i.e. non-base) forms were equally effective primes of another oblique form. This finding suggests that the relations between representations within the satellite system are not homogenous. Instead some connections between representations of morphological relatives are stronger than others. Fowler and Feldman (1987) argued that this conclusion was difficult to reconcile either with a model that proposes fully independent representations of each word form, or with models proposing that the recognition of morphologically related words is mediated through the activation of a representation of the common base morpheme (see also Schriefers, Friederici, & Graetz, 1992, for a similar result in German).

Following Fowler at al's (1985) attempt to demonstrate that repetition and morphological priming effects were not due to the effects of episodic memory, Napps (1989) attempted to reduce the influence of episodic factors in morphological priming effects by reducing the proportion of related items seen by subjects (see also Jacoby & Dallas, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977). In this study only approximately 6% of items were related, either by being repeats of previous items or by being semantically or morphologically related. In addition, the lag between related items varied between 0 and 10 intervening items. Napps (1989, experiment 1) found reliable effects of morphological priming on root words. The magnitude of these effects were equivalent for inflectional and derivational forms. In a second experiment Napps (1989) found that priming for suppletive forms was abolished when one or more items intervened between related items, whilst in a third experiment she found reliable priming effects for associatively related words, but not for synonyms. These findings suggest that morphological priming effects with regularly related forms cannot be reduced to semantic priming. However unlike other studies using irregularly related forms, the longevity of morphological priming effects was similar to that of the priming effects seen between semantically associated words.

Feldman and Moskovljevic (1987) demonstrated repetition and morphological priming effects of similar magnitude on probe words written in the Roman script regardless of whether the prime words was also written in the Roman script or whether the prime was written in the Cyrillic script. This result makes it unlikely that such effects were mediated by episodic memory. In a second experiment Feldman and Moskovljevic (1987) found that only when word pairs were morphologically related was there a reliable priming effect across encounters. Orthographic or phonological similarity between words was not sufficient to elicit reliable priming effects.

Forster, Davis, Schoknecht and Carter (1987, experiment 7) investigated morphological priming used masked primes in a LDT. Masked priming paradigms have been used in an attempt to minimise the influence of episodic memory (see Section 1.7). Primes were irregular verb inflections and irregular plural nouns which differed by one or two letters from a target word. Forster et al (1987) found a reliable effect of morphological priming. This effect was equal in magnitude to the effect of repetition. Grainger, Cole and Segui (1991) also attempted to eliminate episodic effects by using masked primes. When measured against formally related words and unrelated words, prefixed and suffixed morphologically related forms showed facilitatory effects. Unfortunately, since Grainger et al (1991) did not include a repetition condition, it is not known whether the morphological effects were as great as repetition effects would have been under the same conditions. Nonetheless, the results of these studies using masked primes also suggest that morphological priming effects are not a result of processes involved with episodic memory.

Feldman (1991, experiment 2) compared priming effects with inflectional and derivational relatives in Serbo-Croatian whilst carefully controlling for differences in degree of formal similarity between the two word types. Feldman (1991) found that in the LDT priming by inflections resulted in a 'full' priming effect, whereas priming by derivations gave rise to only a 'partial' priming effect. In a naming task, inflectional but not derivational priming effects were reliable. In three repetition experiments Feldman (1994) matched the degree of formal overlap between prime and probe items across the two prime types. Derivational and inflectional forms maintained their word class between prime and probe words. In each case stronger priming effects were found with inflectional forms as primes than with derivational forms, with the effects of derivational priming being only marginally reliable.

Feldman (1991; 1994) suggested that these differences between inflectional and derivational forms supported the view that these classes of word differed with respect to their representational basis. These effects are equally consistent with models which propose a morphologically decomposed lexicon and models which propose a lexicon of whole word forms. However because of her findings across a range of tasks and materials, Feldman favoured a morphologically organised lexicon of whole word forms.

Katz, Rexer and Lukatela (1991) investigated the effects of inflectional morphology in both English and Serbo-Croatian. They presented inflectional forms as whole words or as 'decomposed' forms with the presentation of the constituent morphemes separated in time by intervals increasing in steps of 1/60 th of a second. Katz et al (1991) argued that if the lexicon contained morphologically decomposed forms, then presentation of words in decomposed form would aid their recognition. On the other hand if words were represented as full forms, then they would most easily be recognised when presented as full forms. In both English and Serbo-Croatian lexical decision times were fastest when the word was presented as an intact word, suggesting that in neither language does a process of pre-lexical decomposition occur.

Drews and Zwitserlood (1995) required subjects to perform a LDT. Monomorphemic German probe words were preceded 8 to 12 items previously by a regularly inflected related form or by the target word itself. The morphological and repetition priming effects were each reliable, and the repetition effect was reliably greater than the morphological priming effect. There was no reliable effect due to formal similarity between related items. In further experiments, Drews and Zwitserlood (1995) used a morphological priming procedure with a 300 ms SOA between prime and probe word. In each case they found a reliable facilitatory effect of morphological priming, together with an inhibitory effect of formal priming. In the one experiment that included a repetition condition the magnitude of the repetition effect was greater than that of the morphological priming effect. A similar pattern of results was observed when the prime words were masked so as to prevent their identification.

Laudanna, Badecker and Caramazza (1992) compared the effects of derivational and inflectional priming in Italian and found equal amounts of priming on a citation form[2] probe word. Laudanna et al (1992) investigated whether representations within the lexicon were based upon a root morpheme or on a stem morpheme. In Italian, inflected words which have homographic root morphemes typically produce inhibitory effects on one another (Laudanna, et al., 1989). Laudanna et al (1992) argued that if the lexical representation of a derived word was also its root rather than its stem, then such words should have inhibitory effects on words having homographic roots. However they found that only inflected words had such inhibitory effects, suggesting that whilst inflected words are represented as their roots, derived words are represented as their stems.

Marslen-Wilson et al (1994) reported a series of experiments investigating the representation of prefixed and suffixed derived words in English. Marslen-Wilson et al (1994) used a cross-modal priming paradigm in which the prime word was an auditorily presented derivational form and the probe word was its root form presented visually (e.g. 'friendly' - 'friend'). The probe word was presented at the offset of the corresponding prime word. It was suggested that this cross-modal paradigm meant that any effects observed would reflect the operation of a central lexicon rather than a modality specific 'peripheral access' system.

Marslen-Wilson et al (1994) found reliable morphological priming effects but formally related words showed a slight inhibitory effect. The morphological priming effect found between stem and derived forms did not depend upon phonological transparency between the words, but did

---

[2] The citation form refers to that form of a word normally given as a main entry in a dictionary.

depend upon the relation between them being semantically transparent (e.g. 'serenity' and 'serene'). There were no reliable priming effects found between two suffixed derived forms irrespective of whether there was or was not a transparent semantic relationship between them. In experiments with prefixed words there were reliable effects between two semantically transparent prefixed derived forms (e.g. 'unfasten' - 'refasten').

The types of models proposed to account for these effects will be discussed at length in the following section. For now it can be noted that the results of the studies reviewed above provide further support for the view that the morphological structure of words does affect their processing during word recognition. The effects of morphological similarity can be distinguished from the effects of formal and/or semantic similarity. The effects of formal similarity appear to be either inhibitory or weakly facilitatory and short-lived, while semantic priming effects also appear to be relatively small in magnitude and short-lived. In contrast, morphological priming effects are invariably facilitatory and are often as robust as word repetition effects both in terms of their magnitude and their longevity. Morphological priming effects have been demonstrated even when efforts have been made to reduce the contribution of episodic and/or strategic factors to the priming effects observed. This is consistent with the view that morphological effects, firstly, provide evidence of the existence of a lexicon, and secondly reveal the internal structure of such a lexicon.

1.10.2.4 Models of the representation of morphologically related words

In the previous three sections I have reviewed studies that have used three experimental paradigms on the representation of morphological relatedness in lexical memory. The results of these studies have been claimed in support of a number of different theoretical positions. The nature of these alternatives have been discussed by Feldman (1994) and by Marslen-Wilson et al (1994). In this final section of this chapter, I will briefly summarise these varying positions and indicate how the study of event-related potentials may be able to contribute to their evaluation.

Decompositional models are generally associated with the work of Taft and Forster (1975; Forster, 1976; Taft, 1979a; 1979b; 1981; 1985). Their affix-stripping model involves the active removal of prefixes from morphological complex words. This allows the base form of the word to enter a two stage process of lexical identification. In the first stage 'an orthographic access file' is searched for an appropriate entry. If this search is successful then an entry in a 'central master file' or 'lexicon proper' is opened and information concerning the semantic and syntactic function of the word is made available. Although differing from such a serial search model in fundamental respects, Morton's logogen model has also embraced the notion of affix stripping (see Morton & Patterson, 1980). However Taft (1985) has distinguished the fate of prefixes which are stripped off a base form prior to lexical access, from that of suffixes. The base form of a word is separated from any suffix by means of a left-to-right parsing mechanism which identifies a base form which can be used to access the lexicon. Thus base morphemes are 'stripped' from their suffixes rather than *vice versa*. Taft (1985) has identified the experimental evidence concerning the delay in the processing of pseudo-prefixed words as particularly important evidence in favour of a decompositional account. The majority of studies which have manipulated the morphological complexity of words and the effects of base vs whole word frequency have favoured some form of decompositional model.

Taft (1994) has proposed an alternative account of the way in which morphological information is represented and utilised during word recognition. This model extends McClelland and Rumelhart's (1981) interactive activation model to include a sub-lexical nodes representing morphemes and word 'bodies' (see Section 1.9), as well as a supra-lexical nodes representing 'concepts'. In this model, identification of individual morphemes in a polymorphemic word occurs 'passively' as a result of the interconnections between the nodes corresponding to the letters constituting a morpheme and representations of morphemes. The extent to which the morphemes of a word contribute to its recognition depends upon the relative frequencies of the constituent morphemes. Although Taft (1994) appears to incorporate a morphemic level of representation into his model, it is far from clear morphological relationships are encoded in a way that would be recognised by the proponents of a 'linguistically-driven' architecture of word recognition (e.g. Henderson, 1989). Thus Taft (1994) suggests that 'Such a [prefix/stem] structure would emerge from the relationships between words which share the same letter sequences' (Taft, 1994, p. 283). Such a model, based upon the distribution of orthographic patterns in a word, has much in common with the account of morphological representation as an emergent property of word structure proposed by Seidenberg and McClelland (1989) in their distributed representation model of word recognition. Taft's (1994) proposal may be susceptible to the same criticisms as have been made of the Seidenberg and McClelland (1989) model (see Section 1.10).

The AAM model of Caramazza and colleagues (see Section 1.10.2.2) is a two-stage model having a pre-lexical access procedure and a lexicon proper. In these respects it is similar to the serial search model described above. However this model also includes representations of whole words, a feature which Taft (1985) has explicitly rejected. This model receives most support from experiments which have varied the morphological complexity of experimental materials, but cannot easily account for effects of morphological complexity with real words since the recognition of these words should proceed without the need for morphological decomposition.

As a result of their experiments Marslen-Wilson et al (1994) also favoured a two-stage process involving the mapping of perceptual representations of orthographic structure onto a modality-independent lexicon decomposed into abstract representations of stem morphemes. Marslen-Wilson et al (1994) proposed that a representation of a stem morpheme has mutually inhibitory connections to representations of all suffixes with which it can be combined. These inhibitory connections between suffixes account for the absence of facilitatory effects between pairs of suffixed derived forms. The representation of a stem morpheme is also connected to representations of all prefixes with which it can legally be combined, however these connections are not mutually inhibitory. Critically for this model, only morphologically related words for which there is a synchronic semantic relationship are represented as morphologically related. Thus Marslen-Wilson et al (1994) distinguish between a morpheme identified on linguistic grounds (e.g. the {mit} of 'permit' and 'submit') and a 'cognitive' morpheme (e.g. the stem morpheme of 'vanity') identified on empirical grounds. This semantic basis for morphological priming effects does not mean that the mechanism underlying these effects are similar to those underlying semantic priming effects. Rather the recognition of the semantic transparency of the relation is a necessary condition for the construction of the morphologically structured lexical representation. There is no explicit 'affix-stripping' mechanism in Marslen-Wilson et al's model. Instead representations of orthographic form map directly on to lexical representations.

Other models do not include a capacity to decompose morphologically complex words. These models can be seen as variants of what has been described as the 'full listings hypothesis' (Butterworth, 1983). Under such models morphologically complex words are represented as whole words, but non-independently. Related words are interconnected in a manner which reflects the degree of relationship between words, but the precise nature of the representations and the interconnections between them varies between models. One particularly influential model of this type has been the satellite entry model of Lukatela et al (1980). Other models which have proposed that morphologically complex words are represented as whole words include that proposed for German by Schrieffers et al (1992) and for English and Serbo-Croatian by Fowler and Feldman (Feldman, 1991; 1994; Feldman & Fowler, 1987; Fowler, et al., 1985). Under such models priming effects arise because of the links between representations of words which lead to a spread of activation through representations of related words. Asymmetries in priming effects can be accounted for as reflecting asymmetries in the strength of the connections between pairs of words. Such models have difficulty accounting for effects of increasing morphological complexity of non-words, however these effects of morphological complexity may reflect an increasing difficulty in making non-word decisions as the non-words become more similar to words.

Despite the wealth of experimental data now available on morphological effects in word recognition, it is far from clear that these data distinguish between morpheme based and whole-word based models of morphological representation. In support of their decompositional model Marslen-Wilson et al (1994) are forced to argue that 'it would be *counter-intuitive* to argue that semantically transparent forms ... are represented as unanalysed individual entries' (p. 31, italics added). That even after some of the most careful experiments on the representation of morphologically complex words, one model is to be preferred to another on the basis of intuition suggests that the empirical evidence which will definitively favour one model over another will not be easily forthcoming.

Given this difficulty, one way forward may be to employ as wide a variety of experimental techniques as possible in an attempt to discriminate between models. In the next chapter I introduce the ERP technique and discuss why it may inform questions concerning the representation of morphologically complex words.

Chapter 2

Word repetition and lexical memory: Electrophysiological investigations

2.0 Introduction

ERPs have been used in a range of experimental paradigms which have also employed behavioural measures. Although ERPs have been shown to be sensitive to semantic and formal similarities between words, little work has been done to investigate the sensitivity of the ERP to morphological relationships between words. In the present context, the particular feature of the ERP technique which is most relevant is their high temporal resolution (see Section 2.1). When the nature of the processing occurring during the recognition of a morphologically complex word can be tracked closely in time, then it may be possible to provide further empirical support for one or other model of the representation of such words. In particular, it may be possible to fractionate the processing of morphologically complex words into different components. Such components may correspond to processes of morphological decomposition. Furthermore, it will be possible to determine whether monomorphemic and polymorphemic words respond to repetition with a similar time course and thus provide further evidence of the similarity or otherwise of their representation. This is an example of a 'chronopsychophysiological' approach (Coles, Smid, Scheffers, & Otten, 1995; van der Molen, Bashore, Halliday, & Callaway, 1991) in which ERPs are used to investigate not only the identity of cognitive processes but also the temporal relationship between them. Before describing experiments which have addressed these issues specifically, I will describe the ERP technique and briefly review the results of the experiments which have suggested that ERPs may, directly or indirectly, be sensitive to lexical representations and/or processes.

2.1 The ERP

This discussion of the nature of the ERP and the way it is recorded, measured and evaluated is based on the accounts given in Coles and Rugg (1995), Garnsey (1993) and Picton, Lins and Scherg (1994). An ERP is a signal present in an EEG waveform which is time-locked to an internal or external 'event'. Typically, in the research discussed in this chapter, the event in question is the visual presentation of a word or non-word. The voltage by time function recorded after such a presentation is typically characterised by a series of negative and positive deflections of the waveform. These deflections are generally identified by their polarity and by either their latency or their position in an ordinal sequence of deflections of a given polarity. Thus the P300 or P3 refers to a positive-going deflection of the waveform which often occurs at approximately 300 ms post stimulus onset, and is typically the third prominent positive-going deflection in the ERP. Although described with reference to such an ordinal sequence, the underlying neural activity giving rise to these features of the ERP need not be temporally discrete (e.g. Curran, Tucker, Kutas, & Posner, 1993).

The deflections in the ERP waveform have generally been held to reflect different 'components' of the ERP, but the definition of an ERP component is not universally agreed. Coles and Rugg (1995) contrast 'physiological' and 'functional' approaches to component identification. By the physiological approach (e.g. Naatanen, 1982), a component of the ERP waveform refers to that part of the ERP which is derived from the activity of a single neural generator. Under this description a positive- or negative- going deflection in the ERP waveform may have one or more constituent components. In contrast a 'functional' component may reflect the activity of a set of neural generators. Each member of such a set contributes to the performance of a single cognitive operation. Some definitions of a component have combined both physiological and functional characteristics (e.g. Donchin, Ritter, & McCallum, 1978).

Components of the ERP waveform have been characterised as being either endogenous or exogenous. The amplitude and/or latency of the exogenous components are largely determined by the physical characteristics of the stimulus, for example the sensory modality and intensity. In contrast, endogenous components are generally insensitive to such characteristics, but are sensitive to the nature of the cognitive processes brought to bear on the stimulus. Although the division between endogenous and exogenous components of the ERP is not clear cut, the experiments reported in this thesis are concerned with the modulation of components of the ERP generally agreed to be endogenous.

A number of endogenous components have been extensively investigated over the last two decades in particular. Coles and Rugg (1995) have provided a compendium of these components. A number of early components - those occurring prior to approximately 200 ms - seem to be reflect processes of sensory analysis and which have been extensively investigated by those interested in mechanisms of selective attention (e.g. Mangun & Hillyard, 1995; Naatanen, 1982; Woldorff, Hackley, & Hillyard, 1991)

The most extensively investigated ERP component has been the P3 or P300 component (see Donchin & Coles, 1988; Pritchard, 1981; Verleger, 1988). The latency of the P3 is generally thought to covary with the time required to categorise an experimental item; as an item becomes more difficult to categorise then the P3 latency increases. On the other hand P3 latency does not seem to reflect processes involved in response selection and execution. The amplitude of the P3 depends upon the subjective probability and the task-relevance of the eliciting event. For present purposes the P3 is of significance for two reasons: Firstly, to the extent that the evaluation of a repeated item will be easier than will the evaluation of one being presented for the first time, ERPs elicited by repeated and unrepeated items may be expected to differ because of differences in the latency of the P3. Secondly, to the degree that experimental conditions differ in their subjective probability then the ERPs recorded in these conditions may differ because of the difference in P3 amplitude consequent upon such a probability difference.

A second component of the ERP which has attracted considerable attention is the N400. Although some have taken it as an example of the earlier N2 component (e.g. Deacon, Breton, Ritter, & Vaughan, 1991), it is generally considered to be different component. Since the experiments reported here are mainly concerned with modulations of this component of the

ERP, Section 2.5 considers in some detail the functional signficance of this component of the ERP. The remainder of this section will continue to examine the nature of ERPs in general.

2.1.1 The Neurogenesis of the EEG

The following discussion of the biophysics of the EEG is drawn from the discussions of this topic by Allison, Wood and McCarthy (1986), Nunez (1981; 1990) and Picton et al (1994). The EEG consists of a voltage by time function recorded at the scalp, generally at multiple locations. Usually its magnitude is in the microvolt (μV) range and may contain frequencies of some 40 Hz or greater. Allison et al (1986) suggest that the electrical events which constitute the scalp recorded EEG consist mainly of changes in the polarisation of the cell bodies and dendrites of the cortical pyamidal cells, rather than of axonal action potentials. These electrical events fulfill a number of criteria necessary for electrical changes in the brain to be measurable at the scalp. Two of the most important criteria are the orientation of the cells and the synchrony of the electrical events associated with them.

1. *Orientation.* Pyramidal cells occur in large numbers and have cell bodies and dendritic processes with similar orientations. Some 70% of these neurons are oriented perpendicular to the cortical surface. This arrangement creates an 'open field' in which the post-synaptic electrical potentials associated with each individual neuron summate. In contrast, the collateral axons associated with the pyramidal cells are more randomly orientated. As a consequence the potentials associated with these fibres create a 'closed field' and tend to cancel out. They therefore contribute little to the potential measured at the scalp. Closed fields are also found in the cortical sulci. In this case the potentials associated with the pyramidal cells on opposite sides of the sulcus tend to cancel each other out. The cellular architecture associated with other brain structures (e.g. the thalamus) is also thought to be unsuited to generating potentials that can be recorded at the scalp.

2. *Synchrony.* Electrical potentials may cancel not only because of their spatial configuration, but also because of their pattern of activity over time. Thus if neighbouring neurons (or sets of neurons) are firing such that at a particular time they are generating potentials of opposing polarity, these potentials will cancel out. Nunez (1981) suggests that only a small percentage of the cells over an area of a few centimetres of cortex need to be firing synchronously for a measurable scalp potential to be generated.

Because a particular event may lead to activity which is either in neural configurations which do not generate scalp potentials, or lead to asynchronous activity in populations of neurons, the scalp recorded EEG, and any ERPs derived from it, contains only a partial record of the neural activity consequent upon the presentation of a stimulus. The degree to which the ERP derived is a true reflection of stimulus-related neural processing is also compromised by the contamination of the EEG signal with potentials which do not originate in the neural tissue of the brain. The nature of these artifacts and the approaches that have been taken to minimise their effects are described in section 2.1.3

2.1.2 Recording EEG

This discussion of some of the issues relevant to the recording of the EEG, and the discussion of the issues involved in signal extraction and analysis are derived from only a few of the many papers written on the subject (Coles, Gratton, Kramer, & Miller, 1986; Coles & Rugg, 1995; Garnsey, 1993; Picton, et al., 1994; Rugg & Coles, 1995). The EEG is a record of the potential difference recorded between two points on the skin. Contact with the skin is made through recording electrodes. Prior to electrode attachment the skin must be prepared so as to reduce the impedance of the electrode connection. Picton et al (1994) suggest that typically the unprepared skin has an impedance of some 50 KΩ. Such a high impedance results in an unacceptable level of electromagnetic artifact in the EEG. Generally, this impedance is reduced to 5 KΩ or below, either by using an abrasive paste or by puncturing the skin. Electrodes are generally held in place either with an adhesive or by mechanical pressure exerted by means of an elasticated cap.

The connection between skin and electrode is made indirectly through an electrode jelly.This indirect connection acts to stabilise the skin-electrode interface and thus prevents the introduction of artifacts as a result of changes in the characteristics of the interface. An exchange of ions occurs between the electrode and the jelly (and between the jelly and the skin), the characteristics of which depend upon the metal used to make the electrodes. By acting as a low frequency filter these ion-exchanges can significantly affect the characteristics of the EEG recorded. This filtering effect can be minimised by using 'reversible' electrodes.

EEG is recorded using a 'differential amplifier' having an input channel for each site from which EEG is to be recorded. A differential amplifier amplifies the difference between two signals. Hence any signal which is common to both signals should not be amplified. The degree to which the amplifier is successful at removing such common signals is measured by the Common Mode Rejection Ratio. Each 'active' electrode is connected to one side of one channel of the differential amplifier.

Typically, the other side of each amplifier channel is connected to the 'reference' electrode. The reference electrode may be 'virtual' in that it may consist of the average of two electrodes one placed on each of the mastoid processes (a 'linked mastoid' reference), or on the the chest and lower neck (a 'non-cephalic' reference), or the reference may be taken to be the average potential of all the active sites (an 'average' reference). The potential at each 'active' site is measured with respect to the potential at the reference. The position of the reference therefore determines the absolute potential difference measured between two points. The potential measured at an active site may be positive with respect to one reference, but negative with respect to a second reference. For this reason the locations at which a change in absolute polarity occurs are not informative. Such a location may change whenever the location of the reference changed. However the rate of change of potential over space is constant regardless of the absolute potential difference recorded between the active and reference electrodes. The choice of any reference has consequences for both the signal recorded and its interpretation. A linked mastoid reference, as used in the present experiments, may allow the 'shunting' of current from one side of the head to the other and consequently distort the signal being measured. It has been argued that this rarely happens in practice (Miller, Lutzenberg and Elbert, 1991, cited in Picton et al, 1994, p.434).

In addition to the EEG recorded from each active site, an electro-oculogram (EOG) is also recorded. When the EOG channel exceeds a specified voltage limit, the EEG for that trial may be rejected on the grounds that the EEG will contain too large a degree of EOG artefact, and, as a result, the signal-to-noise ratio would be unacceptably low. Alternatively, an attempt may be made to assess the nature of the EOG artefact in the EEG and remove it. In the experiments reported here, experimental trials contaminated with EOG were excluded from further analysis. Generally one electrode on the scalp is attached to a ground connection. This acts as the centrepoint of the differential amplifier.

The signals emanating from the differential amplifier are usually subject to analogue filtering. Both low-pass and high-pass filters are generally applied; the former attenuates components of the waveform with frequencies present in the waveform above those of interest, whilst the latter attenuates components of the wavefom with frequencies below those of interest. The characteristics of analogue filters are often specified by reference to the frequency which the filter attenuates to some 70% of its unfiltered value. Low pass filters reduce the amount of muscle activity in the signal, generally derived from the face and neck muscles, which otherwise reduces the signal-to-noise ratio. A low pass filter also attenuates interference derived from the electrical mains. Such interference may also be removed using a 50 Hz 'notch' filter. Because analogue filters do not have discrete cut-off frequencies they may also attenuate frequencies in the waveform that result from brain activity. Furthermore because they respond differently to different frequencies, analogue filters may also distort the temporal relationship between different components of the waveform.

Following amplification and filtering, the EEG signal is generally passed to an analogue-to-digital converter (ADC). The ADC converts the analogue EEG voltage into a digital value. The nature of this conversion depends upon the resolution of the ADC in respect of the frequency with which the ADC samples the incoming voltage and the minimum voltage difference between two adjacent samples that can be discriminated. If the sampling frequency is not at least twice the highest frequency in the waveform being sampled (the Nyquist frequency), then the waveform will be distorted due to an aliasing bias in which higher frequency components will appear as a lower harmonic. The ability of the ADC to discriminate different voltages depends upon the number of 'bits' available for the conversion. In a typical 12 bit converter, the voltage may take on any of 2^{12} or 4096 different values. With a typical dynamic range of +/- 5V, this means that the ADC discriminates input voltages that differ by 2.4mV. If the signal has been amplified by a factor of 20000, then the digitised waveform discriminates between voltages which differ by 0.122 μV at the scalp.

2.1.3 Extracting the ERP from the EEG

Having recorded the EEG from a subject the ERP must be extracted. As noted in Section 2.1, the ERP is time-locked to the onset of a stimulus. However the ERP (the 'signal') is of relatively small amplitude compared to the magnitude of the the background EEG in which it is embedded. This background EEG contains an electrical record of brain processes occurring which are not relevant to the processing of the stimulus, as well as artefacts from other electrical sources. This noise must be removed to enable the ERP signal to be determined. A number of approaches to extracting the signal have been proposed. The most simple is the technique of 'signal averaging'. This method requires the recording of a number of epochs of EEG during which one class of experimental stimuli are presented. For such items, the variance in each epoch of EEG associated with the onset and processing of the experimental item is assumed to be constant. In contrast, variance in the EEG which is not time-locked to the processing of a particular event will be essentially random with respect to that event. When each time-point in the epochs of EEG are summated across the individual epochs, this 'random' or 'stationary' noise should cancel out, whilst the constant signal should summate. An average epoch can then be produced by dividing the summed value for each time-point by the number of epochs. The signal-to-noise ratio, i.e. the extent to which the noise is eliminated, is inversely proportional to the square root of the number of epochs from which the average is derived. Thus increasing the signal-to-noise ratio in an averaged ERP by increasing the number of epochs contributing to an averaged waveform becomes increasingly difficult as the number of epochs increases. Averaged ERPs are formed relative to a pre-stimulus baseline period, a procedure which compensates for differences in absolute voltage between the different epochs recorded.

Not all the noise in the EEG is random. Some eye movements may be linked to the display of a stimulus. Such artifacts will not be removed by signal averaging. Large eye movement artifacts which are easily detectable in an EOG recording may be automatically rejected from the averaging process. Similarly slow drifting artifacts, possibly arising from a physically unstable skin-electrode interface, may also be rejected from the averaging process.

Signal averaging has a number of drawbacks, the averaging process may obscure the relationship between the averaged ERP and the ERP elicited in the individual trials. The averaging process will not reproduce the waveform shape of the individual trials when the waveforms making up the average have a bimodal distribution with respect to either the latency of onset or the amplitude of components of the waveforms. Although not used here, a number of alternative methods have been developed to complement the averaging technique. These have tended to employ cross-correlational techniques in an attempt to identify the signal in the background EEG. Such techniques have their own difficulties, particularly when the signal-to-noise ratio is small and the cross-correlations are also consequently small, and have not be widely used in studies of ERPs and language processes.

2.1.4 The measurement and statistical evaluation of ERPs

Once obtained the averaged ERP must be quantified. ERPs differ in the onset latency of various components of the waveform, the magnitude of these components as well as their distribution across different recording sites. Any or all of these features may be used in the process of quantifying and differentiating ERPs. For present purposes the most important is the measurement of the mean amplitude of a region of the ERP.

For a given region of the ERP waveform, the mean value of the sampling points within that period is calculated relative to the mean value of the sampling points in the baseline period. Generally because of the gross non-independence between consecutive samples of EEG, such measurements are made over as wide a region of the waveform as is consistent with assessing the apparent differences between two waveforms. Typically this region may be from one to several hundred milliseconds long. Such a mean amplitude measurement will usually be made on the waveform recorded at each site and in each experimental condition.

Differences between experimental conditions are generally evaluated using Analysis of Variance (ANOVA). Such ANOVAs may be univariate or multivariate. Each method has its proponents. The univariate method has the virtue of comparative simplicity and was used to assess the reliability of the effects found in the present experiments (see also Section 3.2).

2.1.5 The interpretation of ERPs

The great advantage of ERP methodology over other functional imaging techniques is held to be its high degree of temporal resolution. Thus samples of the EEG can be taken, at multiple locations, at intervals of several milliseconds or less. This, in principle at least, provides an opportunity to observe the temporal dynamics of cognitive operations with a high degree of resolution. In practice the usefulness of this high resolution may be limited. Since different components of the ERP may overlap and summate, differences in temporal characteristics between two ERPs may not directly reflect differences in the temporal charateristics of the underlying cognitive processes.

The high temporal resolution of ERPs contrasts with their poor spatial resolution compared to other imaging techniques. Because of the summation of signals derived from multiple sources at a possibly very large number of locations, the identification of the neural sources responsible for a particular pattern of surface potentials is impossible. However with additional constraints on the likely location of the 'neural generators' underlying a particular pattern, plausible solutions of this so-called 'inverse problem' can be proposed.

ERPs only partially reflect the electrical activity in the brain engendered by the presentation of an experimental item. This factor places constraints on the conclusions that can be drawn from differences between ERPs elicited in different experimental conditions (Garnsey, 1993; Rugg & Coles, 1995). For example, the absence of a difference between ERPs recorded in two experimental conditions does not allow the conclusion that the two conditions engaged identical processes. Although this conclusion may be correct it is equally possible that the processing that differentiated the two conditions was not reflected in the ERP. When ERPs elicited in a number of experimental conditions do differ, such differences may be in respect of their mean amplitudes, their latency of onset (and/or offset) and their spatial distribution. Statistically reliable differences between experimental conditions are generally used as a basis from which to conclude that the cognitive processing accorded to the items in the various experimental conditions also differed.

Generally the onset of an ERP effect is considered to provide information concerning when a cognitive process is engaged whilst the amplitude of an ERP effect may indicate the extent to which it is engaged (e.g. Van Petten, 1993). With respect to the onset of an ERP difference, the onset latency provides only an upper boundary of when a difference in processing between two conditions occurs. The processing accorded two conditions may have differed prior to the onset latency but in brain structures, or in a manner, not reflected in the ERP.

Differences in amplitude between ERPs recorded in different conditions and which do not differ in their spatial configuation are typically interpreted as reflecting variations in the strength of activity within the same set of neural generators. In contrast when two sets of ERPs can be shown to have different spatial configurations then it follows that they reflect the operation of at least partially independent sets of generators. The criteria for establishing the reliability of such 'topographic' differences are discussed in Section 3.2. Differences in the topography of ERPs elicited by different experimental conditions are assumed to reflect the engagement of non-identical cognitive processes in those conditions. The difficulties embodied in this assumption are discussed by Rugg and Coles (1995). They argue that this assumption fails if ERPs are sensitive to the content as well as the identity of different cognitive operations. I return to this question of the interpretation of topographic differences between experimental conditions in Section 9.3, where it is particularly relevant to the interpretation of Experiments 3, 4 and 5.

In Section 2.1, I have examined the nature of the ERP, the way it is recorded and the way in which this measure can in principle be used to distinguish between the operations of different cognitive processes. In the remaining sections of this chapter I will selectively review specific studies which have used the ERP technique to investigate the cognitive processes engendered by the visual presentation of words.

2.2 ERPs and item repetition

The first investigation of the ERP response to the repetition of experimental items in an indirect task was reported by Rugg (1985b). In this study subjects were required to make lexical decisions to words which were being seen for the first time, being seen for the second time or were semantic associates of a previously occurring word. Rugg (1985b) found that, between approximately 300 ms and 600 ms after stimulus onset, ERPs elicited by repeated words were more positive-going than were waveforms elicited by words being seen for the first time. Words which had been semantically primed elicited a positive-going shift in the ERP that was smaller in amplitude and more temporally constrained than that elicited by word repetition. Nevertheless, the ERP repetition and semantic priming effects had similar scalp topographies indicating that the two experimental manipulations may have modulated the same set of cognitive processes. The relationship between ERP repetition and semantic priming effects will be further considered in Section 2.6.

As discussed by Rugg (1987), a comparison of ERPs elicited in experimental conditions for which reaction times vary is complicated by changes in the amplitude and latency of the P3 component which may be superimposed on other differencs between the ERPs elicited by those experimental conditions. In order to minimise these P3 effects, Rugg (1987) required subjects to count the number of non-words occurring in an experimental session. This task, whilst requiring subjects to make implicit lexical decisions, did not require the speeded response which typically leads to the generaton of a large P3 component. In a number of subsequent studies Rugg and his colleagues have used a LDT in which a motor response was required only to target items (words, non-words or members of a specified semantic category), but not to the critical repeating and non-repeating items. The use of this paradigm again means that the waveforms of primary interest are not heavily contaminated with a response-related activity.

Rugg (1987) again found a large positive-going shift in the ERP elicited by repeated words compared to the ERP elicited by words seen for the first time. This positive-going shift onset at approximately 300 ms, continued throughout the recording epoch and was greater over the right hemisphere than over the left. In contrast to the effects of repetition, semantic priming had a much more restricted effect on the ERP, resulting in a small positive-going shift that was reliable only after some 450 ms post stimulus onset and that was greatest at the Fz electrode.

Since these initial reports, there have been a number of other demonstrations of 'ERP repetition effects' using the LDT (Bentin & McCarthy, 1994; Bentin & Peled, 1990; Hamberger & Friedman, 1992; Karayanidis, Andrews, Ward, & McConaghy, 1991; Nagy & Rugg, 1989; Otten, Rugg, & Doyle, 1993; Rugg, 1987; 1994; Rugg, Doyle, & Melan, 1993; Rugg & Nagy, 1987; Smith & Halgren, 1987). Repetition effects have also been found with a semantic categorisation task (McCarthy & Nobre, 1993; Rugg, et al., 1994; Rugg, Furda, & Lorist, 1988; Young & Rugg, 1992), and when words have been repeated in sentence contexts (Besson, Kutas, & Van Petten, 1992; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). These studies have attempted to identify the cognitive process or processes whose operation is reflected in an ERP and which may be modified by repetition. These studies have employed a similar set of experimental manipulations to those which have been used in the study of behavioural repetition effects and which were reviewed in Chapter 1.

2.3. The component structure of the ERP repetition effect

A number of studies have addressed the issue of whether the ERP repetition effect is a modulation of only one or more than one ERP components. Rugg (1990 see also Halgren & Smith, 1987; Polich & Donchin, 1988; Young & Rugg, 1992) recorded ERPs to high and low frequency words on both their first and second presentations. In the first phase of the experiment, subjects were presented with high and low frequency words which were either repeated after 6 intervening items or were not repeated. In a second phase of the experiment, the non-repeated words from the first phase were re-presented, together with a further set of non-repeating high and low frequency words. The interval between the first and second phases of the experiment was some 15 minutes.

There were two notable aspects of the results of this study. Firstly, the repetition of low frequency words resulted in a modulation of the ERP between approximately 300 - 500 ms and between approximately 500 - 800 ms post-stimulus onset. In contrast the repetition of high frequency items resulted in a modulation of the waveform in only the first of these intervals and this effect was reliably smaller than was the repetition effect for repeating low frequency words. Secondly, in the second phase of the experiment only the repetition of low frequency words resulted in a modulation of the waveform, and then only in the 500 - 800 ms region of the waveform. Rugg (1990) interpreted the dissociation by frequency of the repetition effects in the earlier and later epochs as evidence for their being two components to the ERP repetition effect. The first, he argued, is sensitive to repetition of both high and low frequency words, and the second sensitive only to the repetition of low frequency words.

Van Petten et al (1991) also investigated the component structure of the ERP repetition effect. EEG was recorded whilst subjects to read passages of text presented one word at a time. Within these passages a number of words repeated one or more times at a variety of lags. The segments of EEG were averaged according to whether a word was presented for the first time or was a repeat and according to the lag between the presentations of a particular word. Van Petten et al (1991) found that repetition resulted in a positive-going shift in the ERP around 400 ms post stimulus onset which was greater for low than for high frequency words. There was also a negative-going shift in the ERP from approximately 600 ms post stimulus onset which also was greater for low than for high frequency words. Van Petten et al (1991) argued that this biphasic modulation in the ERP could not, unlike the results reported by Rugg (1990), be accounted for in terms of a single positive-going modulation of the waveform. Rather the most parsimonious interpretation of their results was that two underlying components had been differentially modulated by word repetition.

Further evidence for the involvement of two components to the ERP repetition effect was provided by Besson et al (1992). This study involved the presentation of single sentences, one word at a time, which ended with either a congruent or incongruent word. Besson et al (1992) found that around 400 ms, differences between ERPs generated by congruous and incongruous words had the same scalp distribution and magnitude as did the differences between the first and second presentations of incongruous words. This similarity of the effects of congruity and repetition around 400 ms contrasted with their effects in a subsequent region of the ERP. In this region, the repetition of congruous words resulted in a small negative-going shift in the waveform, whilst the repetition of incongruous words resulted in a larger positive-going shift, similar to that observed by Rugg (1990). Furthermore, whilst the effects of the earlier repetition effect was greatest at centro-parietal sites, and had a tendency to be greater over the right hemisphere than over the left, the later repetition effect was equipotentially distributed over the head. Besson et al (1992) argued that this difference in the scalp distributions of the two modulations of the ERP meant that they could not be accounted for by the action of a single underlying generator.

There have been a number of indications that modulations of other components of the ERP may be sensitive to repetition. Rugg (1987) and Nagy and Rugg (1989) have reported that repetition results in a negative going shift in the ERP around 200 ms and which Rugg (1987) interpreted as reflecting automatic processing. However this effect is not always found in studies of word repetition (e.g. Bentin & McCarthy, 1994; Bentin & Peled, 1990; Rugg, et al., 1988). Nobre and McCarthy (1994) have suggested that semantic priming modulates two different components in the region around 400 ms post-stimulus, one of which is enhanced by semantic priming whilst the other is attenuated. Further research will show whether a similar distinction can be made between components in this latency range for the repetition effect.

Despite these questions concerning the precise characteristics of the component structure of the repetition effect, Rugg (1990), Van Petten et al (1991) and Besson and Kutas (1993) have all argued that the ERP repetition effect has two main components. They suggest that the earlier component is the N400, and the later one a component generally identified as the Late Positive Component (LPC). However the different authors have assigned different functional roles to the cognitive processes reflected in these components. I will first briefly discuss the various proposals that have been made to account for modulations of the LPC. Although of considerable interest, for present purposes the functional significance of the LPC is not of primary importance. In contrast the experiments reported in this paper directly address interpretations of the significance of modulations of the N400, and I will discuss at some length the different views of the process(es) thought to be reflected by the modulation of this component.

2.4 Modulations of the LPC and their interpretation

Rugg (1990) proposed that because of the sensitivity of the LPC to word frequency, it reflected differences in the 'relative familiarity' of stimuli. Relative familiarity is a concept derived from the dual-process theories of recognition memory (Jacoby, 1983b; Mandler, 1980), and is derived from changes in the efficiency or 'fluency' (Jacoby, 1983b) with which words are perceived after repetition. Thus this later component was held to reflect the operation of processes which allowed an event to be judged as old in the absence of episodic information concerning its specific occurrence.

In contrast to the 'familiarity' account of the LPC proposed by Rugg (1990), Van Petten et al (1991) suggested that the LPC reflected episodic retrieval processes. They argued that the differences between the negative-going LPC repetition effect which they observed and the positive-going LPC repetition effect observed by Rugg (1990) reflected the varying demands on episodic memory imposed by the differing experimental tasks. Van Petten et al (1991) argued that in a task where only words repeat, the LDT reduces, at least in part, to one of episodic memory for repeating stimuli. Under this task description, the demands on episodic memory are primarily made when a word is repeated. Thus if the LPC reflects the operation of episodic memory then second presentations will be more positive going than first presentations - the findings reported by Rugg (1990).

In contrast , Van Petten et al (1991) argue that in their text reading experiment, the primary demands on episodic memory are made when a word is encountered for the first time since it is then that the meaning of the word will be retrieved. When a word is repeated in a passage of text, the meaning is more likely to still be in working memory, and therefore the likelihood of retrieval from episodic memory is less. Thus episodic retrieval processes will be greater on the first presentation and repetition will result in a negative-going shift in the LPC - the results observed by Van Petten et al (1991).

Besson and Kutas (1993) also advocated an episodic account of the LPC in which this component reflected the degree to which a sentence terminal word had been 'remembered', and more recently this account has gained support from the results of investigations of the modulations of ERPs in experiments on recognition memory. Wilding, Doyle and Rugg (1995) demonstrated that there was a large positive-going shift in the ERP in the region of the LPC only when subjects could correctly categorise a word as being new or repeated and, for repeated words, could also identify whether they had been seen or heard on their first presentation. That modulations of the LPC were oberved only when such contextual information was available suggests this component reflects recollection of specific episodes because only recollection is thought to supply information about the context in which an item was encountered (see also Paller, Kutas, & McIsaac, 1995; Smith, 1993).

2.5 Modulations of the N400 and their interpretation

There are a number of reviews which have been mainly concerned with the functional significance of the N400 (Fischler & Raney, 1991; Holcomb & Osterhout, 1995; Kutas & Van Petten, 1988), but I will briefly describe the initial demonstrations of modulations of the N400 component and two opposing accounts of its functional role.

The modulation of the N400 component was first demonstrated by Kutas and Hillyard (1980; 1984). They presented subjects with sentence frames such as:

'He spread the warm bread with ...'

These sentence frames were completed with words which were either semantically congruous (e.g. 'butter') or semantically incongruous (e.g. 'socks') with the frame, or with words which were physically incongruous (presented in a different sized font). Kutas and Hillyard had predicted that in the conditions in which the sentence frame was completed by an unexpected stimulus they would see a modulation of the P3 component.

In the case of the semantically incongruent sentence ending only, rather than a modulation of the P3, Kutas and Hillyard (1980) observed a negative-going deflection of the waveform which peaked at around 400 ms. In the light of the apparent specificity of this N400 component to semantic manipulations, Kutas and Hillyard (1980) proposed that it reflected an interruption to the normal processing of meaning which occurs during the reading of a sentence. This 'semantic hypothesis' received some support with a further demonstration of the sensitivity of the region of the waveform around 400 ms to semantic, but not grammatical, incongruency (Kutas & Hillyard, 1983, but see; Muente, Heinze, & Mangun, 1993, and Rosler, Putz, Friederici, & Hahne, 1993).

Kutas and Hillyard (1984) presented subjects with sentence frames which were completed by words which varied in 'cloze probability' (Taylor, 1953). Cloze probability describes the likelihood that, given a particular sentence frame, a subject would complete the sentence with a particular word. The more likely a particular word would be used to complete a sentence the higher its cloze probability. Kutas and Hillyard (1984) demonstrated that the amplitude of the

N400 varies inversely with cloze probability and argued that the amplitude of the N400 was determined by semantic 'expectancy' rather than incongruity *per se*.

Critically however, Kutas and Hillyard (1984) also demonstrated that the amplitude of the N400 was attenuated not only by words which were of high cloze probability, but also by words which, although themselves of low cloze probability, were semantically related to high cloze probability words. Thus the sentence frame

'He liked lemon and sugar in his ...'

could be completed not only by its best completion (i.e. 'tea') but also by a semantic associate of the best completiton (e.g. 'coffee') and an attenuation of the amplitude of the N400 would result. Kutas and Hillyard (1984) suggested that the N400 reflected a spread of activation between semantically related words, and that the N400 was an electrophysiological indicator of automatic lexical and/or semantic processing and was specific to linguistic or potentially linguistic materials (see also Kutas, Lindamood, & Hillyard, 1984). Consistent with this proposal, Besson and Macar (1987) showed that an N400 was not generated when any expectation of a forthcoming experimental item was not realized. They presented subjects with simple musical scales or simple tunes, and recorded ERPs to the final note which either did or did not complete the scale or tune appropriately. In these circumstances neither an N400 nor a 'congruity' effect was observed.

Van Petten and Kutas (1990) reported that the effects of semantic congruity and frequency had interactive effects on the amplitude of N400, whilst Van Petten et al (1991) argued that frequency and repetition have similar effects on the amplitude of the N400 as would be expected if they exerted their effects through a common mechanism. Besson et al (1992) suggest that the interaction between congruity and repetition 'can be interpreted in like manner' (p. 144) to the interaction between repetition and frequency; that is they reflect a process of lexical identification. Van Petten et al (1991) argued that 'Our knowledge of the N400 to date characterises it as a rather ubiquitous marker of lexical processing' (p. 140). Besson and Kutas (1993) also argued that the modulations of the N400 reflect 'language-specific knowledge', whilst Holcomb and Neville (1990) have argued that the amplitude of the N400 elicited by a word reflects the degree to which a lexical representation of that word is activated prior to its presentation.

This 'lexical' hypothesis can be contrasted with a 'contextual integration' hypothsis first proposed by Halgren and Smith (1987) and developed by Rugg (1990, see also Rugg & Doyle, 1994). Under this hypothesis modulations of the N400 reflect the ease or extent to which the representation of an item can be integrated into a representation of the context in which it occured. N400 amplitude is modulated by any variable that affects this process of integration. Repetition effects arise not because there is a change in the representation of a particular item but because the contextual integration of an item is easier, or needs to be done to a lesser extent, as a result of its prior presentation.

The relative merits of these two different accounts of N400 effects will form the backdrop to the discussion of studies which have investigated the way in which N400 and repetition effects can be modulated in response to a variety of experimental variables. I will begin by describing some of the studies which have investigated the sensitivity of the N400 component to semantic priming manipulations.

2.6 The modulation of ERPs by semantic similarity

The apparent sensitivity of the N400 component to semantic processes as demonstrated by Kutas and Hillyard (1980; 1984) led to a number of reports of the sensitivity of ERPs to semantic priming in paradigms similar to those used to investigate behavioural priming effects (e.g. Bentin, McCarthy, & Wood, 1985; Polich, 1985; Rugg, 1985b; 1987).

As already noted, Rugg (1985b; 1987) found reliable effects of semantic priming in the LDT in both of his studies. These ERP modulations however did not have the centro-parietal maximum, and right-hemisphere-greater-than-left pattern found in the earlier reports of modulations of the N400. In the Rugg (1985b) study the semantic priming effects were evenly distributed over the head, whilst in the Rugg (1987) study they had a frontal maximum, and were greater over the left hemisphere than over the right. This difference in distribution led Rugg (1987) to argue that modulation of the N400 was not a necessary consequence of the manipulation of semantic processing. Bentin et al (1985) also found reliable semantic priming effects. These effects were greatest at centro-parietal midline sites but were equally large over the left as over the right hemisphere. Bentin et al (1985) did not identify this modulation of the ERP as a modulation of the N400 component, but suggested it could equally be seen as a modulation of an earlier N200 component thought to be sensitive to mismatches between stimuli (see Ritter, Ford, Gaillard, Harter, Kutas, Naatanen, et al., 1984).

Holcomb (1988) investigated the degree to which ERP semantic priming effects were a consequence of processing which was automatic (Kutas, et al., 1984) or processing which was under conscious control. Holcomb (1988) varied the instructions given to subjects and the proportion of trials on which the prime and probe words were related. Probe words on a LDT were preceded either by a semantically related word, by a semantically unrelated word or by a blank screen. In the 'automatic' condition, 12.5% of target words were preceded by related words, whilst in the 'attentional' condition 50% of target words were preceded by related words. Holcomb predicted that if the effects on the N400 deflection were due to automatic spreading activation alone, then the automatic vs attentional manipulation should have no effect on the size of the N400 deflection. Holcomb found a reliable positive-going shift in the ERP at approximately 400 msec in both the attentional and automatic conditions, but this modulation was greater in the attentional condition than in the automatic condition. As Holcomb notes, this result is inconsistent with the view that N400 is an index of a purely automatic semantic process. Indeed since there was little evidence that the priming effect in the automatic condition was uncontaminated by an attention-dependent processing of the prime stimulus, the more parsimonious conclusion is that the modulation of the N400 largely, if not entirely, reflects cognitive processes which are not automatic.

The degree to which N400 effects reflect automatic and controlled processing was also investigated by Boddy (1986) using a manipulation of SOA. Boddy (1986) found the amplitude of a component which peaked at 340 ms and which he identified as the N2 component was inversely proportional to the semantic relationship between prime and probe words at SOAs of between 200 ms and 1000 ms. For the methodological reasons noted by Anderson and Holcomb (1995), the results reported by Boddy (1986) are difficult to interpret. Anderson and Holcomb (1995) also investigated the response of ERP semantic priming effects to variations in SOA. They found a positive-going shift in the ERP around 400 ms for semantically related word pairs compared to unrelated word pairs at SOAs of 0, 200 and 800 ms. The size and duration of these effects varied across SOA and Anderson and Holcomb (1995) proposed that these differences could be attributed to differences in the degree to which processes of automatic spreading activation between lexical entries, and subsequent attentional processes were elicited at the different SOAs.

Brown and Hagoort (1993) investigated the effects of masked semantic priming on ERPs. Subjects performed a LDT in which the critical words were preceded by either an associatively related or an unrelated word. In one block the prime words were unmasked so that they could be clearly identified whilst in a second block the prime words were pattern-masked so as to prevent identification. Brown and Hagoort (1993) found reliable priming effects on reaction times in both the masked and unmasked conditions, with the unmasked priming effect being considerably greater than that in the masked condition. A positive going shift in the ERP occurred between approximately 200 and 500 msec post-stimulus for related targets compared to unrelated targets in the unmasked priming condition, but this modulation was not seen in the masked priming condition. Brown and Hagoort argued that if the behavioural masked priming effect was evidence for an automatic process, then the absence of a modulation of the N400 under masked priming conditions suggests that modulations of N400 do not reflect automatic processing.

This interpretation can be questioned on two grounds. Firstly, the presence of visual masking is confounded with changes in the display duration of the probe item. Thus whilst the unmasked primes were displayed for some 230 ms, the masked primes were displayed for only 40 ms. Secondly, Brown and Hagoort's interpretation of their results rests on the acceptance of a null effect in the masked ERP priming condition compared to the reliable RT priming effects. As Brown and Hagoort acknowledge, this comparison assumes that the RT and ERP measures have an equally good signal-to-noise ratio, such that small effects are equally likely to be observed with each measure. Although Brown and Hagoort argue that this is a reasonable assumption, the contrary case can also be convincingly made. Notwithstanding these concerns, these findings constitute evidence against the view that modulations of the N400 reflect lexical processes engaged automatically during word recognition. Brown and Hagoort (1993) suggest that the processes reflected by the N400 were concerned with the integration of a word's meaning into the context in which it occurs, and these processes were attention-dependent.

Kutas and Hillyard (1989) were also concerned with the supposed automaticity of the processes underlying the N400. In their study word pairs were presented which were highly, moderately or not related and subjects were required to decide whether or not a letter presented subsequently had been present in both the words. Large effects of degree of semantic association were seen in the amplitude of the N400 despite the fact that this task did not require semantic processing. However these semantic priming effects were smaller than those found when explicit attention to the semantic relationship was encouraged. Kutas and Hillyard (1989) claimed that 'there is an automatic component to semantic priming that is reflected in the N400 elicited in this word pair task, but ... N400 amplitude can be modulated by attentional mechanisms as well' (p.45). Nevertheless, the validity of this conclusion can be questioned since subjects may have attended to the semantic properties of the words even when not encouraged to do so.

McCarthy and Nobre (1993) and Bentin, Kutas and Hillyard (1995) have reported the effects of manipulating attention on the modulation of the N400 by semantic priming. McCarthy and Nobre (1993) found that modulations of the N400 were found in a semantic priming experiment only when the prime and probe words were presented in a spatial location to which subjects were attending. Bentin et al (1995) found that in a dichotic listening task, only when semantically related words were presented to the attended ear did a reliable modulation of the N400 result. This was in spite of behavioural evidence that unattended words were semantically processed, although not in a manner which allowed them to be explicitly remembered. Bentin et al (1995) argued that although the generation of the N400 did not require conscious attention, modulations of the N400 as a result of semantic priming were dependent upon subjects being aware of the relationship between prime and probe items.

A number of other studies have used a semantic priming paradigm in attempting to identify the functional significance of modulations of the N400. Holcomb (1993) has investigated the effects of stimulus degradation on the magnitude of modulations of the N400 resulting from semantic priming in a LDT. Stimulus degradation was chosen since this variable has been argued to particularly affect processes operating at a lexical level (see Section 1.4). Holcomb (1993) argued that if stimulus degradation does indeed exert its influence at a lexical level, and if the N400 reflects lexical processing, then the modulation of N400 may be expected to differ when stimuli are degraded compared to when they are readily identifiable. In two experiments, Holcomb (1993) found that semantic priming resulted in a reliable modulation of the N400 with a centro-parietal maximum, and which was greater over the right than the left hemisphere. However this modulation was equivalent for intact and degraded stimuli, although the peak latency of the N400 was delayed in the degraded condition. Holcomb (1993) interpreted the delay in the N400 latency brought about by degradation, together with the absence of an effect of degradation on the amplitude of the N400 modulation, to mean that the process reflected by modulations of the N400 amplitude occurred subsequently to that affected by stimulus degradation. Since, as noted above, degradation is thought to affect word-level processes, Holcomb (1993) proposed that modulations of the N400 amplitude reflected a process of contextual integration, a process which must be consciously engaged.

Nigam, Hoffman and Simons (1992) also argued that modulations of the N400 did not reflect lexical processing. Nigam et al (1992) investigated the effects of completing a sentence not only with congruous or anomalous words, but also with pictures whose names formed congruent or anomalous endings to a sentence. They found that the differences in the N400 between congruous and anomalous sentence completions were equivalent whether the sentences were completed with words or with pictures. Nigam et al (1992) proposed a 'conceptual' hypothesis of the N400 in which modulations of the N400 reflect processing in an amodal conceptual system to which both words and pictures have access. As noted by Nigam et al (1992), this hypothesis sits uneasily with apparent demonstrations of N400-like effects as a result of phonological and orthographic similarity between experimental items (see Section 2.13). Furthermore the report by Holcomb and Neville (1990) that there are topographic differences between the modulations of the N400 resulting from semantic priming in the visual modality and those in the auditory modalities also raises questions over whether modulations of the N400 reflect processing in an amodal conceptual system.

The experiments described in this section demonstrate the sensitivity of the N400 to semantic similarity between experimental items. Although the N400 may be the 'primary index of semantic processing in ERP research' (Curran, et al., 1993 p.207), as will become evident it is unlikely that semantic similarity is a necessary condition for modulations of the N400 to be observed. The results of these studies which have attempted to manipulate the degree to which semantic priming effects were a reflection of automatic processes have not been conclusive. Both Holcomb (1988) and Kutas and Hillyard (1989) have suggested that automatic and intentional processes are both reflected in the modulation of the N400. However in each case the modulations of the N400 may have reflected the strategic deployment by subjects of their knowledge of the semantic relationship between items. In the one study that most likely prevented the use of non-automatic processes (Brown & Hagoort, 1993), the N400 component was not modulated by semantic priming. Studies which have manipulated the extent to which a primed item is the focus of attention have also failed to observe modulations of the N400.

These results suggest that modulations of the N400 largely, if not entirely, reflect non-automatic processes.

2.7 The ERP repetition effect and inter-item lag

As discussed in Section 1.7, inter-item lag has been one experimental variable which has enabled the behavioural repetition effect to be fractionated into possibly three different components. Repetition lag has also been used in studies of ERP repetition effects with the same aim.

Nagy and Rugg (1989) compared, in separate experiments, repetition effects at lag 0 with repetition effects at lag 6, and repetition effects at lag 6 with repetition effects at lag 19. In both experiments, Nagy and Rugg (1989) found reliable repetition effects in the region of the N400 and the LPC which were not differentiated by repetition lag. Although Nagy and Rugg (1989) expressed concern over the power of their experiments to detect differences in the magnitude of the effects at the various lags, any diminution in the size of the effects between the lag 0 and lag 19 conditions was small. The pattern of results contrasts somewhat with the pattern of results seen with behavioural measures in which there is a sharp decrease in the magnitude of the effects as lag is increased from 0 to 2 or more items and threafter remains constant.

Bentin and Peled (1990) examined the effects on the ERP word repetition effect of increasing repetition lag from 0 to 15 intervening items. Words were repeated in two different tasks; firstly, a LDT and secondly the study phase of a memory test. Repetition at lag 0 produced large and equivalent effects in the two tasks, but only in the LDT was there a repetition effect at lag 15. This absence of a lag 15 repetition effect in the memorise task occurred despite subjects performing at a high level in a subsequent test of recognition memory. Bentin and Peled (1990) argued that the failure to observe a repetition effect at lag 15 could not have been a result of subjects forgetting the word between encounters. Rather they argued that the absence of the ERP repetition effect in the memorise task at lag 15 was because the 'memorise' task, unlike the LDT, required no decision to be made to the critical word.

Closely related to this 'decision-related' hypothesis is the possibility that repetition effects are generated because subjects retrieve an episodic memory of the response made on the previous encounter with a word. However Rugg, Brovedani and Doyle (1992) observed reliable repetition effects even when subjects made different responses to words presented for the first and second times. Furthermore, it is unclear how decision- or response-based accounts of ERP repetition effects deal with the findings of Van Petten et al (1991) that repetition effects can be obtained for words in text even when 20 or more words intervene between first and second presentation. Thus making a categorical response, whether that response be covert or overt, does not appear to be a necessary or a sufficient condition for the observation of repetition effects.

Karayanidis et al (1991) repeated words with either 0 or 4 words intervening between the first and second presentations. Karayanidis et al (1991) argued that the longer lag was sufficient for the short-lasting repetition effect, proposed to account for larger behavioural effects at lag 0, to have decayed away. At both lags the effects of repetition were reliable, but the effects of repetition at lag 4 were somewhat smaller post- 400 ms than were the effects of immediate repetition. Karayanidis et al (1991) suggested that the smaller repetition effect at lag 4 was in accord with the numerically smaller repetition effects at longer lags reported by Nagy and Rugg (1989). Although Karayanidis et al (1991) discuss the degree to which there results can be seen as being consistent with a view of two components reflecting lexical and episodic effects of word repetition, they reject a simple identification of ERP components with putative cognitive processes. Rather they suggest that the amplitude of any ERP component may reflect the 'activation' of the eliciting item, with this activation accruing from both episodic and non-episodic sources. Further evidence against the view that ERP repetition effects can easily be identified with the proposed components underlying behavioural repetition effects was supplied by Rugg (1990). In that study, the ERP repetition effects, at least in the region of the N400, do not survive an interval of some 15 minutes between first and second presentations.

To summarise these investigations of the effects of variations of inter-item lag on the ERP repetition effect: The persistence of the ERP repetition effects in the region of the N400 up to lags of 19 intervening items suggests that modulations of this component do not reflect the same processes responsible for the larger behavioural repetition effects at lag 0 compared to longer lags. Nor can such effects be seen as reflecting the operation of a short-term or working memory which is generally thought to have a capacity of only approximately 7 items. On the other hand the absence of repetition effects on the N400 after periods of approximately 15 minutes suggests that this ERP effect does not reflect the same set of processes underlying the more persistent behavioural repetition effects. Although the repetition effects in the region of the LPC do persist over this longer interval, this component appears to be linked with processes of recollection which are also thought to be distinct from those responsible for long term behavioural repetition effects.

2.8 ERPs and the repetition of non-words

The functional locus of the processes reflected in the modulation of the N400 have also been investigated by means of the repetition of non-words. The rationale for these studies has been similar to that underlying the study of the behavioural effects of non-word repetition; if repetition effects are mediated by lexical representations then they should not be found with non-words. Such a rationale is equally open to the counter-arguments discussed in Section 1.6.1 concerning the partial activation of lexical representations by orthographically legal non-words.

As a part of his investigation into repetition and semantic priming effects, Rugg (1987) compared ERPs elicited by repeated and unrepeated orthographically legal non-words. There were two main differences. Firstly at about 200 ms repetition resulted in a small negative-going shift in the ERP, and, secondly, from approximately 400 ms post-stimulus onset, ERPs elicited by repeated non-words were more positive-going than were ERPs elicited by unrepeated non-words. Whilst the earlier effect was similar to that which had been observed when words were repeated, the onset of the later effect was delayed compared to the equivalent effect with words. Rugg considered two interpretations of the differences in the late effect for words and non-words. Firstly the word repetition effect could have reflected both a lexical process and an episodic process, with only the latter being engaged by non-word repetition. Secondly, both word and non-word repetition could have engaged the same process(es) but, because of the availability of a pre-existing representation, words did so more quickly than did non-words.

Rugg and Nagy (1987) also investigated the nature of the processes engaged by non-word repetition. They repeated orthographically illegal as well as orthographically legal non-words. Illegal non-words, being novel combinations of letters, should not have been encountered previously by subjects and hence subjects were unlikely to have pre-existing representations of them. Any evidence of repetition effects with such stimuli was likely due to processes specific to the previous episodic encounter. Rugg and Nagy (1987) found that, whilst orthographically legal non-words resulted in repetition effects which resembled those found with words, the repetition of orthographically illegal non-words had essentially no effect on the ERP.

Rugg and Nagy (1987) considered that the non-word effects may have been generated either as a result of the partial activation of lexical, and possibly semantic, representations by the word-like non-words. Alternatively they suggested that a unitised code may have been generated for the non-word as a result of the operation of sub-lexical orthographic to phonological mappings. Such unitised codes may allow further elaborative processes to be applied. The generation of such an internally consistent unitary phonological code would not be possible for orthographically illegal non-words (see also Rugg & Doyle, 1994). Under this account, ERP non-word repetition effects can be generated without the mediation of processes associated with the meanings of words.

The nature of the mechanisms underlying word and non-word ERP repetition effects was also the subject of two studies by Rugg and his colleagues. Rugg, Doyle and Melan (1993) reported the effects of within- and across-modality repetition effects for words in a LDT, whilst Rugg, Doyle and Wells (1995) compared the same repetition conditions in a semantic categorisation task, as well as the effects of the repetition of non-words in the LDT. In both studies 6 items intervened between prime and probe. Although ERPs were recorded when the probe item was in the visual or in the auditory modality, only the conditions in which the probe item was presented visually are relevant here. In both studies, within-modality repetition gave rise to a typical ERP repetition effect for words. In the across-modality word repetition condition, although there was also a positive-going shift in the ERP, this effect onset some 150 ms later, and had a more posterior distribution over the head, than did the within-modality effect.

Critically, Rugg et al (1995) found a somewhat similar pattern of effects with non-word repetition. Only the onset latency of the repetition effects clearly distinguished the word and non-word effects with the non-word effects onsetting some 200 ms later. However this delay was equally true of the within- and across-modality non-word repetition conditions. Rugg et al (1995) argued, as had Rugg et al (1993), that the early part of the within-modality effect reflected orthographic processing, whilst the across-modality effect reflected phonological processing. The delay in the onset of the effects with non-words may reflect differences in the availability of unitised codes for real words and non-words.

Although not investigating repetition effects, a difference in processing between legal and illegal non-words was also demononstrated by Holcomb and Neville (1990). They showed that in both visual and auditory modalities, legal non-words elicited a prominent N400 component. However in neither modality did the presentation of an illegal non-word elicit an N400 component. The contrast between effects seen with legal and illegal non-words suggests that demonstrations of ERP repetition effects are not dependent upon a lexical representation of a repeating item. However demonstrations of repetition effects may depend upon using experimental items for which it is possible to generate a unitised representation of an experimental item. The absence of repetition effects with orthographically illegal non-words suggests that repetition effects cannot be elicited by any repeating stimulus (Rugg & Nagy, 1987, see also Thomas, 1992).

2.9 ERP repetition effects and manipulations of task and attention

In this section I describe a number of studies which are loosely linked in that they vary the way in which experimental items are processed either by by manipulations of task or instructions. Rugg and Nagy (1987) had suggested that one reason why orthographically illegal non-words had failed to produce a modulation of the N400 was because these items could be identified as non-words on the basis of a 'shallow' analysis of their visual form. They suggested that modulations of the N400 may depend upon 'deeper' processing of the critical items.

Rugg, Furda and Lorist (1988) repeated words in upper-case letters whilst subjects identified occasional targets. Target items could either be identified on the basis of their physical form (i.e. lower-case words), their lexical status (i.e. non-words) or their semantic status (i.e. animal names). Rugg et al (1988) argued that this manipulation of task would allow an assessment of the effects on the N400 of variations in the depth of processing accorded the experimental items. Rugg et al (1988) found that there was indeed a difference in the nature of the repetition effect between the three tasks. Although each task produced a repetition effect, in the case-detection task this was small, and was both topographically and temporally restricted. In contrast, in the other two tasks word repetition resulted in relatively large, topographically widespread and persistent repetition effects. Rugg et al (1988) suggested that this result was more consistent with a post-lexical account of ERP repetition effects than a lexical account and that the ERP repetition effect may be more relevant to general issues of memory function rather than to processes involved in word recognition.

Bentin and McCarthy (1994) investigated the effects of item repetition on ERPs in five different tasks which varied to the extent that they required the engagement of semantic and/or lexical processes. Bentin and McCarthy (1994) observed ERP repetition effects in the LDT, as well as in a face recognition task, and a letter search task, but not in tasks which required subjects to discriminate between faces and non-faces, or between words and numbers. Bentin and McCarthy (1994) argued that the latter two tasks involved a relatively superficial categorisation which did not require consultation of semantic memory. Only when semantic processing was involved would an N400 be generated. Repetition attenuated this N400 because semantic processing would be attenuated when the item was recognised as old and the decision and response which had been made on its previous occurrence were recalled.

McCarthy and Nobre (1993) and Otten et al (1993) manipulated the degree to which subjects attended to a clearly visible repeating word. McCarthy and Nobre (1993) presented words vertically in either the left or right visual field. There was a reliable positive-going shift in the ERP when both words were presented in a visual field to which subjects were attending, but little modulation of the ERP as a result of word repetition in an unattended visual field. Because the ERP effect depended on selective attention, McCarthy and Nobre (1993) argued that it did not reflect the operation of automatic processes. Otten et al (1993) presented words and non-words in their normal orientation. Selective attention was manipulated either by the colour in which a word was presented (experiment 1) or by both colour and a spatial cue (experiment 2). In both experiments there was a positive-going ERP repetition effect when both words were attended. In contrast when both words were unattended there was a negative-going shift in the ERP. The functional significance of this 'negative repetition effect' remains to be determined. Otten et al (1993) concluded that the more typical positive-going repetition effect could only be observed when both encounters with a word were the focus of selective attention.

These studies suggest that whenever the demands of an experimental task mean that a word is processed superficially, then the positive-going shift in the ERP consequent upon item repetition is markedly reduced. This superficial processing may be induced by the particular task which the subject is asked to perform, or by a manipulation of attention. The sensitivity of the ERP repetition effect to selective attention and depth of processing suggests that the effect largely depends upon non-automatic processing.

2.10 ERP repetition effects and manipulations of context

The claim that modulations of the N400 as a result of item repetition reflect post-identification processes which integrate an identified item into a representation of the context in which it occurs was the focus of the study by Rugg et al (1994). The results of the study by Besson and Kutas (1993) are also relevant to this issue.

Rugg et al (1994) presented subjects with word pairs and required them to make a lexical decision to each word (experiment 1) or to decide whether the two words were semantically related (experiments 2 ,3 and 4). In the 'Uncrossed' condition a word was paired with the same word on first and second presentations. In the 'Crossed' condition, a word was paired with a different word on its second presentation than it had been on its first presentation. Rugg et al (1994) argued that this change in word pairing constituted a change in 'local context'. Rugg et al (1994) predicted that if the N400 was sensitive to processes of contextual integration then there should be no or little modulation of the N400 in the 'crossed' condition. This was because in that condition the context in which a word was presented changed between presentations. Consequently the amount of processing required to integrate this repeated word into a new context would be similar to that required to integrate a word being seen for the first time into its context. Only when a word was repeated in the same context (i.e. the uncrossed condition) would there be an attenuation of the N400. This prediction was not fulfilled. The positive-going shift in the ERP was as great in the crossed condition as in the uncrossed condition. Although it is possible that the manipulation of context used by Rugg et al (1994) was not strong enough to affect the amplitude of the N400, the results of their study constitute *prima facie* evidence against a contextual integration account of the N400.

In an additional experiment Rugg et al (1994) found that ERPs elicited by a word pair consisting of one repeated word and one new word were no more positive-going than ERPs elicited by a pair of words consisting of two new words. The amplitude of the N400 seems therefore to be determined by the presence of a new word rather the presence of a repeated word, and suggests that the N400 is elicited maximally by any item which must be identified 'from scratch' irrespective of the context in which it occurs. This conclusion is supported by the results of a study by Kutas, Hillyard and Gazzanniga (1988). Subjects in their study listened to a sentence frame. Subsequently visually presented congruent and incongruent completions to the frame were presented to each visual field. Kutas et al (1988) found that the amplitude of the N400 elicited when the word presented to one visual field was congruent and the other was incongruent , was only marginally smaller than its amplitude when both words were incongruent. As with the result reported by Rugg et al (1994), this result suggests that the magnitude of the N400 asymptotes when one incongruent or new item is presented.

Besson and Kutas (1993) also investigated the context-specificity of the N400. They presented subjects with a sentence 'frame' followed by a word to complete the sentence, recording ERPs elicited by this completing word. A large attenuation of the amplitude of the N400 was observed when the whole sentence was repeated but not when the final word was repeated with a different sentence frame, or when the sentence frame was repeated with a different final word.

Besson and Kutas (1993) claim that this result demonstrates unequivocally that the attenuation of the N400 depends upon exact repetition, but there are two aspects of their study which mean that this conclusion must be questioned. Firstly, subjects were asked to memorise the final word of the sentence for a subsequent cued-recall test. As Besson and Kutas (1993) acknowledge, it is uncertain if the same pattern of effects would be found when subjects were not attempting to explicitly remember the final word of the sentence. Secondly, as noted by Rugg et al (1994), Besson and Kutas (1993) did not include a condition in which both sentence context and final word had previously been encountered but on separate experimental trials. Only a comparison of this condition with the exact repetition condition could confirm the necessity of conjoint repetition of sentence context and final word in modulating the N400, rather than the repetition of each part of the sentence *per se*.

The results of studies relevant to the evaluation of a contextual integration account of modulations of the N400 have been inconsistent. This inconsistency may reflect differences in materials (sentences vs word pairs) and/or other differences in experimental task (e.g. the extent to which they encourage the use of explicit memory). Nonetheless the direct test of the contextual integration hypothesis reported by Rugg et al (1994) failed to support the hypothesis.

2.11 The modulation of ERPs by formal similarity

As described in Section 2.8, comparisons of the effects of within- and across- modality repetition indicate a role for orthographic and phonological representations in the generation of ERP repetition effects. The results of a number of earlier studies also indicated that ERPs may be sensitive to formal similarity between prime and probe items. Rugg (1984; 1985a; Rugg & Barrett, 1987) has reported a series of experiments which have demonstrated that ERPs are sensitive to orthographic and phonological similarity between words in a rhyme-judgement task. Thus Rugg (1984) found that when either a word or a non-word had been preceded by a word that rhymed with it (e.g. 'paws' - 'gauze'; 'sighs' - 'mize'), there was an attenuation of a negative-going component of the ERP that peaked at approximately 450 ms, with this effect being greater over the right hemisphere than over the left. Rugg and Barrett (1987) considered that although these ERP effects were seen with orthographically different words such as 'paws' and 'gauze', they might nonetheless reflect orthographic priming. This was because a given word will rhyme only with words having a limited number of orthographic patterns. They found that an N450 component was significantly attenuated by either phonological or orthographic similarity. This attenuation was markedly asymmetric, being considerably larger over the right hemisphere than over the left. There were some indications that the two types of similarity had additive effects. Rugg and Barrett (1987) argued that similarity on either orthographic or phonological dimensions was sufficient to result in an attenuation of the N400 component.

The effects of the orthographic and phonological similarity of members of a word pair on a negative ERP component were also investigated by Kramer and Donchin (1987, see also Polich, McCarthy, Wang, & Donchin, 1983). Kramer and Donchin (1987) reported that the amplitude of this component was greatest for word pairs which were orthographically and phonologically dissimilar, least for pairs which were orthographically and phonologically similar and intermediate in magnitude for pairs which were similar on one dimension but dissimilar on the other.

Rugg and Barrett (1987) argued that the N450 component was closely related to the N400 component, with the N400 being sensitive to similarity of meaning and the N450 being sensitive to similarity of form. The relationship between the N400 and N450 components were also investigated by Perez-Abalo, Rodriguez, Bobes, Gutierrez and Valdes-Sosa (1994). They found that the latency of the onsets of the two components was dependent upon the modality in which words were presented. Thus in the visual modality, the onset of the N400 in a semantic matching task preceded the onset of the N450 in a phonological (rhyme) matching task, but this ordering was reversed when words were presented in the auditory modality.

Praamstra and Stegeman (1993, see also Praamstra, Meyer, & Levelt, 1994) did not distinguish between N450 and N400 components but rather identified the phonologically sensitive negative-going component identified by Rugg as the N400. Praamstra and Stegeman (1993) showed that phonological similarity between spoken words in the LDT resulted in the modulation of the N400. Praamstra and Stegeman (1993) suggest that the modulation of the N400 in a task which does not require the appreciation of phonological similarity supports the claim that modulations of the auditory N400 reflect, at least in part, automatic processes. However since there is no reason to suppose that subjects did not use the phonological similarity between items as an aid to performance in the LDT, this claim should be treated with caution.

2.12 Modulations of the N400 and morphological priming

The functional significance of the N400 remains unclear. Although it may be sensitive to semantic processing, the results of studies using formally similar words, and of studies using non-words, makes it unlikely that the N400 can be considered to be a specific marker of semantic processing. Attempts to tie modulations of the N400 to variations in automatic lexical processing have not been successful. The results of studies using masked priming and stimulus degradation techniques have not supported a lexical locus for modulations of the N400. Neither does the similarity of word and non-word ERP repetition effects, both within- and across-modality, support a lexical locus for N400 effects. It is possible such similarity may be explained as a result of the partial activation of lexical representations by orthographically legal non-words, but, given the other evidence against a lexical hypothesis, this account seems unparsimonious.

On the other hand little or no direct evidence is available in support of the non-lexical contextual integration view of N400 effects. The results of the one direct test of this hypothesis failed to support it. Thus, although modulations of the N400 appear to reflect processes which depend upon conscious attention, the nature of such processes remains unclear.

Although modulations of the N400 do not directly reflect lexical processing, it is nonetheless possible that they may reflect processes which are sensitive to the outcome of such processing. Thus, for example, the differences between within- and across-modal priming reported by Rugg et al (1993; 1995) may reveal differences in the timing of lexical processing in orthographic and phonological domains indirectly because a subsequent process which is reflected in the ERP takes the output of a lexical processor as its input. If this is the case then ERPs may be of use in investigating the representation of morphologically complex words even if ERPs do not directly reflect lexical processes.

Given that regularly morphologically related words are similar to one another with respect to their meaning and their form, the studies reviewed above demonstrating the sensitivity of ERPs to formal and semantic similarity are particularly relevant. Morphological priming may be expected to produce modulations of the ERP if only because morphologically related words, or at least the ones used in the present study, are also semantically and formally related. For a conclusion that ERPs are sensitive to morphological relationships to be upheld requires that any ERP morphological priming effect differs from a formal or a semantic priming effect when the degree of formal or semantic similarity between prime and probe words is equivalent in the two priming conditions. In each of the first three experiments described here the sensitivity of ERPs to morphological similarity between words is investigated. Experiment 1A investigates whether ERPs are sensitive to morphological relationships between words, and if so whether this effect can be accounted for in terms of their formal similarity.

Chapter 3

Experiment 1A

A comparison of ERPs elicited by word repetition, formal and derivational priming at lag 0.

3.0 Introduction

Experiment 1A investigated whether ERPs are sensitive to a relationship of derivational morphology between words. Specifically, the effects of preceding a word by its derivational root form were compared with the effects of word repetition.

The comparison of such a derivational priming condition with the repetition condition was considered an appropriate initial contrast. Behavioural studies of derivational priming have used the similarity of derivational priming to repetition priming, in terms of its magnitude and persistence, in order to distinguish it from the effects of orthographic, phonological, and semantic, similarity.

In words which are regularly derivationally related, morphological, semantic and formal similarity between the words is confounded. This confounding is a breach of what is generally an arbitrary relationship between a word's form and its meaning. Consequently, any priming effects resulting from the pairing of derivationally related words cannot be unambiguously attributed to their morphological relationship. This problem can be overcome in two ways. Firstly, the confounding of morphological and other properties of words can be avoided by the use of irregularly related words (e.g. buy - bought) in which the overlap in the formal properties of the morphologically related words is minimised. Secondly, the priming effects seen with derivationally related words can be compared with those of words which are as formally similar to each other as are the derivationally related words, but which share no morphological relationship. Thus the members of the word pair 'scan' - 'scandal' are as formally similar to each other as are the members of the pair 'ruin' - 'ruinous'. However whilst the words 'ruin' and 'ruinous' are derivational relations, the words 'scan' and 'scandal' are not and, their formal similarity is an etymological accident.

Whilst studies of morphological relationships have not always included such control conditions, those that have done so (e.g. Drews & Zwitserlood, 1995; Fowler, et al., 1985), have either not attempted to control for both formal and semantic similarity between words, or have not done so in the same experiment. In this initial experiment, the ERP modulations resulting from repeating a word or from preceding it with a derivational relative are compared with the ERP consequences of formal priming. If the formally related pairs are as orthographically and phonologically similar to one another as are the derivationally related pairs, then any differences between the derivational priming condition and the formal priming condition may be attributed to either the morphological or semantic similarity between the two words. Whether such modulations of the ERP are a result of semantic or morphological similarity could then be the subject of further investigation. On the other hand, should no differences between the derivational and formal priming conditions be apparent, this would indicate that any effects which were evident would likely be a result of the formal similarity between the words.

In Experiment 1A, words were either repeated or followed by derivationally and formally related words at a lag of 0 intervening items. Furthermore the majority of words presented to subjects were either repeated, or followed by a formally or derivationally related word, or were such repeated or formally primed words. Also probe words were chosen which had a relatively low frequency of occurrence (Rugg, 1990). Because of constraints on stimulus selection, the first member of a formally related pair had, on average, a higher frequency of occurrence than did the probe word with which it was paired. Thus whilst repetition effects resulted from the presentation of two low frequency words, the effects of formal similarity were assessed using a pair containing a slight frequency disparity. Since the significance of the prime and probe word frequencies in the modulation of ERPs is not known the importance of this difference between conditions is uncertain. Critically however, the ERPs used to evaluate the repetition and formal priming efects were all elicited by probe words which were approximately equal in frequency in the formal and derivational conditions.

Short inter-item lags, a high density of primed items and low frequency words may all be expected to contribute to a robust ERP effect. However this effect may arise as a consequence of sub-lexical or lexical processing and/or of processing associated with conscious recollection of previously presented items. Once a robust priming effect has been demonstrated, then the conditions under which they are manifest, and the particular processes responsible can be the subject of further investigation.

3.1 General Procedure - Experiments 1A, 1B and 2

A number of features of the experimental paradigm, EEG recording parameters and stimulus display parameters were common to each of the first three experiments. These features will be described in this section, and will be referred to during the description of each of the experiments reported.

3.1.1 EEG Recording

EEG was recorded from 9 sites which were either sites defined by the International Ten-Twenty system (Jasper, 1958), or were sites the locations of which were determined relative to these standard locations. Electrodes were placed at Fz, Cz, Pz, and at locations 75% of the distance from Fz to F7 (left frontal, LF) and F8 (right frontal, RF), 75% of the distance from Cz to T3 (left temporal, LT) and T4 (right temporal, RT), and 75% of the distance from Pz to T5 (left parietal, LP) and T6 (right parietal, RP). The electrodes at these sites were referenced to linked electrodes on the mastoid processes. In addition, EOG was recorded bipolarly from electrodes placed adjacent to the outer canthus of the left eye and just above the right supra-orbital ridge. Inter-electrode impedances were maintained at or below 5 KΩ. All channels were recorded with a bandwidth of 0.03-30 Hz (3 dB points). EEG was sampled every 4 ms for a period of 1024 ms, beginning 100 ms before stimulus onset. In experiments 1A and 1B, EEG was recorded with Ag/AgCl electrodes attached to the scalp using an adhesive (Collodion). In Experiment 2, EEG was recorded using tin electrodes embedded in an elasticated cap (Electro-Cap International Inc., Eaton, Ohio).

3.1.2 Procedure

After the attachment of the electrodes, subjects were seated in a dimly lit room, approximately 80 cm away from a monitor linked to an Amiga 2000 microcomputer. They were told that they would see a number of strings of letters appearing on the screen one by one. For each experiment subjects decided as quickly and as accurately as possible whether or not each letter string was a real word in English. Subjects were required to press a microswitch with the index finger of their right hand whenever they decided that the string of letters did not constitute a real English word.

Subjects were told that some of the strings of letters that they saw would occur more than once. They were also told such repetitions were incidental to the task they were to perform, and that they should make their decisions as quickly and as accurately as they could.

In addition to the task instructions, subjects were requested to remain as relaxed as possible for the duration of the experiment. They were also asked to attempt to blink only during those periods when the fixation point was visible on the screen. This was in order to minimise the number of trials in which the EEG recorded was contaminated with EOG and could not be used in the averaging process. The few subjects who had difficulty in controlling the timing of their blinks were encouraged to blink deliberately at the end of each trial and to refrain from blinking at other times.

Each trial began with a fixation point on the monitor. This fixation point consisted of an asterisk, and occupied the same location on the screen as would the second letter of the subsequent letter string. This fixation point remained on the screen until 100 ms prior to presentation of the letter string, at which point the screen was blanked and sampling of EEG began. The letter string was presented for 300 ms, and was followed by a period of 700 ms during which the screen was blank and in which the sampling period was completed. The fixation point then reappeared for the remainder of the trial. The total length of each trial was 3.21 s, of which the fixation point was visible for 2.11 s.

Stimuli were presented in upper case white letters on a black screen and presented a vertical angle of 0.5 degrees and a horizontal angle of between 1.0 degrees and 2.0 degrees.

3.1.3 Signal Averaging and Waveform Quantification

For each subject, average waveforms were formed for each of 6 experimental conditions. These experimental conditions consisted of, for each word type, the first presentation of words later repeated, repeated words, and words which had been partially primed. Thus, across subjects, because of the rotation of words around experimental conditions, waveforms in the three conditions for each word type were elicited by the same set of words.

For each each experimental condition and for each subject, mean amplitudes of waveforms recorded at midline and lateral electrodes were measured for each of three 200 ms wide epochs. The first epoch was between 200 and 400 ms post-stimulus onset, the second between 400 and 600 ms and the third between 600 and 800 ms post-stimulus onset . These three epochs coincide with intervals during which the pattern of ERPs recorded in the various experimental conditions appear to differ in a consistent manner in each of the experiments. The broadest possible epochs consistent with this pattern were selected so as to minimise the number of non-independent comparisons made. When they are informative, analyses on more restricted time intervals will be reported. In addition to these broad interval measures, mean amplitude measures were made around the N1 and P2 peaks. The latencies of these peaks were measured in the grand averaged waveform at Cz for each experimental condition and the peak latency of the respective component was taken to be the mean of these values. Mean amplitude was then measured over a 48 ms window centred on the nearest sampling point to this peak measure.

In addition to these measurements of the ERP for each condition and each subject, measurements were taken of the mean amplitude of the 'subtraction' or 'difference' waveforms for each condition for each subject. Subtraction waveforms were produced by subtracting, point-by-point, from the mean amplitude of the waveform elicited in each of the priming conditions, the mean amplitude of the waveform elicited in the corresponding first presentation condition. Thus for each subject there were four sets of subtraction waveforms; one set for each of the derivational partial, derivational repetition, formal partial and formal repetition priming conditions. Analysis of the subtraction waveforms allows the effect of the priming manipulation to be compared across experimental conditions even when there are differences in the gross morphology of the waveforms elicited in these different conditions.

These measurements of the subtraction waveforms were also rescaled using the procedure recommended by McCarthy and Wood (1985). McCarthy and Wood (1985) point out that the multiplicative manner in which signals are propagated to the scalp contravenes the additive assumptions underlying the ANOVA. This breach of the basic assumptions of the ANOVA means that interactions between experimental condition and electrode site can arise as a result of a difference, not in the location of the underlying generators, but in their strength. To address this problem, McCarthy and Wood (1985) proposed a rescaling method which proportionalises the mean amplitude of each condition relative to the range of the values for that that condition.

This procedure equates the rescaled mean amplitudes associated with each condition and allows interactions between experimental condition and electrode site to be more confidently ascribed to differences in the identity of the underlying generators.

3.1.4 Statistical Analysis

The statistical analysis of the measurements obtained consisted primarily of a number of repeated measures analyses of variance (ANOVAs). Prior to this however, a series of point-by-point t-tests were performed on the mean amplitudes of the subtraction waveforms. For each site in each experimental condition, an across-subject t-statistic was computed against the null hypothesis of no difference from baseline. As in Rugg (1987), the onset latency of an effect was defined as the latency from which at least 15 consecutive t-values were significant at the 5% level or better. Unless otherwise stated these latency values were measured at Cz, the site at which they tended to first become reliable. The onset latency values obtained by this method could be used to assess differences in the onset of priming effects in the various priming conditions.

Repeated measures ANOVAs were performed on the mean amplitudes of the non-subtracted waveforms, on the mean amplitudes of the subtraction waveforms and on the rescaled mean amplitudes of the subtraction waveforms. The nature and rationale for these analyses is given below.

3.1.4.1. ANOVA of mean amplitude measures of the non-subtracted waveforms

The mean amplitude measurements of the ERPs in each epoch measured were entered into repeated-measures ANOVAs, in which each site was taken as a separate observation. One disadvantage of this approach concerns the possible violation of the 'sphericity' assumption underlying the repeated measures ANOVA. This assumption requires that the covariance between each pair of measurements within the set of repeated measures is approximately equivalent. Although the repeated measures ANOVA is tolerant of minor violations of the sphericity assumption (see Winer, 1971 p.522), it is likely that when used in conjunction with mean amplitude measurements of ERPs, such violations are more substantial. This is because the covariance of measurements derived from electrodes which are geographically close is likely to be greater than is the covariance of measurements derived from electrodes which are geographically more distant. Such inhomogeneity of co-variance can be compensated for by using the procedure proposed by Greenhouse and Geisser (1959 cited in Winer, 1971, p.523). This procedure involves the adjustment of the degrees of freedom of the relevant F ratio by ε, a measure of the degree to which the co-variance assumptions underlying the repeated measures ANOVA are not met. In the descriptions of the ANOVAs performed, the uncorrected degrees of freedom will be reported, together with the F ratio, probability level and the value of ε derived from the Geisser-Greenhouse procedure.

Repeated measure ANOVAs on the mean amplitude measures of the non-subtracted ERPs were performed to determine the reliability of the repetition and partial priming effects irrespective of any differences between them, or between the effects of word type. These analyses are necessary since the interpretation of the presence or absence of differences between the various priming conditions is dependent upon the reliability of each of the individual effects.

The first set of ANOVAs assessed the reliability of the partial priming effects. These ANOVAs, in addition to the topographic factors of site and, where appropriate, hemisphere, included the factor of word type with the levels of derived and formal, and the factor of presentation type also with two levels, first presentation and partially primed. These ANOVAs provided a test for the presence of a reliable partial priming effect independently of the presence of a repetition effect. In addition planned comparisons were performed for each word type separately to determine whether the partial priming effect was reliable for each word type separately. When appropriate, Newman-Keuls test were performed on differences between conditions at individual sites, while reliable interactions were further investigated using Scheffé's procedure.

A second set of ANOVAs evaluated the effect of repetition to determine whether it was reliable. ANOVAs in this second set, in addition to the topographic factors included a factor of word type with two levels, derived and formal, and a factor of presentation type, again with two levels, first and second presentations. As with the partial priming effects, planned comparisons were performed to determine the reliability of the priming effects for each word type, Newman-Keuls tests were used to test for differences between conditions at individual sites, and Scheffé tests were used to decompose reliable interaction effects. Since the comparison being made in this analysis was between the repetition of bimorphemic derived words and of monomorphemic formal words, significant effects of word type would indicate that the representational bases of mono- and bi-morphemic words differ.

3.1.4.2. ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms

The relative magnitudes of the priming effects in the partial and repetition priming conditions for each word type were assessed by means of the analysis of the mean amplitude measures of the subtraction waveforms. The mean amplitudes of the subtraction waveforms in each priming condition were entered into separate repeated measures ANOVA for each of the 200 ms epochs analysed. Each ANOVA employed the factors of word type (derived vs formal), prime type (repetition vs partial), site, and for the lateral sites only, hemisphere. Planned comparisons of the magnitudes of the partial and repetition priming effects were performed separately for each word type. Planned comparisons of the magnitudes of the partial priming effects for formal and derivational words, and of the magnitudes of the repetition priming effects for the two word types, were also performed. Differences between the priming effects seen for the two word types would indicate that the priming effects seen with the derived words could not result solely from the orthographic, phonological and visual similarity between derivationally related words. Similarities and differences between the repetition and partial priming effects would potentially impose constraints upon the nature of the cognitive processes modified in these two priming conditions.

3.1.4.3. ANOVA of the rescaled mean amplitudes of the subtraction waveforms

This analysis of the non-rescaled subtraction waveforms allows conclusions to be drawn concerning the relative magnitudes of ERP modulations in different conditions. However as discussed above, because of the way the ERP mean amplitude measures breach the assumptions underlying the ANOVA, differences between the mean amplitudes of the subtraction waveforms cannot be used as a basis for claims concerning differences in the pattern of generators between experimental conditions. In order for such conclusions to be drawn, reliable effects must be shown in the analysis of the rescaled data.

In the analysis of the rescaled data, the mean amplitude measurements from all 9 sites were included in each ANOVA performed. The 9 sites were subdivided into three chains of three electrodes. The midline chain consisted of the Fz, Cz and Pz electrodes, the left hemisphere chain consisted of the LF, LT and LP electrodes, while the right hemisphere chain consisted of the RF, RT and RP electrodes. Given the previous reports of hemispheric differences in the magnitude of the modulations of the N400 and N450 components (Kutas, Van Petten, & Besson, 1988; Rugg & Barrett, 1987), the sub-division of the electrodes by chain allows a test of the relative magnitudes of the effects seen over the two hemispheres and an evaluation of their magnitude over each hemisphere in comparison to their magnitude over the midline. The presence of, and differences in the form of, reliable interactions between the factors of word type and/or prime type, and the topographic factors of site and chain in the analysis of the rescaled data, would provide evidence of differences in the identity of the generator(s) underlying the various ERP priming effects. In the absence of such differences between word or prime types, a reliable main effect of the factor of electrode chain would be indicative of differences in the relative size of the effects over the midline and the left and right hemispheres. Given the *a priori* interest in differences in the sizes of the ERP priming effects over the right and left hemispheres, for each word type, pairwise planned comparisons were performed across electrode chains to determine whether there were reliable differences between them in the magnitude of the priming effects.

Where the analyses of the rescaled subtraction data in each of the broad epochs suggested differences in the pattern of effects across successive epochs, then such topographic differences across epochs were tested directly by an ANOVA that included a factor of epoch, in addition to those of word type, prime type, chain and site. Such across-epoch comparisons of the rescaled data were used to address two questions: Firstly, are there topographic differences across epochs in the ERP elicited by a single experimental condition that can be attributed to changes over time in the set of generators responsible for that ERP effect? Secondly if such differences exist, do the effects in the different priming conditions show similar changes in the pattern of effects over time? This type of analysis provides a further dimension on which experimental conditions can be discriminated.

3.2 Methods

3.2.1 Subjects

12 adults (5 female), with a mean age of 22 years (range 18 - 34 years), were paid £3 per hour for participating in the experiment. All but one subject was right handed.

3.2.2 Materials

The experimental items consisted of 240 pairs of words. The words in 120 of these pairs were derivationally related to one another (e.g. ‘ruin’ - ‘ruinous’), whilst the words in the second set of 120 pairs were only formally related (e.g. ‘scan’ - ‘scandal’). In order to facilitate discussion of these various word types the following nomenclature will be adopted. Words such as 'ruin' will be referred to as 'root words' and words such as 'ruinous' will be described as 'derived words'. Words such as 'scan' will be referred to as 'formal root words' and words such as 'scandal' will be referred to as 'formal words'. The 120 derivational words were all suffixed forms, and there were 23 different types of suffix used. The derivationally- and formally-related word pairs are given in Appendices 1 and 2 respectively.

The two sets of 120 word pairs were chosen such that the mean word lengths and mean word frequencies (Francis & Kucera, 1982) of the root and formal root words were approximately equal, and the word lengths and frequencies of the derived and formal words were also approximately equal (Table 3.1). Because of the limited number of possible experimental pairs, the frequencies of the root items were allowed to vary over a relatively wide range. As a result, the mean frequency of the root words was somewhat higher than that for the derived and formal words. This asymmetry was, however, equally true of both word sets. Within each word type, the critical words were rotated around the unrepeated, partial priming and repetition priming. Thus for each word type, across subjects waveforms in each experimental condition were elicited by the same set of words.

A further constraint on the choice of items was a requirement that the degree of orthographic overlap in the derivationally related pairs was matched by a similar degree of overlap in the formally related pairs. The degree of overlap was estimated by determining the ratio of the number of letters the prime and probe words had in common to the length of the probe word.

Table 3.1 Word length and word frequency values for word pairs of each word type. Standard deviations are given in parentheses.

	Prime Words		Probe Words		
	Length	Frequency	Length	Frequency	Overlap
Derived	4.5 (0.8)	29.2 (30.6)	6.8 (0.9)	3.2 (3.2)	0.68 (0.04)
Formal	4.2 (0.7)	28.1 (34.6)	6.4 (1.1)	4.6 (4.0)	0.64 (0.06)

The number of common letters was defined as, proceeding from left to right, the number of letters up to, either the first letter in the root word that differed from the corresponding letter in its paired word, or to the end of the root word. Thus for the pair 'scan' - 'scandal', there are four letters in common (i.e. 'scan') and the formal word is 7 letters long, producing a ratio of 0.57. For the pair 'raise' - 'raisin', there are also four letters in common, i.e. 'rais'. However, since, in this example, the formal word is 6 letters long, the ratio is 0.67.

Each of the two sets of 120 word pairs was divided into three sub-sets of 40 pairs, with each of these sub-sets being matched for word length, word frequency and degree of orthographic overlap between paired words.

In addition to these experimental items a further 82 words were selected from Francis and Kucera (1982). They were selected so as to cover a similar range of word frequency and word length as was found in the experimental items. From these 82 items, 78 were used to produce pronouncable non-words. This was done by changing one or two letters of the word. Two of these non-words together with the 4 words not used to construct non-words were used as filler items. Twenty four of the non-words were used to form a set which were repeated during the experiment. A further set of 24 non-words were used to create a group of so-called 'pseudo-derived' non-words. This was done by adding a legal derivational suffix to the non-word. Thus from the non-word 'frab' the pseudo-derived non-word 'frabbage' was formed. These non-word/pseudo-derived non-word pairs (i.e. 'frab' - 'frabbage') were also presented during the experiment. The remaining 28 non-words were presented once during the experiment.

The derived items from one sub-set of 40 derivationally related pairs were repeated (e.g. 'ruinous' - 'ruinous' referred to hereafter as 'derivational repetition priming'). The formal words from one of the sub-sets were also repeated (e.g. 'scandal' - 'scandal' ; 'formal repetition priming'). The derived words from a second set of derivationally related pairs were primed by their root words (e.g. 'ruin' - 'ruinous' ; 'derivational partial priming'), whilst the formal words from a second of the formally related sets were primed by their formal root word (e.g. 'scan' - 'scandal' ; 'formal partial priming'). Twenty root words from the third sub-set of derivationally related pairs and 20 formal root words from the third sub-set of formally related pairs were also repeated (e.g. 'ruin' - 'ruin' ; 'scan' - 'scan'). Of the remainder of these final subsets of derivational and formal word pairs, 10 root words and 10 formal root words were presented unrepeated, as were the remaining 10 derived words and 10 formal words. The repetition of root words and the single presentation of both root, formal root, formal and derived words reduced the degree to which the occurrence of a word of a particular type on one trial was not predictive of the type of word which would occur on the immediately succeeding trial.

Items presented as the first of a pair of words in which the second word is either a repeat of, or is related to, the first, will be referred to as the 'prime words', whilst the repeated or related items presented second will be referred to as the 'probe words'.

The 440 words were combined with the 124 non-words and 6 filler items in a pseudo-random order, producing a sequence of 570 items, sub-divided into 6 blocks of 95 items. This ordering was constrained such that :

(i) prime words and the corresponding probe words and items in the non-word pairs occurred on immediately succeeding trials, e.g. the lag between prime and probe was 0.

(ii) a filler item was presented on the first trial of each block.

(iii) the experimental items were evenly distributed across the blocks, as were the different types of non-word.

Two further lists were produced by rotating the three sub-sets of each word type around conditions. A further three experimental lists of stimuli were produced by again rotating sub-sets of items around conditions, but using a different pseudo-random ordering of conditions.

3.2.3 Procedure :

The procedure used in this experiment for stimulus display, EEG and EOG recording and data analysis are as described in Section 3.1.

After the task had been explained to them, subjects completed a short practice block of 30 items, which included examples of all experimental conditions using words not included in the experimental set. The practice block also included non-words similar to those presented in the experimental lists. On satisfactory completion of the practice set, subjects were given a break of approximately 1 minute before the beginning of the first block of the experimental list. Subjects were allowed a rest period of approximately 30 seconds after each block of 95 stimuli. Their performance was monitored throughout the experiment to ensure that they maintained both an acceptable level of performance in detecting the non-words, and a relatively low rate of blinking during the EEG sampling period.

3.3 Results

3.3.1 Behavioural Data

Mean RT for a response to a non-word was 783.9 ms (standard deviation (sd) = 109.6 ms). The overall error rate, collapsed across false alarms and misses was 9.0% (sd = 4.3%). Subjects made an average of 7.9% (sd = 4.7%) false alarm responses to the words, with a mean reaction time of 856.9 ms (sd = 132.6%). Of the targets, 13.0% (sd = 9.1%) were missed.

3.3.2 Event Related Potentials

Grand average waveforms evoked by words in each of the critical conditions can be seen in Figures 3.1, 3.2 and 3.3. Figure 3.1 shows waveforms evoked by derived words presented for the first time, and by words in the derivational partial and repetition priming conditions, at each of the nine recording sites. Figure 3.2 shows the analogous conditions for the formally related words, whilst Figure 3.3 shows, on a larger scale, the waveforms recorded at midline sites for both derived and formal words, thus allowing the similarities and differences between conditions to be seen more clearly.

In all conditions there are prominent N118 and P191 peaks followed by a positive slow wave which continues for the remainder of the recording epoch. Across subjects the N118 had a ranged from 112 to 124 ms, whilst across subjects the P191 peak ranged from 184 to 196 ms.

The experimental conditions are most clearly differentiated during the period between 200 and 600 ms post-stimulus. During this interval the waveforms evoked in the primed conditions show a positive shift relative to those evoked by words presented for the first time. Although this differentiation begins at approximately 200 ms post-stimulus, the point-by-point t-tests suggest that it becomes reliable somewhat later, at 360 ms and 304 ms for the derivational and formal repetition priming conditions respectively and at 360 ms and 252 ms for the derivational and formal partial priming conditions respectively.

The subtraction waveforms for the derived words can be seen in Figure 3.4 and for the formal words in Figure 3.5. The positive-going shift in the waveforms elicited by partially primed and repeated words, although initially of approximately equal magnitude in all the priming conditions, begins to differentiate between them at approximately 400 ms post-stimulus. This results in the two repetition conditions being most positive, followed by the derivational partial priming condition and with the smallest positive shift associated with the formal partial priming condition. The positive-going shifts evident in all the waveforms evoked by repeated or partially primed words, declined to zero by approximately 600 ms post-stimulus onset, to be replaced by a negative going shift. This was especially so in the repetition conditions.

The mean number of trials contributed by each subject to each experimental condition was 33, 32 and 35 for the formal first presentation, formal partial and formal repetition conditions respectively. The values for the equivalent derived word conditions were 35, 33 and 35. Tables 3.2 - 3.6 give the mean amplitude of the average waveform at each site and in each condition for the epoch around the N118, the epoch around the P191 and in each of the three 200 ms epochs.

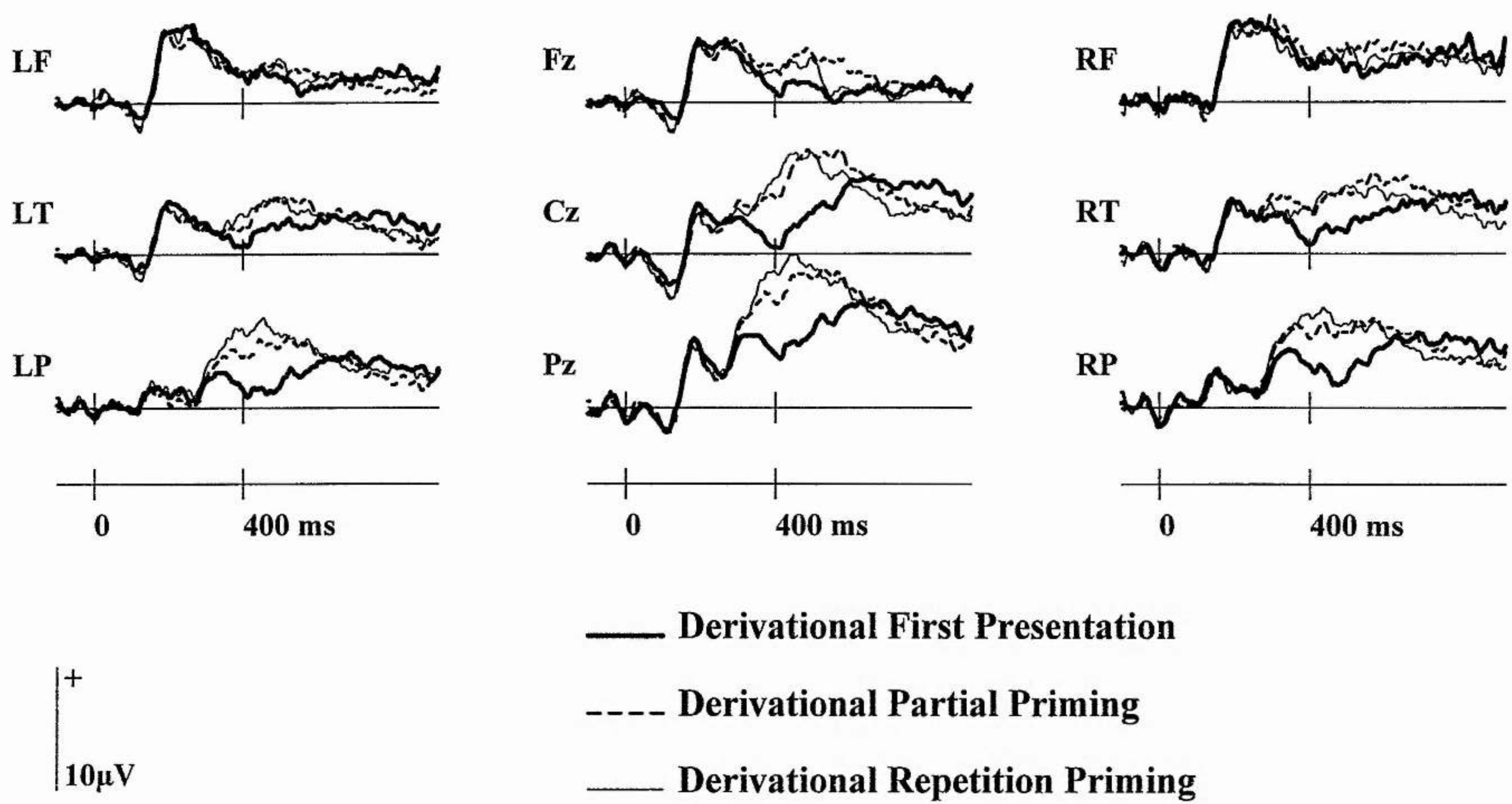


Figure 3.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 1A. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

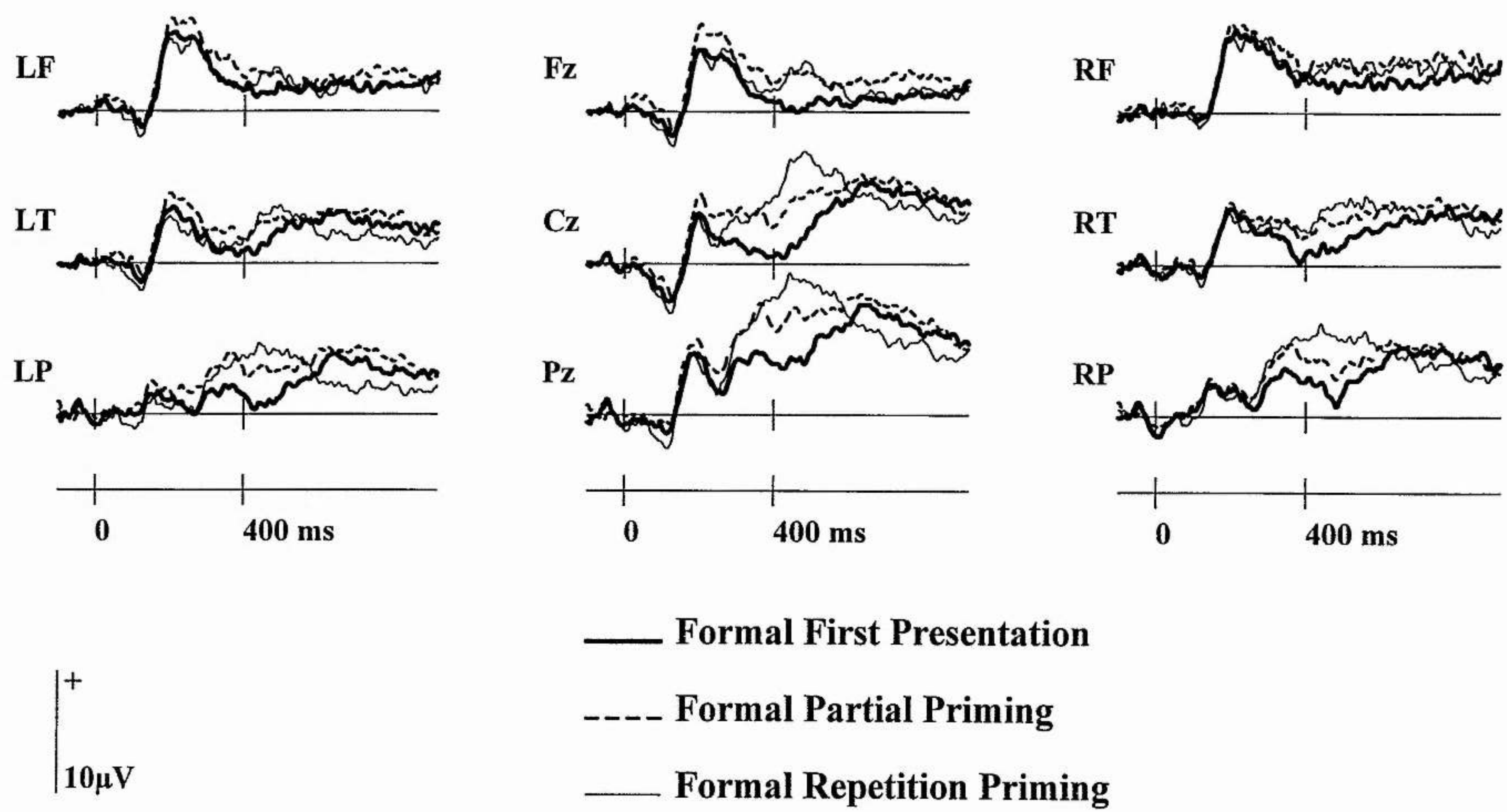


Figure 3.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 1A. Electrode sites as in Figure 3.1.

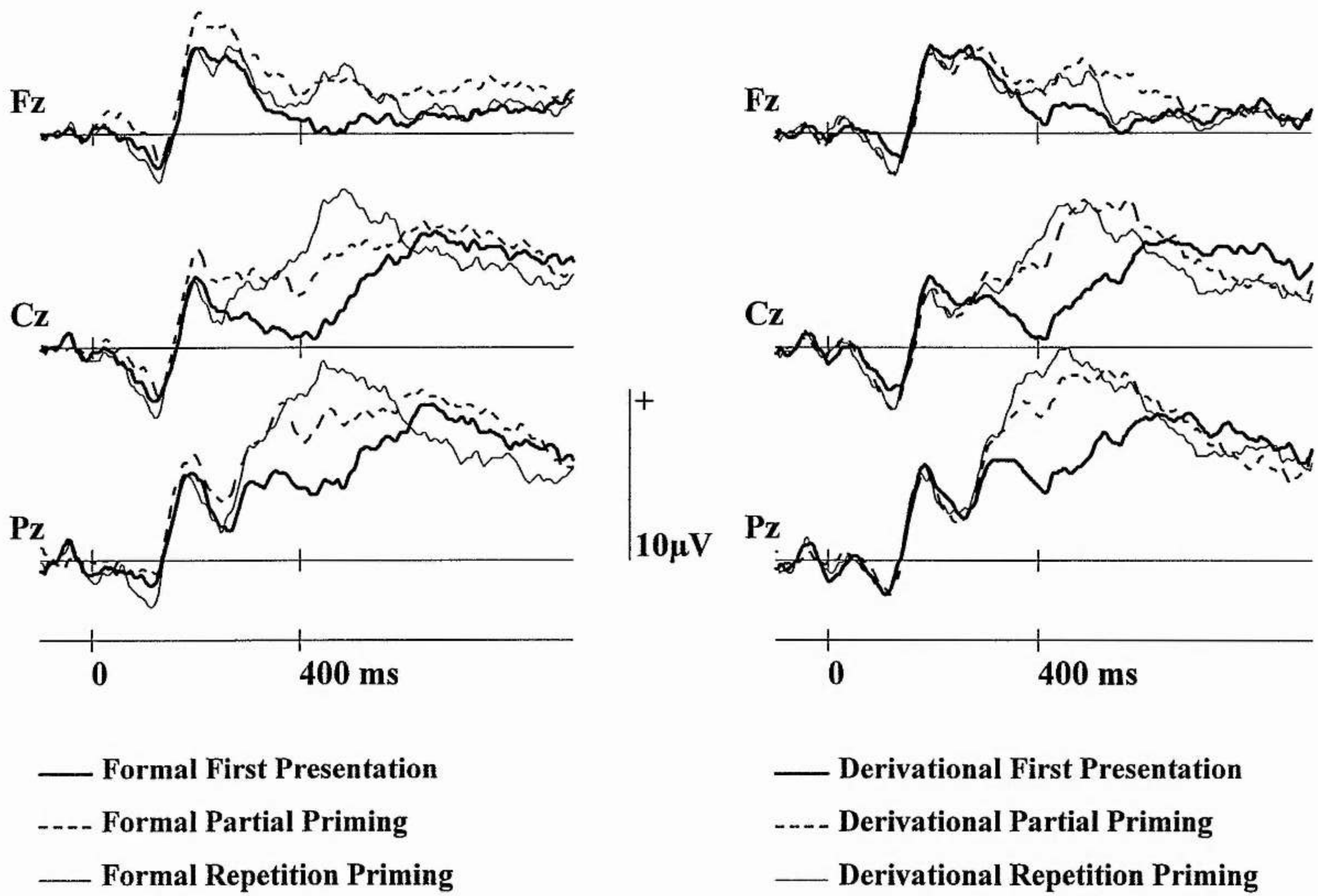


Figure 3.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 1A. Electrode sites as in Figure 3.1.

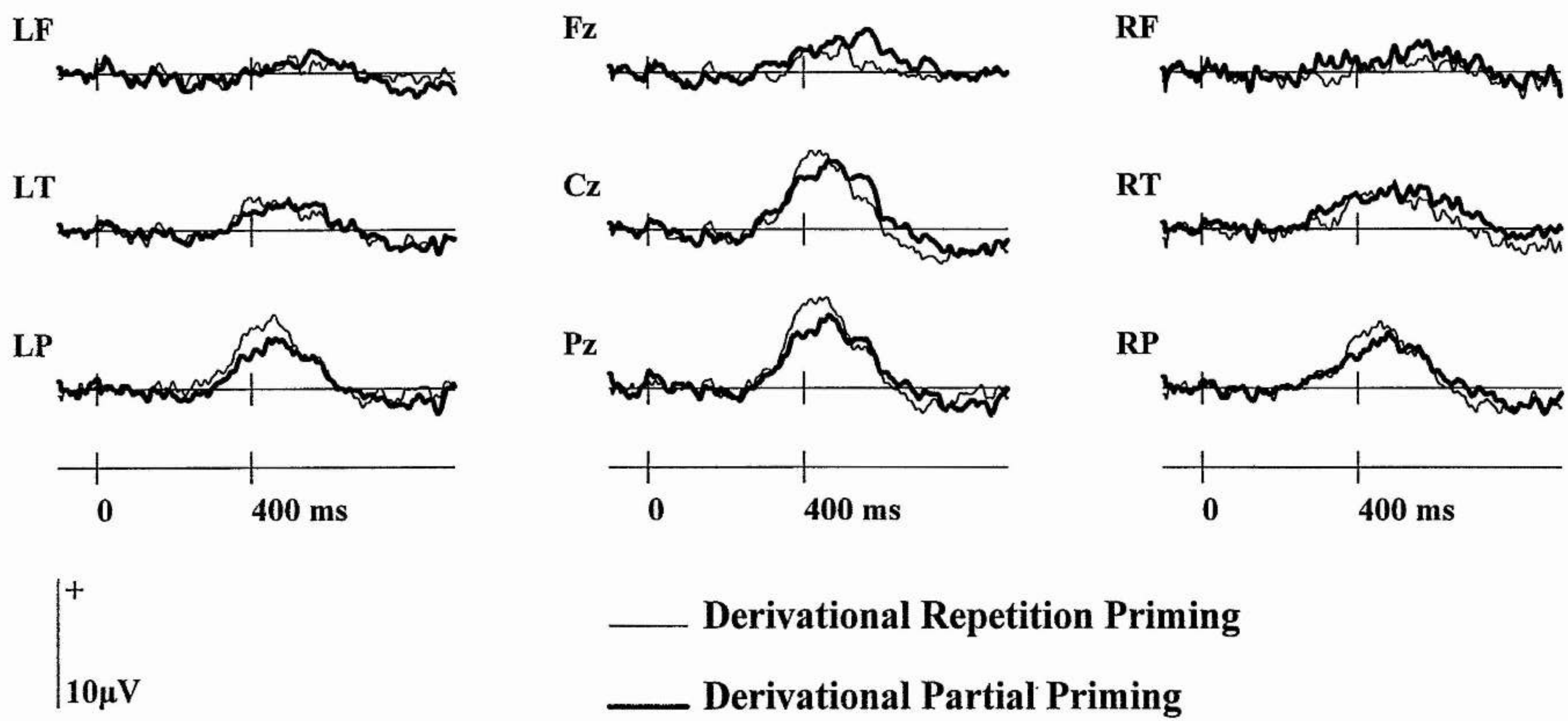


Figure 3.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 1A. Electrode sites as in Figure 3.1.

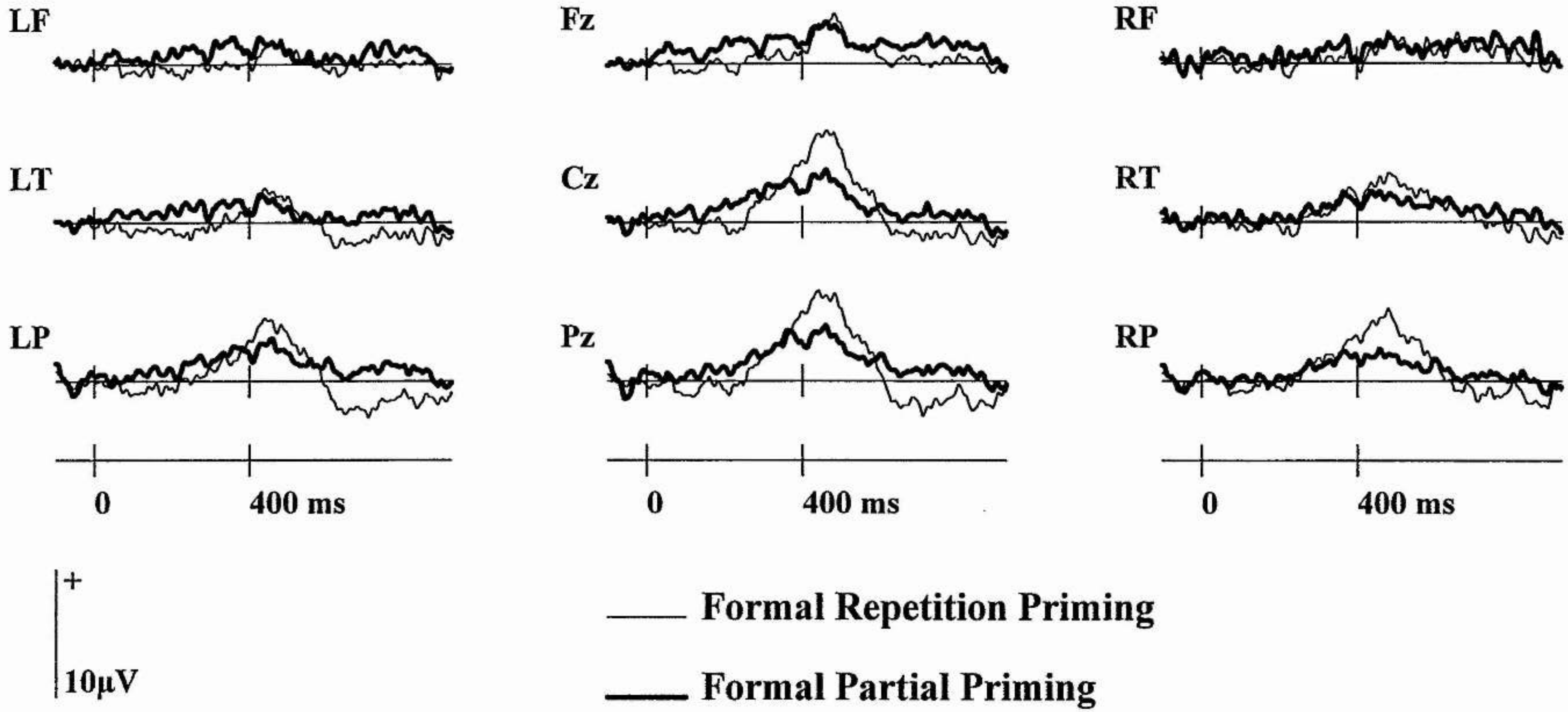


Figure 3.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 1A. Electrode sites as in Figure 3.1.

Table 3.2 Mean amplitudes of waveforms in each experimental condition at each electrode site, +/- 24 ms around the N118 peak in Experiment 1A.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	-1.47	-2.67	-0.78	-0.78	-1.08	0.38	-0.27	-0.49	1.43
Formal Priming	-0.75	-1.97	-0.21	-0.48	0.36	1.01	-0.01	-0.33	1.68
Formal Repetition	-2.17	-3.34	-1.78	-1.42	-1.76	-0.54	-0.83	-1.05	0.69
Derived First Pres.	-0.99	-2.21	-1.09	-0.94	-1.02	0.44	-0.23	-0.53	1.53
Derivational Priming	-1.97	-3.1	-1.22	-1.33	-1.21	0.66	-0.74	-0.59	1.02
Derivational Repetition	-1.7	-2.9	-1.06	-1.31	-1.53	0.21	-0.49	-0.80	1.12

Table 3.3 Mean amplitudes of waveforms in each experimental condition at each electrode site. +/- 24 ms around the P192 peak in Experiment 1A.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	3.83	3.03	4.49	5.12	3.80	1.46	5.25	3.93	2.39
Formal Priming	5.28	4.27	5.70	5.93	4.71	2.13	5.62	4.16	2.26
Formal Repetition	3.95	2.90	4.33	4.72	3.05	0.72	5.25	3.67	1.72
Derived First Pres.	3.96	3.17	4.91	4.85	3.51	1.35	3.38	3.83	2.02
Derivational Priming	3.35	2.60	4.60	4.53	3.27	0.88	4.94	3.75	1.77
Derivational Repetition	3.86	2.51	4.45	4.88	3.39	1.52	4.84	3.35	1.64

Table 3.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 1A.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	2.99	1.84	4.01	4.14	2.32	1.42	4.82	2.68	2.64
Formal Priming	4.74	4.12	6.27	5.44	3.58	3.19	5.70	3.68	3.84
Formal Repetition	3.40	3.55	5.82	3.88	2.06	2.41	5.05	3.35	4.00
Derived First Pres.	3.60	2.44	4.62	4.72	2.49	1.83	5.38	2.86	2.90
Derivational Priming	3.98	3.55	5.81	4.20	2.48	2.27	5.73	4.15	3.85
Derivational Repetition	3.55	3.58	6.52	4.30	2.68	3.23	3.85	3.52	4.22

Table 3.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 1A.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	0.70	3.11	5.67	1.80	2.49	1.86	2.57	2.08	3.01
Formal Priming	2.70	5.39	8.32	2.72	3.40	3.81	3.76	3.69	4.47
Formal Repetition	2.71	7.74	10.37	2.54	3.75	4.86	3.78	4.78	6.66
Derived First Pres.	1.06	3.27	6.26	1.89	2.18	2.18	2.98	2.44	3.38
Derivational Priming	3.40	7.49	10.34	2.76	3.97	4.99	4.26	5.23	6.36
Derivational Repetition	2.32	7.32	11.09	2.46	3.96	6.00	3.61	5.04	7.03

Table 3.6 Mean amplitudes of waveforms in each experimental condition at each electrode site; 600 - 800 ms post-stimulus onset in Experiment 1A.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	1.17	6.11	8.18	2.03	3.63	4.25	2.73	4.02	5.49
Formal Priming	2.76	6.76	9.12	2.93	4.19	5.22	4.28	5.00	5.87
Formal Repetition	1.42	5.28	6.66	1.89	2.30	2.37	3.98	4.45	4.80
Derived First Pres.	1.10	5.91	8.09	2.02	3.15	3.96	3.68	4.31	5.60
Derivational Priming	1.68	5.30	7.69	1.72	2.75	3.31	4.22	5.37	5.22
Derivational Repetition	0.86	4.23	7.16	2.10	2.53	3.48	3.65	4.15	4.67

3.3.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms

Partial Priming

A summary of the results of the ANOVAs performed to assess the reliability of the partial priming effects is presented in Table 3.7.

N118

In comparison with the ERP elicited by words on their first presentation, the ERP elicited by words in the derivational partial priming condition showed a negative-going shift in N118. In contrast the ERP elicited in the formal partial priming condition resulted in a small modulation of the ERP of similar magnitude but of opposite polarity. This difference between experimental conditions resulted in a significant interaction at midline sites between word type and presentation type. Separate planned comparisons of the formal and derivational partial priming effects indicated that neither effect alone was reliable. Although the same pattern of priming effects was evident at lateral sites, the effects were smaller and not reliable.

P191

At both midline and lateral sites there were main effects of word type and interactions between word type and presentation type. At midline and parietal sites formal partial priming resulted in a positive-going shift in the waveform, whilst derivational partial priming had the reverse effect.

Planned comparisons indicated that at neither midline nor lateral sites were the priming effects for either word type alone statistically reliable, although the positive shift resulting from partial priming over the midline was nearly so ($0.05 < p < 0.10$).

200 - 400 ms

Over the midline sites, ANOVA revealed a main effect of presentation type together with a reliable interaction between presentation type and word type. Planned comparisons between the mean amplitudes of first presentation and partial priming waveforms for each word type indicated that the positive-going shift resulting from partial priming was reliable only for the formal partial priming condition.

This difference in the reliability of the two effects, may have been due to differences in their latency of onset. The results of the point-by-point t-tests on the subtraction waveforms indicated the effects in formal partial priming condition became reliable some 50 ms before the effect for derived words. ANOVA was therefore performed on the mean amplitudes of the waveforms between 300 and 400 ms post-stimulus, a period during most of which the t-tests on the magnitude of the partial priming effects were reliable for both word types. Over the midline

Table 3.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and partial priming conditions in each epoch analysed in Experiment 1A.

N118	Midline	presentation type x word type	$F(1,11) = 7.55$	$p < 0.05$
	Lateral	No Significant Differences		
P191	Midline	word type	$F(1,11) = 13.45$	$p < 0.005$
		presentation type x word type	$F(1,11) = 9.41$	$p < 0.05$
	Lateral	word type	$F(1,11) = 6.38$	$p < 0.05$
		presentation type x word type	$F(1,11) = 5.85$	$p < 0.05$
200 - 400 ms	Midline	presentation type	$F(1,11) = 27.82$	$p < 0.001$
		presentation type x word type	$F(1,11) = 13.85$	$p < 0.005$
	Lateral	presentation type	$F(1,11) = 4.94$	$p < 0.05$
		word type x hemisphere	$F(1,11) = 5.68$	$p < 0.05$
		presentation type x word type x hemisphere	$F(1,11) = 18.68$	$p = 0.001$
400 - 600 ms	Midline	presentation type	$F(1,11) = 55.95$	$p < 0.001$
	Lateral	presentation type	$F(1,11) = 26.52$	$p < 0.001$
600 - 800 ms	Midline	No Significant Differences		
	Lateral	word type x hemisphere	$F(1,11) = 20.50$	$p = 0.001$
		presentation type x hemisphere	$F(1,11) = 7.54$	$p < 0.05$

this analysis resulted in highly reliable main effect of presentation type. Planned comparisons indicated that the partial priming effect was reliable for each word type. There was a reliable interaction between presentation type and site. Post-hoc tests indicated that the partial priming effects were reliable at Cz and at Pz. Scheffé tests indicated that the partial priming effect at Fz differed reliably from that at Pz.

At the lateral sites, in both the 200 - 400 ms and the 300 - 400 ms intervals, there were reliable main effects of presentation type. Planned comparisons of the mean amplitudes of the first and partially primed waveforms over the broad epoch showed them to differ for the formal words but not for the derived words. The analogous analyses for the narrower epoch showed the partial priming effects to be reliable for both word types. In the 200 - 400 ms epoch there was also a reliable 2-way interaction between word type and hemisphere, and a reliable 3-way interaction between presentation type, word type and hemisphere. The formal partial priming effect was approximately symmetrical across the hemispheres. In contrast, the derivational partial priming effect in the waveforms recorded from the right hemisphere electrodes was greater than the equivalent effect in the waveforms recorded from left hemisphere electrodes. Analysis of this interaction with Scheffé's procedure, confirmed that, for the derived words only, the partial priming effect was greater over the right hemisphere than it was over the left.

400 - 600 ms

The positive-going shifts in the ERP resulting from partial priming seen in the previous epoch continue throughout the second epoch. ANOVA on the data from midline and lateral sites revealed main effects of presentation type. Planned comparisons indicated that both partial priming effects were reliable when tested separately. This was the case in midline and lateral analyses. None of the effects involving the word type factor was reliable.

600 - 800 ms

At midline sites, ANOVA revealed no reliable effects of word or presentation type. Although there was a tendency for the waveforms evoked by partially primed formal words to be more positive-going than their respective first presentation waveform, a planned comparison indicated that this effect was not reliable.

At lateral sites, ANOVA revealed no reliable main effects of word or presentation type, nor did planned comparisons reveal a reliable partial priming effect for either word type when they were tested separately. However, there was a reliable interaction between presentation type and hemisphere. Waveforms elicited in each presentation condition were more positive-going over the right hemisphere than over the left, however this asymmetry was reliable only for waveforms elicited by the partially primed words.

ANOVA also revealed a reliable 2-way interaction between word type and hemisphere. The ERPs evoked by both word types were more positive-going over the right hemisphere than over the left, however Newman-Keuls tests indicated that this asymmetry was only reliable in the case of the derived words.

Repetition Priming

A summary of the outcome of the analyses performed to assess the reliability of the repetition effects can be seen in Table 3.8.

N118

The mean amplitude around the N118 peak was largest in all conditions at centro-temporal sites. Although the N118 peaks in waveforms evoked by repeated words were more negative-going at all sites than were those in waveforms evoked by words seen for the first time, the main effect of presentation type was reliable only at the lateral sites. Planned comparisons indicated that the effect of presentation type was not reliable when each word type was tested alone. This was the case at midline and at lateral sites. None of the effects involving the factor of word type approached significance.

P191

Repetition resulted in a reduction in the amplitude of the P191 component at all sites. However ANOVA on the mean amplitude measures from midline and lateral sites did not reveal any reliable modulation of the P191 peak amplitude as a function of word or presentation type. Planned comparisons indicated that the effect of presentation type was not reliable for either word type when they were tested separately.

200 - 400 ms

ANOVA revealed that the main effects of word and presentation type were not reliable, nor did planned comparisons indicate that the repetition effect for either word type was reliable. ANOVA did reveal reliable interactions between presentation type and site in midline and lateral data sets. Newman-Keuls tests indicated that at no single site were the effects of presentation type reliable. Scheffé tests indicated that, over the midline, the repetition effects at Fz were smaller than were the effects at the other two midline sites which did not themselves differ.

At the lateral sites, the main effects of word and presentation type were not reliable, and nor were the differences between presentation types reliable when tested separately. Newman-Keuls tests did reveal that, collapsed over hemisphere, the effect of presentation type was reliable at the parietal sites. In addition, a Scheffé test showed that the effect of presentation

Table 3.8 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and repetition conditions in each epoch analysed in Experiment 1A.

N118	Midline	No Significant Differences			
	Lateral	presentation type	$F(1,11) = 8.86$	$p < 0.05$	
P191	Midline	No Significant Differences			
	Lateral	No Significant Differences			
200 - 400 ms	Midline	presentation type x site	$F(2,22) = 11.40$	$p = 0.003$	$\varepsilon = 0.65$
	Lateral	presentation type x site	$F(2,22) = 0.35$	$p < 0.01$	$\varepsilon = 0.65$
400 - 600 ms	Midline	presentation type	$F(1,11) = 34.91$	$p < 0.001$	
		presentation type x site	$F(2,22) = 26.19$	$p < 0.001$	$\varepsilon = 0.65$
	Lateral	presentation type	$F(1,11) = 23.90$	$p < 0.001$	
		presentation type x site	$F(2,22) = 11.13$	$p = 0.005$	$\varepsilon = 0.57$
		presentation type x hemisphere	$F(1,11) = 5.43$	$p < 0.05$	
600 - 800 ms	Midline	presentation type x site	$F(2,22) = 7.62$	$p < 0.01$	$\varepsilon = 0.72$
	Lateral	presentation type x hemisphere	$F(1,11) = 7.76$	$p < 0.05$	
		word type x presentation type x hemisphere	$F(1,11) = 4.87$	$p = 0.05$	

type was greater at temporal sites than at frontal sites, and greater at the parietal sites than at the temporal sites.

As with the derivational partial priming effect, reliable repetition priming effects may have been obscured because of the difference of the later onset of the repetition effects as determined by the point-by-point t-tests. ANOVA was performed on the data from the interval between 300 -and 400 ms post stimulus. Over the midline only, there was a reliable main effect of presentation type, but the effects of presentation type for each word type were not reliable when tested separately.

In the midline and the lateral analyses there were reliable interactions between presentation type and site. Post-hoc tests revealed that the differences between the waveforms elicited by the first and second presentations of words were reliable at Cz, Pz and at parietal lateral sites. Scheffé tests indicated that, for the midline, the effects of presentation type at Fz differed from those at Cz and from those at Pz, but that the effects of presentation type were equivalent at Cz and Pz. At the lateral sites, the effects of presentation type at the frontal and temporal sites differed from those at the parietal sites, but did not differ between themselves.

There were no reliable effects involving the word type factor.

400 - 600 ms

There were main effects of presentation type and also reliable interactions between presentation type and site in the midline and lateral analyses.

Over the midline a planned comparison showed the effects of presentation type to be reliable for both word types. Newman-Keuls tests showed that the effects of presentation type were reliable at Cz and Pz, but not at Fz. Scheffé tests indicated that the effect of presentation type was greater at Cz and Pz than at Fz, with the effects at the two more posterior sites not differing reliably from one another.

At the lateral sites planned comparisons also showed that the effects of presentation type were reliable for each word type. Post-hoc tests indicated that the effect of presentation type was reliable at temporal and parietal sites but not at the frontal sites. The presentation type effect was greater at temporal than at frontal sites, and greater at the parietal sites than at either of the other lateral sites.

There was also a reliable interaction between presentation type and hemisphere. The effect of presentation type was larger in the waveforms recorded by electrodes over the right hemisphere than it was in waveforms recorded by electrodes over the left hemisphere. None of the effects involving the factor of word type was statistically reliable.

600 - 800 ms

In this epoch the waveforms recorded in the repetition conditions of the experiment tended to be more negative-going than the waveforms evoked by words on their first presentation. Over the midline, the effects of presentation type were not reliable in either the ANOVA, or in the subsequent planned comparisons. ANOVA did reveal a reliable interaction between presentation type and site. This reflected the smaller negative-going shift at Fz compared to the other two midline sites which did not themselves differ. The effects of presentation type at the individual sites was not reliable. None of the effects involving the word type factor were reliable.

The formal and derived word types were differentiated in the analyses of the data from lateral sites. ANOVA revealed a reliable 2-way interaction between presentation type and hemisphere, as well as a reliable 3-way interaction between these two factors and that of word type. Over neither hemisphere was the repetition priming effect reliable for formal or derived words, but Scheffé tests indicated that the negative-going formal repetition priming effect over the left hemisphere differed reliably from the positive-going formal repetition priming effect over the right hemisphere.

3.3.2.2 ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms

As described in Section 3.1, the purpose of these comparisons was to assess, firstly, whether the effects of partial priming differed for the two word types, and secondly, the degree to which the partial priming effects were similar to the repetition effects. A summary of the outcome of the ANOVAs performed on the non-rescaled measurements of the subtraction waveforms is given in Table 3.9.

None of the ANOVAs performed on the mean amplitude measurements of the subtraction waveforms around the N118 or P191 peaks gave rise to reliable effects of prime type or word type in the non-rescaled data. Planned comparisons of the mean amplitudes of the subtraction waveforms in the various priming conditions also revealed no reliable differences between them.

200 - 400 ms

Over the midline the main effects of word type and prime type were not reliable. Planned comparisons showed that the magnitude of each of the priming effects did not differ between the word types, nor were the differences between the repetition and partial priming effects reliable for either word type.

There was a reliable interaction between prime type and site in the midline and lateral analyses. Over the midline the partial priming effects showed a relatively flat distribution between Fz

Table 3.9 Summary of the results of the ANOVAs performed on the non-rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 1A.

N118	Midline	No Significant Differences			
	Lateral	No Significant Differences			
P191	Midline	No Significant Differences			
	Lateral	No Significant Differences			
200 - 400 ms	Midline	prime type x site	$F(2,22) = 6.80$	$p < 0.01$	$\varepsilon = 0.90$
	Lateral	prime type x site	$F(2,22) = 9.14$	$p < 0.005$	$\varepsilon = 0.85$
400 - 600 ms	Midline	prime type x site	$F(2,22) = 9.53$	$p < 0.005$	$\varepsilon = 0.76$
	Lateral	prime type x site	$F(2,22) = 6.20$	$p < 0.05$	$\varepsilon = 0.55$
600 - 800 ms	Midline	No Significant Differences			
	Lateral	No Significant Differences			

and Pz, but the repetition effects were more posteriorly distributed. The differences between prime types at individual sites were not reliable, but Scheffé tests indicated that the difference in the size of the repetition and partial priming effects was greater at Fz than at Pz.

At the lateral sites the repetition priming effects were also more posteriorly distributed than were the partial priming effects. When the difference in the magnitude of the repetition and partial priming conditions was tested at individual sites, none of the differences was found to be reliable. The effect of prime type at the lateral parietal sites differed from that at the temporal and lateral frontal sites, but the difference between these two more anterior sites was not reliable.

There were no reliable effects involving the word type factor in either the analysis of the midline or the lateral data.

400 - 600 ms

This epoch coincided with the region of the waveforms in which, for both word types, the repetition conditions resulted in numerically larger effects than did the partial priming conditions. However neither the main effect of word type, nor of prime type were reliable. Planned comparisons showed that for neither of the priming conditions was the difference between the word types reliable. Planned comparisons also showed that the difference between the partial and repetition priming effects for the derived words was not reliable. In the case of the formal words the difference between the priming effects was marginally significant ($0.05 < p < 0.10$).

The interaction between the factors of prime type and site was reliable in the analysis of the midline and the lateral data. For both midline and lateral sites, the repetition effects were more posteriorly distributed than were the partial priming effects. At no single site was the effect of prime type reliable. Scheffé tests indicated that the difference between the repetition and partial priming conditions was greater at Pz and Cz than at Fz, and greater at lateral parietal sites than at lateral frontal sites.

Priming effects in waveforms recorded from over the right hemisphere were larger than were the effects in waveforms from the left hemisphere. This resulted in a reliable main effect of hemisphere in the analysis of the lateral data.

600 - 800 ms

In this time interval ANOVAs revealed no significant differences between the mean amplitudes of the subtraction waveforms in either the midline nor the lateral analyses. Planned comparisons also failed to detect any differences in the magnitude of the four priming effects.

3.3.2.3 ANOVA of the rescaled mean amplitudes of the subtraction waveforms

Within Epoch

A summary of the outcome of the ANOVA performed on the rescaled mean amplitudes for each priming effect in each 200 ms epoch analysed is given in Table 3.10. As with the analysis of the non-rescaled data, analyses of the mean amplitudes around neither the N118 component nor the P192 component revealed any reliable effects of prime or word type.

200 - 400 ms

None of the effects involving the factor of word type was significant, but there was a reliable interaction between prime type and site (see Figure 3.6). A Scheffé test showed that the effect of prime type at frontal sites was reliably different from that at parietal sites.

The analysis of the rescaled data also revealed a reliable main effect of chain. Planned comparisons indicated that the magnitude of the priming effects at the midline was proportionately greater than its magnitude over the left hemisphere. Neither of the other pairwise planned comparisons across chains revealed reliable differences.

400 -600 ms

The ANOVA on the rescaled data in this epoch showed that there were no reliable effects involving the prime or word type factors. There was a main effect of chain. Planned comparisons indicated that the priming effects were proportionately greater over the midline than over each of the other two chains. Although the priming effect was greater over the right hemisphere than over the left, this difference was not reliable.

600 - 800 ms

There were no reliable differences between the distributions of the priming effects in this region of the waveform, nor was their a reliable difference between the electrode chains.

Across Epoch

The ANOVA on the mean rescaled amplitudes in the 200 - 400 ms latency showed a reliable interaction between the factors of prime type and site, but the analogous interaction was not reliable in the analysis in the 400 - 600 ms region. This difference across epochs was further investigated using an ANOVA which included factors of epoch, prime type, word type and site (see Table 3.11).

There was a reliable main effect of chain, but also 2 higher order interactions. The first of these interactions was the 4-way interaction between all factors except that of site, whilst the second was the 5-way interaction involving all the factors. Although this finding indicates that there

Table 3.10 Summary of the results of the ANOVAs performed on the rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 1A.

200 - 400 ms	prime type x site	$F(2,22) = 4.75$	$p < 0.05$	$\varepsilon = 0.79$
	chain	$F(2,22) = 6.21$	$p < 0.05$	$\varepsilon = 0.79$
400 - 600 ms	No Significant Differences			
600 - 800 ms	No Significant Differences			

Table 3.11 Summary of the outcome of ANOVA s performed on the rescaled mean amplitudes of the measurements across epochs in Experiment 1A.

200 - 400 ms vs 400 - 600 ms				
	chain	$F(2,22) = 13.26$	$p = 0.001$	$\varepsilon = 0.78$
	epoch x prime type x word type x chain	$F(2,22) = 5.02$	$p < 0.05$	$\varepsilon = 0.66$
	epoch x prime type x word type x chain x site	$F(4,44) = 3.04$	$p < 0.05$	$\varepsilon = 0.83$

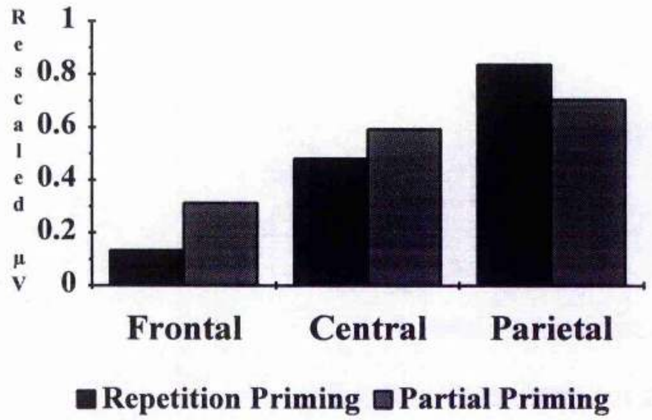


Figure 3.6 Mean rescaled amplitudes of the subtraction waveforms for each prime type, collapsed over word type, between 200 and 400 ms post stimulus onset at midline and lateral sites in Experiment 1A.

were differences in the pattern of effects across epochs, the involvement of all the other factors in this interaction means that its interpretation is unclear.

3.4 Discussion

This experiment sought to determine whether ERPs are sensitive to derivational relationships between words, and, if so, to investigate the nature of such a sensitivity by comparing the effects of repeating a morpheme with that of repeating a whole word. If ERPs reflect processes acting at a lexical locus, and if representations at this locus are decomposed into morphological constituents, then the effects of repetition and morphological priming may show some similarities.

However, only priming effects with derived words which cannot be accounted for in terms of the formal similarity between the members of a word pair, may be seen as reflecting the morphological relationship between derived words and their derivational root words. Even these effects would need to be further investigated to determine whether they arose because of the semantic, rather than the morphological, relationship between the derivationally related words.

Reliable effects of word type in the comparison of the subtraction waveforms, before or after rescaling, would support the view that ERPs were sensitive to more than the formal properties of words. The interpretation of the absence of such a difference would be ambiguous, but it would be constrained if each of the individual priming effects were shown to be reliable. This is because the absence of a difference between the derived and formal effects could less easily be ascribed to a lack of sensitivity of the experimental procedure to priming effects in general.

There were reliable effects of partial and repetition priming in each of the 200 ms epochs analysed. In the analysis of the partial priming effects, the modulation of the ERPs as a result of partial priming did appear to vary as a function of word type. The modulation of the ERP by partial priming was dependent upon the factor of word type between 200 and 400 ms post-stimulus onset. However, this effect of word type was due to the earlier onset of the formal partial priming effects. This early onset of the formal partial priming effect resulted in the mean amplitude of this effect in the 200 ms epoch being somewhat greater than the derived partial priming effect. In the analysis of the interval between 300 and 400 ms, the interaction between presentation type and word type was no longer reliable.

The absence of any differences in the magnitude or distribution of the repetition effects for the two word types in any of the intervals measured indicates that whether words were mono- or bi-morphemic had no effect on the ERPs resulting from their repetition. There was a difference of some 50 ms in the latency at which the point-by-point t-tests indicate that the effects became reliable for the two word types. However the repetition effects for the derived words had the earlier onset. This suggests that the difference in the onset latency was not a reflection of any additional processing required to decompose bi-morphemic words into their morphemic constituents before a lexical representation could be accessed.

When the magnitude of the priming effects in the four conditions were directly compared within each epoch, in none of the analyses was there a reliable effect involving the factor of word type. Thus the effects seen with the derived words could not be distinguished from those seen with the formal words, suggesting that the priming manipulations resulted in the modification of the same set of cognitive processes for both word types. There was therefore no evidence that ERPs were sensitive to derivational relationships between words.

The lack of a difference between word types contrasts with the effects seen for the two different priming conditions. Within the 200 - 400 ms interval and within the 400 - 600 ms interval, the distribution of the two priming effects differed. In each case, the partial priming effects had a somewhat flatter distribution over the midline and over the lateral sites than did the repetition effects. Only in the case of the 200 - 400 ms interval was this difference between the two priming effects reliable after the data had been rescaled. This difference between the rescaled priming effects indicates that, at least between 200 ms and 400 ms post-stimulus onset, the repetition and partial priming effects can be seen as resulting from the activity of at least partially independent generators. Whether the difference in the effects is a result of the sets of generators underlying the two effects being completely independent, or of one set being a subset of the other, or of partially overlapping sets of generators is, from the present results, impossible to determine.

The analyses of the rescaled amplitudes of the subtraction waveforms across the various epochs potentially adds a further dimension in attempting to discriminate between the effects of repetition and partial priming, and between the effects of derivational as opposed to formal priming. Unfortunately this analysis was not especially informative. Although reliable effects involving the word type factor were found in the across epoch analysis, they occurred in the context of the 4- and 5- way interactions in which all the other factors were also involved. Such high level interactions are difficult to interpret and the question of whether the pattern of repetition and formal priming effects differed over time cannot confidently be answered on the basis of the present experiment. The next experiment is, essentially, a repetition of Experiment 1A. One motivation for this repetition is to attempt to clarify the answer to the question of whether there are distributional differences in the priming effects for the two word types, and whether these change over the duration of the ERP.

One account of the differences in magnitude and distribution between the repetition and partial priming effects relies upon the differences in the lengths of the prime words in the two different priming conditions. While this possibility cannot be ruled out, it is unclear why a change in length of the prime word should result in the observed differences between the priming conditions.

The absence of reliable differences between the word types, particularly in the rescaled analysis, suggests that whatever processes underly the priming effects, they are largely equivalent for the two word types. Given that what is common to the two word types is the formal similarity between the prime and probe words, this suggests that the identity of the set of generators whose activity was modified by formal and derivational priming, is determined by this formal similarity, rather than by morphological and semantic similarity. Irrespective of whether the effects seen for the derived words are indeed solely a reflection of their formal similarity, Experiment 1A provides a further demonstration that formal similarity between words is sufficient to produce modulations of the activity of the neural generators underlying ERPs. In addition, in the present experiment, such modulations occurred even though the experimental task did not explicitly require subjects to attend to this formal similarity.

A final question concerns whether the positive-going shifts in the ERP elicited by repetition and partial priming can be considered as examples of the modulation of the N400 component of the ERP. A number of features of these ERP effects suggest that they can. Firstly, although more apparent in the repetition condition, each of the priming effects measured between 200 and 600 ms post-stimulus onset had a centro-parietal distribution. Secondly, in each case the priming effects were greater over the right hemisphere than over the left. As noted in Section 2.5, it has been proposed that a centro-parietal, right-greater-than-left distribution is characteristic of the N400 component. That the waveforms elicited by repetition and formal priming in the present experiment had such a distribution indicates that these manipulations did indeed result in the modulation of the N400 component of the ERP.

If, however, it is concluded that both the repetition and partial priming effects modulated the N400, then the question arises as to the significance of the topographic differences which were found between the two priming conditions. Such topographic differences are generally held to indicate a difference in the component being modulated by different experimental conditions. This is a question to which we shall return in the discussion of the results of the later experiments.

The finding of reliable effects of formal priming, and the similarity of these effects to those of derivational priming, can be accounted for in a number of ways. On the assumption that derivational relationships between words do have functional significance in the identification of words, the absence of reliable effects of derivational priming suggests that ERPs do not reflect the operation of processes involved in word identification. Alternatively, the task and the structure of the words and non-words used in this experiment may have led subjects to employ task-specific strategies to perform the task. As discussed in the Chapter 1, the sensitivity of the LDT to modifications of the processes normally involved in word recognition is likely to be dependent upon the types of words and non-words used in the experiment, and the manner in which they are presented. If subjects in Experiment 1A did employ task-specific strategies to perform the LDT, then the extent to which the cognitive operations normally involved in word recognition were invoked may have been reduced. Alternatively the ERP consequences of such operations may have been obscured by the ERP consequences of the task-specific strategies employed. If so, this may account for the absence of differences between the derivational and formal partial priming conditions. Experiment 1B further investigates the effects of morphological similarity on ERPs, whilst attempting to constrain the strategies that subjects may use to successfully perform the experimental task.

Chapter 4

Experiment 1B

A further comparison of ERP repetition, formal and derivational priming effects at lag 0

4.0 Introduction

The presence of derivational partial priming effects could be taken as an indicator of the role of morphological similarity in the generation of ERP effects. However such a conclusion would be premature. The similarity of the derivational and formal partial priming effects means that, for both word types, the changes in the ERPs can be accounted for as reflecting the formal similarity between the two word types. Thus the major question arising from the results of Experiment 1A concerns the nature of the cognitive operations which are modified by formal similarity between words, and which are reflected in the ERP formal priming effects.

As discussed in the Chapter 1, although performance on the LDT task has been taken by some authors to reflect processes associated with lexical access and semantic processing, performance on this task is more likely a reflection of a number of different processes. Not all of these processes would normally be involved with word recognition. The ERP formal priming effects may reflect the operation of any or all of these processes.

If the ERP effects are held to reflect lexical processes then the similarity of the formal and derivational partial priming ERP effects contrast with the opposite effects found when these two manipulations are employed in analogous experiments using RT as a dependent variable. When words are presented under conditions in which they can be easily identified, the presentation of one word generally has an inhibitory effect on the recognition of a formally similar word. Such an inhibitory effect contrasts with the facilitatory effects generally observed as a consequence of word repetition, or of derivational priming. Despite these differences, it has been argued that the repetition, derivational and formal priming effects are each a consequence of changes in the activation states of lexical representations. If this is the case then it seems unlikely that the ERP effects, which are similar across the three priming conditions, can also each reflect changes occurring at a lexical level of representation.

A lexical account that may more easily account for the similarity of the formal and derivational priming effects relies upon the claim that information from printed words is taken up from left-to-right. (Marcel, 1980; Segui & Zubizaretta, 1985; Taft & Forster, 1975). This left-to-right mechanism does not depend upon subjects adopting a task-specific strategy, and occurs as a normal part of word identification in a language in which grammatical morphemes most often occur as suffixes (Cutler, et al., 1985). Under this account of the partial priming effect, at some point during the identification of a probe word such as 'scandal', an orthographic pattern would be extracted that would match a recently presented formally related prime word (i.e. 'scan'). In these circumstances it is plausible that this orthographic pattern would activate the corresponding lexical representation, a lexical representation which had also been activated by the presentation of the prime word. As a result of this 'repetition' of the prime word, an ERP repetition effect may be generated. Subsequently, when the additional letters making up the word 'scandal' had been processed, the competition between representations of the two words would result in the reduction of activation associated with the lexical representation of the word 'scan'. This would account for why the partial priming effects are initially of similar magnitude to the repetition effects, but seems also to predict that the difference between the partial and repetition priming effects would result from the decline in the partial priming effect rather than an increase in the repetition effect as observed. While this account is compatible with at least some aspects of the ERP data, it is unclear whether it is also compatible with data from the RT studies.

The formal priming effects can also be accounted for without the involvement of lexical processes. Performance of the LDT, unlike the rhyme matching task (Praamstra & Stegeman, 1993; Rugg, 1984; 1985a; Rugg & Barrett, 1987), does not require subjects to attend to the formal similarities between the experimental items. Nonetheless, a number of features of the experimental design and items may have led subjects to attend to such similarity between items, and to have employed task-specific strategies in performing the LDT. Two such features were the high predictability of the occurrence of a probe item given a prime word, and the redundancy of the terminal letters of long words with respect to the LDT.

The proportion of trials in Experiment 1A on which the item presented was formally (and possibly morphologically) related to either the preceding or succeeding stimulus was very high. Only 74 items, out of 570, were not either a prime or probe word from one of the priming conditions, or a non-word which was a repeat or had been partially primed. Thus if an item had not been previously encountered in the experiment, then it was very likely that it would be followed by a stimulus which was, at least, formally similar to it. In most cases, both of these stimuli would have been words. In some cases both of them would have been non-words. Were subjects to adopt a strategy of making the same response (to make or withold a button press) to an item as had been made to its predecessor, when that predecessor had not itself been preceded by the same or a similar word, this would result in a high level of correct performance. Under this account, the partial and repetition priming effect would reflect a reduction in the degree to which stimulus categorisation processes are invoked upon presentation of the primed items compared to when unprimed items are presented.

A second non-lexical account depends upon the structure of the words used in the experiment. Because of the way the stimuli had been selected, the initial 4 or 5 letters of each real word either constituted the whole word (e.g 'scan', 'ruin'), or constituted a word embedded in a longer word (e.g. 'scandal', 'ruinous'). On the other hand, for the non-words, in no case did the initial letter string constitute a real word. Given this contrast between the words and the non-words, the LDT could have been successfully performed by attending to only the initial segment of each letter string.

Each of the possible mechanisms underlying the partial and repetition priming effects outlined above suggest that the partial priming condition can be seen as a *de facto* repetition condition, whether as a result of the action of a lexical parsing mechanism, or as a result of an attentional or response strategy. They thus potentially provide an account of why the formal and derivational partial priming effects are similar, since none of the mechanisms proposed would distinguish between the two word types.

Given that these '*de facto* repetition' hypotheses account for the partial priming effects by suggesting that they are a form of repetition effect, then they also may provide an account of why the partial and repetition priming effects are initially similar in magnitude. However models of this type are unable to account for the differences between the partial priming and repetition effects. These differences occurred in the relative amplitude of the repetition and partial priming effects after 400 ms post-stimulus onset, and in the scalp distribution of the repetition and formal priming effects. Such differences may be indicative of differences in the processing consequences of partial and repetition priming which may occur even when subjects do not use task specific strategies. Such differences may therefore persist even when steps are taken to discourage subjects from employing such strategies.

In Experiment 1B an attempt was made to constrain the strategies that subjects would employ to perform the LDT. The purpose of the experiment was to determine whether the similarities between the formal and derivational partial priming effects, and the pattern of differences and similarities between the partial and repetition priming effects, would persist under circumstances in which subjects were less likely to to perform the LDT using task-specific strategies.

In Experiment 1B word-nonword pairs such as 'cool - coolene' were included. For these stimuli, although the items presented on successive trials each had a real word as their initial segment, different responses were required on the two trials. Thus the correct response can be determined only by attending to the whole of the item. Attending to only the initial letters of the letter string (e.g. 'cool' in this case) would result in an incorrect response on the non-word trials. Furthermore the inclusion of word-non-word pairs would reduce the proportion of trials on which the occurrence of an unprimed item was a reliable cue to the correct response on the succeeding trial. As in Experiment 1A, since some of the non-words were repeated, repetition cannot be used as a cue to the correct response.

Experiment 1B therefore seeks to further investigate formal and derivational priming effects using experimental stimuli which make the experiment less prone to task specific strategies. Two questions are addressed: Firstly, are the similarities and differences between the effects for the formal and derived word types observed in Experiment 1A still found under circumstances in which the utility of task-specific strategies is reduced? Secondly, under these same circumstances, are the similarities and differences between the partial and repetition priming effects found in Experiment 1A still observed?

4.1 Methods

4..1.1 Subjects

12 adults (8 female) with a mean age of 19 years (range 17-23 years) were paid £2 per hour for participating in the experiment. All but one subject was right handed.

4.1.2 Materials

The same sets and sub-sets of derivational and formal word pairs were used in this experiment as were used in Experiment 1A. 40 formal words and 40 derived words were repeated at a lag of 0, and 40 words of each word type were immediately preceded by their partial prime. Of the remaining 40 word pairs of each word type, 20 root words and 20 formal root words were presented and immediately followed by a non-word which consisted of the prime word plus a pseudo-suffix. Thus the true root 'cool' was followed by the non-word 'coolene'. Each subject saw 40 of such pairs of items over the whole experiment. The remaining 20 root words of each word type were repeated at a lag of 0.

To a set of 62 non-words selected from those used in the first experiment were added the 40 pseudo-suffixed non-words described above, to make a total of 102 non-words. Of the 62 non-words, 38 of various lengths were presented unrepeated. 20 of these non-words ended in a legal derivational suffix (e.g. 'bontous'). Of the other non-words, 12 long and 12 short non-words were repeated at lag 0.

The experimental items and the non-word items were combined with 34 filler words to produce experimental lists of 600 stimuli, subdivided into six blocks of 100 stimuli. Two different pseudo-random ordering of conditions were used and the three sub-sets of stimuli were rotated about the experimental conditions, resulting in the formation of six different stimulus lists. As in the first experiment these lists were constructed subject to a number of constraints :

(i) prime words and the appropriate probe word, as well as the non-word pairings, were presented on immediately succeeding trials,

(ii) each block began with an item which was not from the experimental set,

and (iii) the items were distributed such that there were 79 words and 21 non-words in each block.

4.1.3 Procedure

The experiment was conducted using the same equipment and instructions as had been used in Experiment 1A. EEG and EOG were recorded using the same parameters as had been used in that experiment.

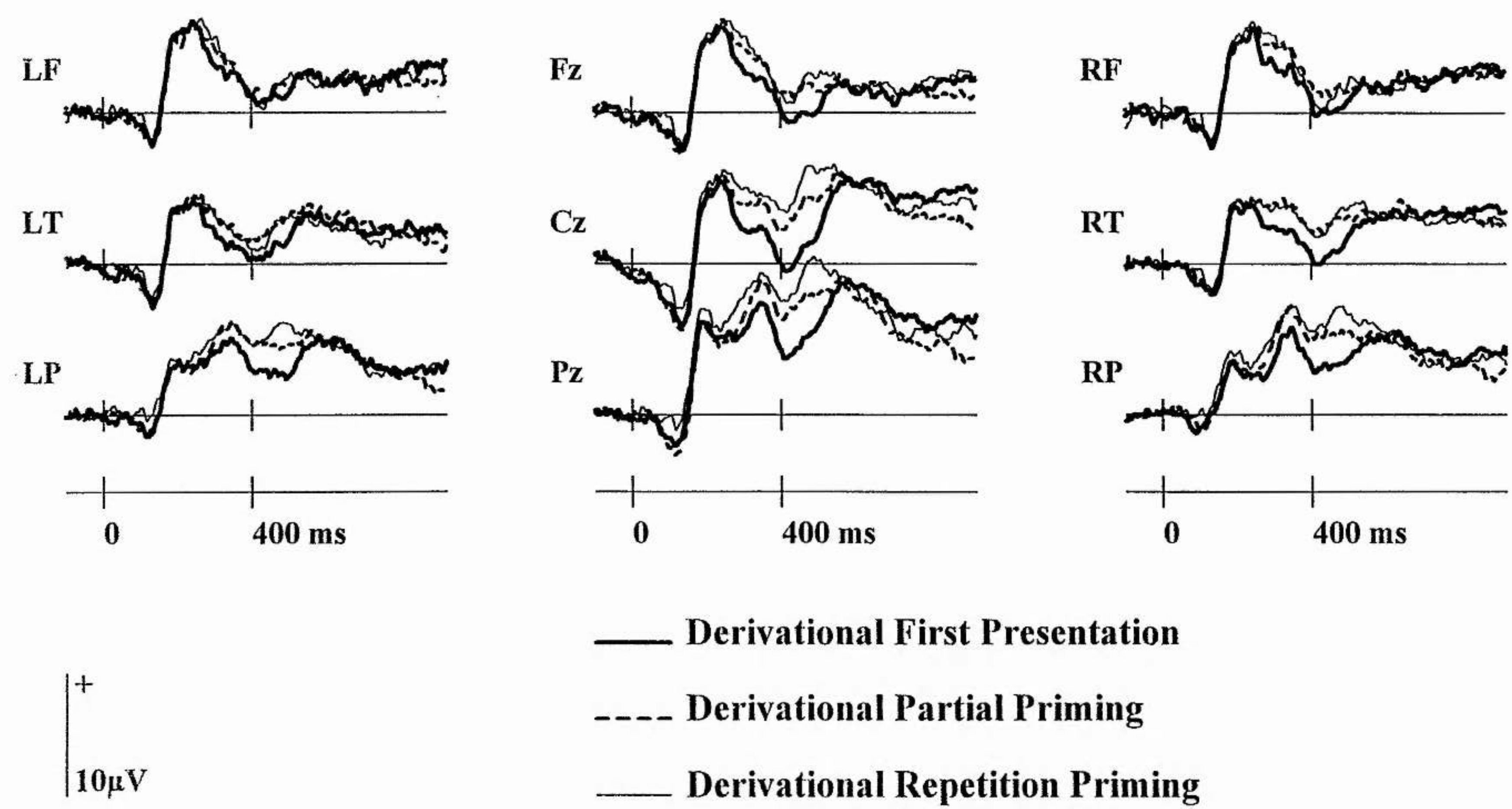


Figure 4.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 1B. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

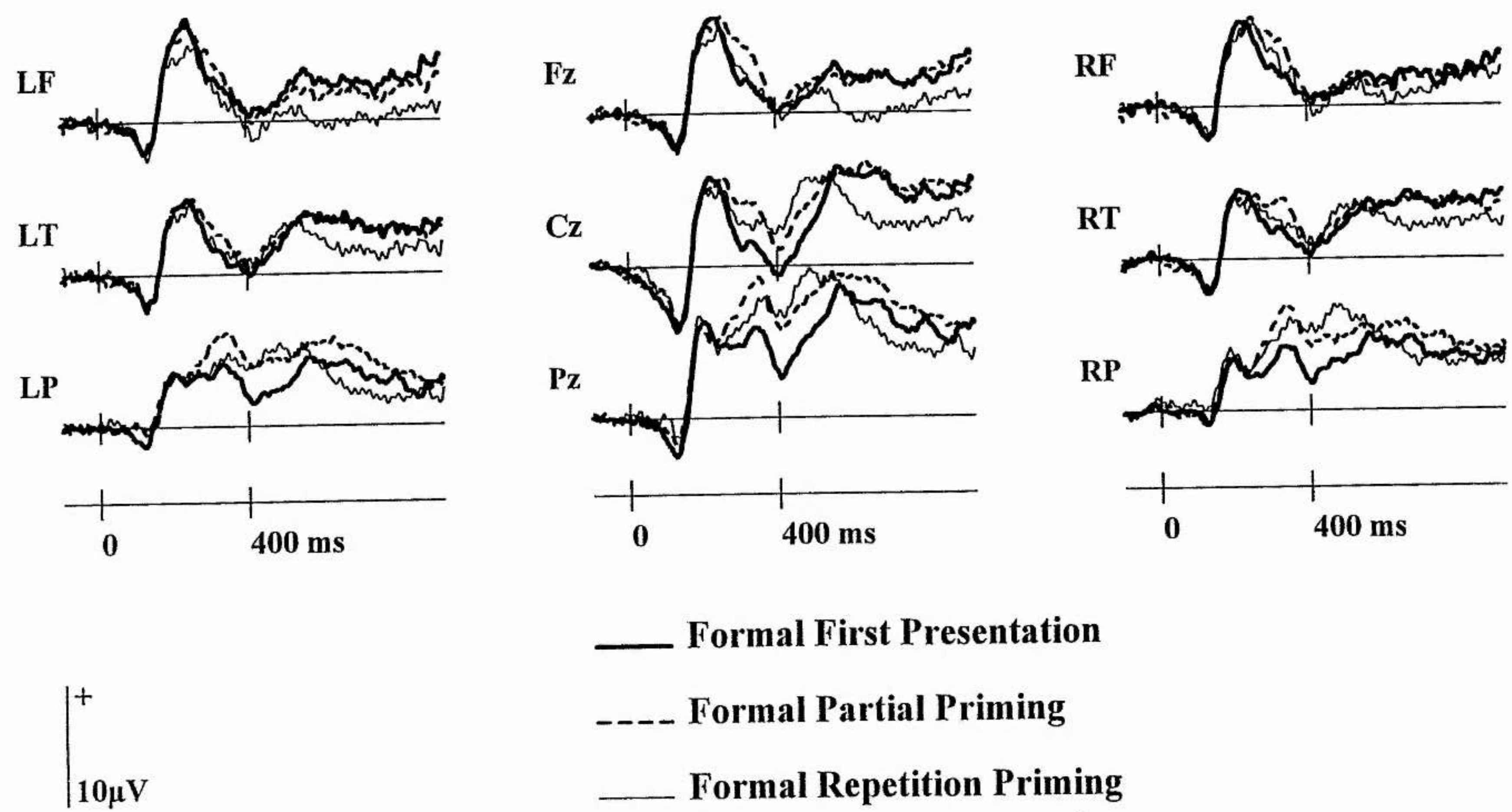


Figure 4.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 1B. Electrode sites as in Figure 4.1.

Table 4.1 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the N126 peak in Experiment 1B.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	-2.39	-4.47	-2.18	-2.02	-2.09	-0.91	-2.20	-2.20	-0.54
Formal Priming	-1.87	-3.89	-1.06	-1.98	-2.14	0.06	-1.91	-2.26	0.01
Formal Repetition	-2.40	-3.76	-0.67	-2.32	-1.96	0.06	-1.74	-1.77	0.83
Derived First Pres.	-2.44	-4.43	-1.52	-1.73	-2.75	-1.03	-1.93	-2.13	0.13
Derivational Priming	-2.86	-4.90	-2.40	-2.06	-2.52	-0.91	-1.90	-1.99	-0.18
Derivational Repetition	-1.84	-3.11	0.10	-1.61	-1.96	0.43	-1.48	-1.49	1.06

Table 4.2 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the P238 peak in Experiment 1B.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	7.32	6.51	6.33	7.65	5.72	3.97	6.50	4.94	3.04
Formal Priming	7.42	6.77	6.84	7.30	5.82	4.52	6.66	5.02	3.80
Formal Repetition	6.35	6.03	6.26	5.62	5.18	4.24	6.36	4.34	3.77
Derived First Pres.	6.60	6.33	6.56	6.99	4.95	4.18	6.20	4.58	3.13
Derivational Priming	7.14	7.05	6.09	6.94	5.52	3.97	6.69	5.27	3.51
Derivational Repetition	7.25	7.38	7.53	7.19	5.26	4.86	7.07	5.21	4.42

Table 4.3 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 1B.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	3.96	3.16	6.40	4.50	3.09	4.18	3.85	2.99	3.88
Formal Priming	5.40	5.22	8.81	4.95	3.98	5.98	5.15	4.25	6.04
Formal Repetition	3.93	4.38	7.86	3.26	3.17	4.85	4.31	3.37	5.63
Derived First Pres.	4.05	3.78	7.24	4.58	2.93	4.92	4.27	3.21	4.66
Derivational Priming	5.18	5.44	8.17	5.02	4.02	5.69	5.44	4.82	5.89
Derivational Repetition	5.50	6.35	9.52	5.29	3.82	6.07	5.56	4.59	6.57

Table 4.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 1B.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	1.94	3.93	7.47	2.29	2.88	3.76	1.56	2.85	4.61
Formal Priming	2.23	5.24	10.13	1.51	3.11	6.00	1.64	3.20	6.44
Formal Repetition	0.94	5.92	10.75	0.00	2.94	5.92	0.77	3.38	7.50
Derived First Pres.	0.75	43.25	7.90	2.06	2.42	4.45	1.14	2.18	5.02
Derivational Priming	2.21	5.61	9.90	2.30	3.79	6.12	2.05	3.79	6.61
Derivational Repetition	2.36	6.99	11.42	2.12	3.13	6.75	1.75	4.01	7.79

Table 4.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 600 - 800 ms post-stimulus onset in Experiment 1B.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	2.86	6.61	8.56	3.17	4.01	4.49	2.46	4.74	5.24
Formal Priming	2.76	7.17	10.13	2.26	4.07	6.01	2.41	4.64	6.60
Formal Repetition	-0.03	3.57	6.75	0.02	1.92	2.93	1.17	2.86	4.61
Derived First Pres.	1.65	6.10	8.96	2.65	3.02	4.83	2.65	4.28	5.59
Derivational Priming	1.81	5.17	7.51	2.68	3.52	4.70	2.89	4.37	4.91
Derivational Repetition	2.22	5.43	7.91	2.65	2.52	4.48	2.71	3.74	5.14

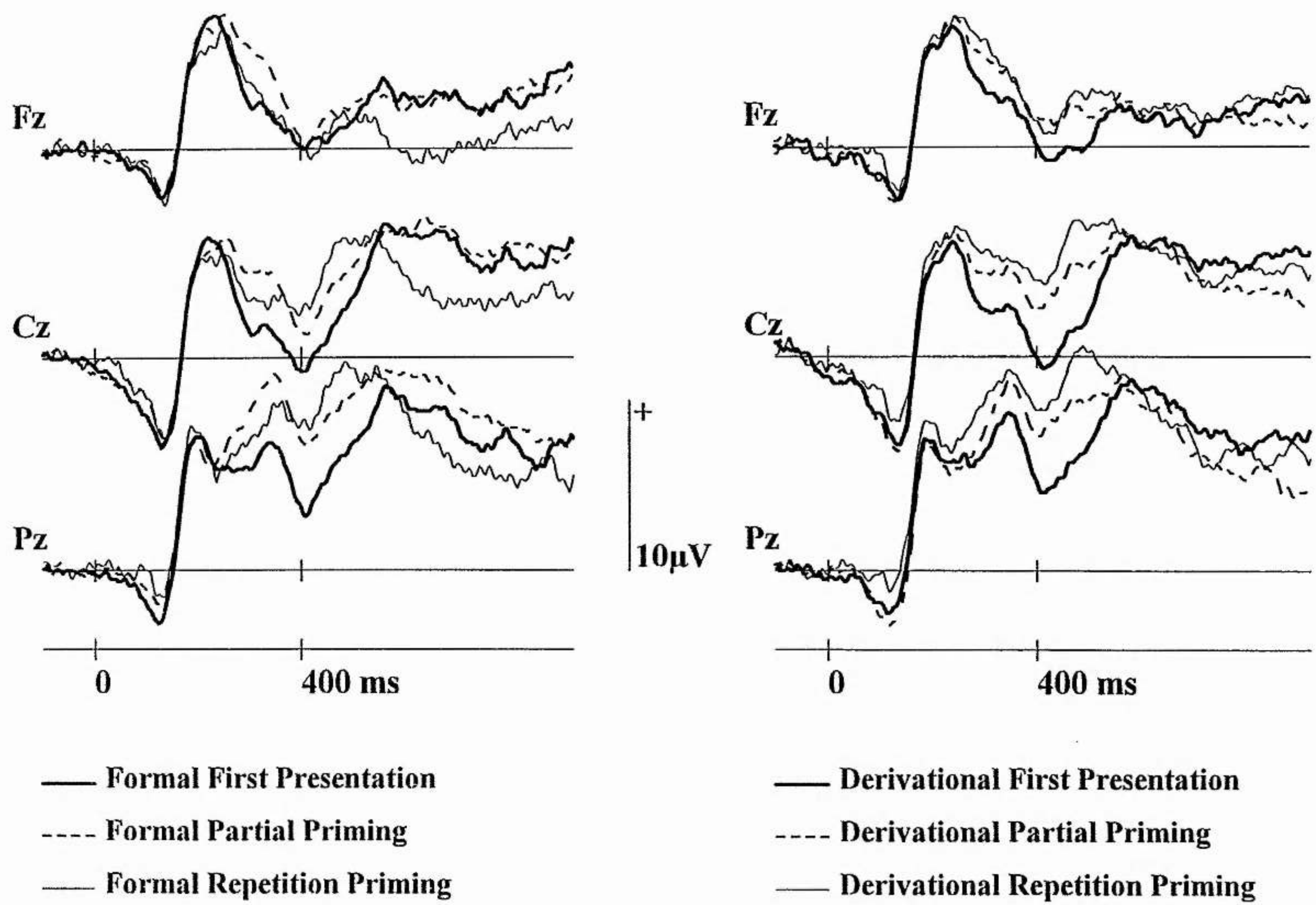


Figure 4.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 1B. Electrode sites as in Figure 4.1.

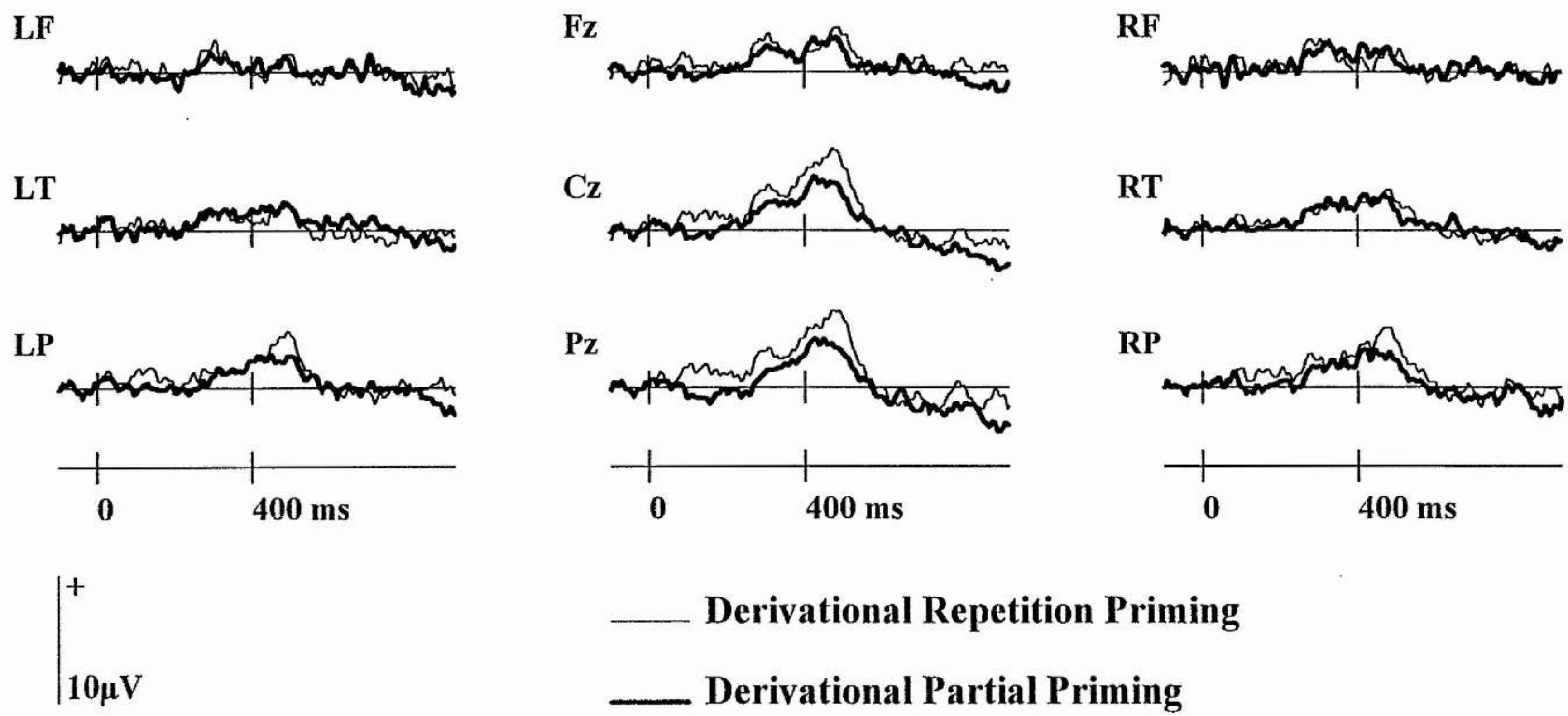


Figure 4.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 1B. Electrode sites as in Figure 4.1.

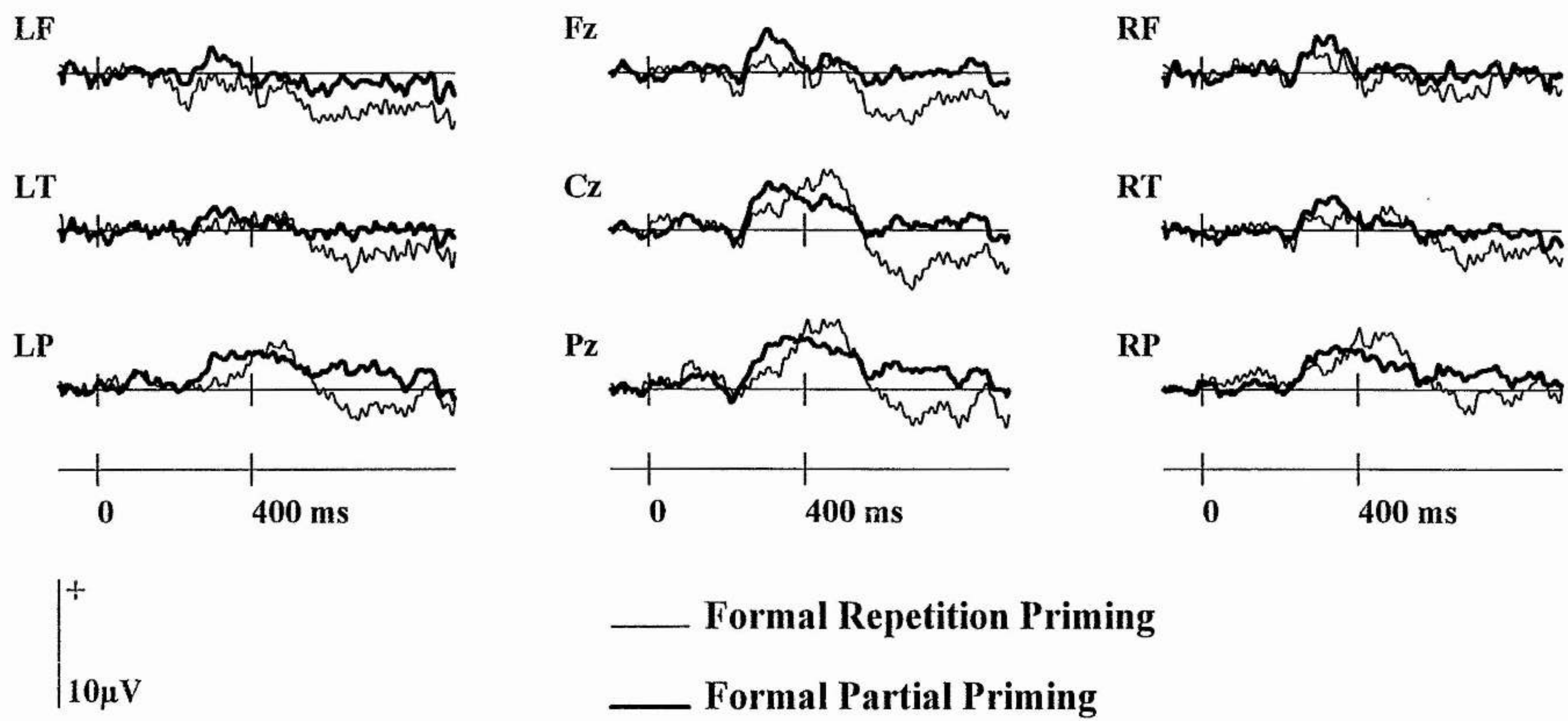


Figure 4.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 1B. Electrode sites as in Figure 4.1.

4.2 Results

4.2.1 Behavioural Data

The mean response time across subjects was 828.3 ms. (sd = 86.3). The mean of the standard deviations across all the subjects was 206.4 (sd = 37.3). The overall error rate was 7.9%. Subjects failed to respond to 10.5% of the target non-words, whilst incorrect responses were made to 7.2% of the real words. The mean response time for these false alarms was 895.1 ms (sd = 114.1) and they were associated with a mean standard deviation across subjects of 236.3 ms (sd = 45.8).

4.2.2 Event Related Potentials

Figures 4.1 and 4.2 show waveforms evoked, by the derived and formal words respectively, in each of the priming conditions at all 9 recording sites. Tables 4.1 - 4.5 give the mean amplitude of the waveforms at each site and in each condition. To more easily allow comparison of the priming effects for the two word types, Figure 4.3 juxtaposes waveforms recorded at midline sites for the formal and derived words. Waveforms from all experimental conditions exhibit prominent N126 (range 116-132 ms) and P238 (range 216-256 ms) deflections.

These early deflections are followed, in all the waveforms, by a slow wave which lasts for the remainder of the recording epoch. As was the case in Experiment 1A, the ERPs elicited by primed words are distinguished from those to unprimed words by a positive-going shift which starts at approximately 200 ms post-stimulus and continues until approximately 600 ms. Point-by-point t-tests indicated that in the repetition conditions the effects for the formal and derived words become reliable across subjects at 360 ms and 268 ms respectively. In the partial priming conditions the effects become reliable at 264 ms for formal words and at 300 ms for derived words.

Subsequent to this slow positive wave, waveforms elicited by the repetition of formal words show a negative going shift relative to the waveform elicited by unrepeated words. This negative-going shift continues for the rest of the recording epoch.

Differences between the effects of the various priming manipulations can be more clearly seen in Figures 4.4 and 4.5 in which the subtraction waveforms are plotted for the derived and formal words respectively. The priming effects in this experiment are similar in a number of ways to the corresponding effects in Experiment 1A. Between 200 and 400 ms post-stimulus onset the formal words show larger effects of partial priming than of repetition. In the following epoch, the formal repetition effect is greater than is the formal partial priming effect. The formal repetition effect appears to have a more posterior distribution than does the formal partial priming effect.

In the third epoch, only the ERP elicited by the repetition of formal words deviates to any degree from that elicited by words on their first presentation. This takes the form of a large negative-going shift of the waveform which is largest at the midline and left hemisphere sites.

The effects for the derived words also show similarities with those found previously. Although the repetition effects are slightly larger than the partial priming effects in the first epoch, this difference is more pronounced in the second epoch. This is especially so at the posterior sites and reflects the more posterior distribution of the repetition priming effects. In the final epoch, the repetition of derived words produces a small negative going shift in the waveform. Partial derivational priming resulted in a waveform which at lateral sites tends to overlie that evoked by words on their first presentation, and over the midline resulted in a negative-going shift of similar magnitude to that produced by word repetition.

The mean number of trials contributed by each subject to each experimental condition was 31, 32 and 31 for the formal first presentation, formal partial and formal repetition conditions respectively. The equivalent values for the derived word conditions were 32, 30 and 31. The statistical analysis of this second experiment will follow the model described in Section 3.1.

4.2.2.1 ANOVA of the mean amplitude of the non-subtracted waveforms

Partial Priming

Table 4.6 summarises the results of the ANOVAs performed on the mean amplitude measurements of waveforms elicited by formal and derived words on their first presentation and when partially primed.

N126

Partial priming of formal and derived words resulted in a pattern of small negative- and positive-going shifts across the midline and lateral sites. ANOVAs performed on the data from midline and lateral sites revealed no reliable effects of prime or word type. Planned comparisons on the effect of partial priming for each word type also failed to detect any significant effects of this variable.

P238

The effects of partial priming on P238 amplitude were small at all sites and mostly consisted of positive-going shifts in the waveforms evoked by the primed words. No statistically reliable effects of presentation type were apparent at either midline or lateral sites. Planned comparisons of the effects of partial priming also failed to reveal any reliable differences between the waveforms.

Table 4.6 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the partial priming conditions for each epoch analysed in Experiment 1B.

N126	Midline	No Significant Differences			
	Lateral	No Significant Differences			
P238	Midline	No Significant Differences			
	Lateral	No Significant Differences			
200 - 400	Midline	presentation type	$F(1,11) = 13.42$	$p < 0.005$	
	Lateral	presentation type	$F(1,11) = 13.42$	$p < 0.005$	
400 - 600	Midline	presentation type	$F(1,11) = 5.89$	$p < 0.05$	
		presentation type x site	$F(2,22) = 4.37$	$p < 0.05$	$\varepsilon = 0.68$
	Lateral	No Significant Differences			
600 - 800	Midline	word type x presentation type x site	$F(2,22) = 5.39$	$p < 0.05$	$\varepsilon = 0.02$
	Lateral	No Significant Differences			

200 - 400 ms

There were reliable main effects of presentation type in waveforms elicited over the midline and over the lateral sites. Planned comparisons showed that, for formal words, this shift was reliable at midline and lateral sites. In the case of the derived words the partial priming effect was only marginally significant over the midline ($0.05 < p < 0.10$), but was reliable at the lateral sites.

Because of the delayed onset of the derived partial priming effect compared to the formal partial priming effect, a similar analysis was performed on the mean amplitudes of the waveforms measured between 300 and 400 ms post-stimulus onset. ANOVA revealed a reliable main effect of presentation type in the midline and lateral analyses. Planned comparisons of the mean amplitudes of the first and partially primed presentations revealed that, for each word type, they differed reliably over both the midline and lateral sites.

400 - 600 ms

At midline sites there was a reliable main effect of presentation type but planned comparisons showed that the partial priming effect for neither word type was individually reliable. There was a reliable interaction between presentation type and site. None of the effects of presentation type at individual sites were reliable. Scheffé tests revealed that the priming effect was greater at Pz than at Fz.

A posterior distribution of the partial priming effect is also evident in the waveforms recorded from the lateral sites. However both the main effect of presentation type and the interaction between presentation type and site were each only marginally significant ($0.05 < p < 0.10$, in both cases). Planned comparisons on the repetition effects for each word type indicated that the effects of partial priming at the lateral sites were not reliable. A Newman-Keuls test indicated that, collapsed across word types and hemispheres, the partial priming effect was reliable at parietal sites.

600 - 800 ms

ANOVA showed the main effect of presentation type not to be reliable, nor did planned comparisons for each word type show the effects of partial priming to be reliable. Partial priming of formal words resulted in a positive-going shift in waveforms recorded at Cz and Pz, and a small negative-going shift at Fz. In contrast, partial priming of derived words resulted in a negative-going shift at Cz and Pz and a small positive-going shift at Fz. This difference in the pattern of effects between the word types resulted in a reliable 3-way interaction between word type, presentation type and site. For each word type, although the partial priming effect was greatest at Pz, it was not reliable at this one site. The effects of partial priming did not differ between word types at Fz, but at Cz and at Pz the positive-going formal partial priming effects differed reliably from the negative-going derivational partial priming effects.

At lateral sites, other than at the parietal location, the waveforms elicited by first and partially primed presentations essentially overlaid one another. ANOVA and the subsequent planned comparisons indicated that there were no reliable differences between conditions. Even the 1.4 μV difference between the waveforms elicited at the parietal sites by formal words on their first and partially primed presentations was not reliable.

Repetition Priming

Table 4.7 summarises the results of the ANOVAs performed on the mean amplitude measurements of waveforms elicited by formal and derived words on their first presentation and when partially primed.

N126

Word repetition produced a positive-going shift in the ERP rather than the negative-going effect seen in the previous experiment. The main effect of presentation type was not reliable in either the midline nor the lateral data sets.

In midline and lateral analyses there was a reliable interaction between presentation type and site. For midline sites the positive-going shift was greatest at posterior sites, whilst at lateral sites it was numerically greatest at temporal sites. Post-hoc tests revealed that the repetition effect was not reliable at any one midline site, but that the magnitude of the positive-going shift was greater at Pz than at Fz and Cz. At lateral sites, there was no one site at which the repetition effect was reliable, nor were there any reliable differences in the magnitudes of the effect at the different sites.

P238

The repetition of formal and derived words resulted respectively in small negative- and positive- going modulations in the waveform. Over the midline the main effect of presentation type was not reliable, nor were there any other reliable effects.

At lateral sites, the main effect of presentation type was not reliable, but the 3-way interaction between presentation type, hemisphere and site was. This reliable interaction reflected the contrast between the reduction in the amplitude of the P238 as a result of repetition at the two more anterior sites over the left hemisphere, and the increase in its amplitude at all other sites. Post-hoc tests indicated that at no single site was the repetition effect reliable, but the difference between the negative-going shift at the left frontal site, and the positive-going shift at the right frontal site was reliable.

Table 4.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the repetition priming conditions for each epoch analysed in Experiment 1B.

N126	Midline	presentation type x site	$F(2,22) = 5.38$	$p < 0.05$	$\varepsilon = 0.60$
	Lateral	presentation type x site	$F(2,22) = 4.42$	$p < 0.05$	$\varepsilon = 0.86$
P238	Midline	No Significant Differences			
	Lateral	presentation type x hemisphere x site	$F(2,22) = 4.79$	$p < 0.05$	$\varepsilon = 0.76$
200 - 400	Midline	presentation type	$F(1,11) = 9.95$	$p < 0.01$	
		word type	$F(1,11) = 7.30$	$p < 0.05$	
	Lateral	presentation type	$F(1,11) = 9.57$	$p = 0.01$	
		word type	$F(1,11) = 5.14$	$p < 0.05$	
400 - 600	Midline	presentation type	$F(1,11) = 16.04$	$p < 0.005$	
		presentation type x site	$F(2,22) = 11.11$	$p < 0.005$	$\varepsilon = 0.60$
	Lateral	presentation type	$F(1,11) = 7.85$	$p < 0.05$	
		presentation type x hemisphere	$F(1,11) = 6.59$	$p < 0.05$	
		presentation type x site	$F(2,22) = 9.35$	$p = 0.005$	$\varepsilon = 0.67$
600 - 800	Midline	presentation type	$F(1,11) = 6.11$	$p < 0.05$	
	Lateral	presentation type	$F(1,11) = 6.23$	$p < 0.05$	

200 - 400 ms

In the ANOVA of the midline sites the main effect of presentation type was reliable. Planned comparisons on the repetition effect for each word type separately showed that only the effect for the derived words was reliable. The same pattern of effects was found in the analysis of the data from lateral sites.

For both the midline and lateral sites the interaction between presentation type and site was marginally significant ($0.05 < p < 0.01$ in both cases).

The absence of a repetition effect for the formal words was surprising given the apparent size of the formal repetition effects immediately before 400 ms. The failure of the formal repetition effect to achieve significance may be due to the delayed onset of the effects in this condition. The results of the point-by-point t-tests indicated that the formal repetition effect became reliable only after approximately 360 ms. A further ANOVA was carried out on the mean amplitude of the waveforms in a more restricted time interval, from 300 - 400 ms post-simulus onset. Over the midline there was a reliable main effect of presentation type. Planned comparisons indicated that the repetition effect for each word type was reliable. There was also a reliable interaction between presentation type and site. Post hoc tests indicated that the repetition effect was reliable at Cz and Pz. The magnitude of the repetition effect was reliably smaller at Fz than at Cz and Pz, but the magnitude of the effects at the two more posterior sites did not differ reliably from one another.

There was a similar pattern of effects at the lateral sites in this restricted epoch. The main effect of presentation type was reliable. Furthermore, planned comparisons showed the repetition effect for each word type to be individually reliable. There was also a reliable interaction between presentation type and site. The effect of presentation type was reliable at temporal and parietal sites, collapsed over hemisphere. The positive-going shift at the parietal sites was greater than that at the frontal sites.

The waveforms evoked by the derived words were more positive-going than were those evoked by the formal words. The main effect of word type was reliable in the midline and in the lateral analyses both between 200 - 400 ms and between 300 - 400 ms. In none of the analyses were the interaction effects between the factor of word type and any other factors reliable.

400 - 600 ms

At midline sites, ANOVA revealed a reliable main effect of presentation type, together with a reliable interaction between presentation type and site. Planned comparisons of the repetition effect for each word type showed that the derivational repetition priming effect was reliable, whilst the formal repetition priming effect was not. Post-hoc tests of the repetition effect for formal words at Cz and Pz showed it to be reliable at each of these sites. The repetition of the derived words also resulted in reliable positive-going shifts at Cz and Pz, but the positive-going shift at Fz was not reliable.

At lateral sites there was a main effect of presentation type reflecting the more positive-going waveforms evoked by words on their second, compared to their first, presentation. Planned comparisons across presentation types for each word type showed the effect of presentation type to be reliable only for the derived words.

There was also a reliable interaction between presentation type and site at the lateral sites. The effect of presentation type was larger at the temporal and parietal sites than at the frontal sites. When the effect of presentation type was tested at these more posterior sites, it was reliable for both word types.

The interaction between presentation type and hemisphere was also reliable. The repetition effects were larger over the right hemisphere than over the left.

600 - 800 ms

There were main effects of presentation type in the analyses of data from both midline and lateral electrodes. None of the other effects was reliable. Planned comparisons revealed that, at midline and at lateral sites, the negative-going formal repetition priming effect was reliable, but that the negative-going shift resulting from the repetition of derived words was not.

4.2.2.2 ANOVA of the mean non-rescaled amplitudes of the subtraction waveforms

ANOVAs were performed on the mean amplitudes of the subtraction waveforms using factors of word type (derived vs formal) and prime type (repetition vs partial). These ANOVAs were followed by planned comparisons of the effects of prime type for each word type, and of the effects of word type for each prime type.

Table 4.8 summarises the results of the ANOVAs performed on the mean amplitude measurements of the subtraction waveforms elicited by each word type and in each priming condition.

None of the ANOVAs performed on the non-rescaled or rescaled amplitudes around the N126 and P238 peaks was reliable.

200 - 400 ms

ANOVA revealed no reliable effects over the midline. A planned comparison of the magnitude of the repetition and formal priming effects indicated that they did not differ reliably for either word type. For each priming condition, a planned comparison of the mean amplitude of the

Table 4.8 Summary of the results of the ANOVAs performed on the non-rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 1B

N126	Midline	No Significant Differences			
	Lateral	No Signiificant Differences			
P238	Midline	No Significant Differences			
	Lateral	No Significant Differences			
200 - 400	Midline	No Significant Difference			
	Lateral	No Significant Differences			
400 - 600	Midline	prime type x site	$F(2,22) = 7.62$	$p < 0.05$	$\varepsilon = 0.64$
	Lateral	hemisphere	$F(1,11) = 5.06$	$p < 0.05$	
600 - 800	Midline	prime type x word type	$F(1,11) = 6.95$	$p < 0.05$	
		word type x site	$F(2,22) = 5.36$	$p < 0.05$	$\varepsilon = 0.61$
	Lateral	prime type	$F(1,11) = 6.57$	$p < 0.05$	

waveforms elicited by each word type, indicated that in neither case were the differences between the word types reliable.

At lateral sites, ANOVA revealed no reliable effects. A planned comparison indicated the formal partial priming effect was reliably larger than the formal repetition effect. None of the other planned comparisons of the magnitude of the priming effects showed them to differ reliably at the lateral sites.

400 - 600 ms

ANOVA revealed no reliable main effects of either prime type or word type in the analysis of the data from the midline sites. Planned comparisons revealed no reliable differences between any of the priming conditions.

The midline ANOVA did reveal a reliable interaction between the factors of prime type and site. Although the prime type effect was greatest at Pz, this difference was not reliable when tested at this site alone. The magnitude of the prime type effect was reliably greater at Cz and Pz than that at Fz.

When the analogous ANOVA was performed on data from the lateral sites, none of the effects involving the factors of prime or word type were found to be statistically reliable. The interaction between prime type and site was marginally significant ($0.05 < p < 0.10$), again reflecting the more posterior distribution of the repetition effect compared to the partial priming effect.

600 - 800 ms

Over the midline, the positive-going shift resulting from the partial priming of formal words contrasted with the negative-going shifts seen in the other priming conditions. This difference was reflected in a reliable word type by prime type interaction. Planned comparisons indicated that none of the differences between the priming effects was reliable.

Superimposed upon the difference in the polarity of the effects is a difference in the distribution of the priming effects over the midline sites. While the priming effects for the formal words tend to be more negative-going toward the front of the head, the waveforms elicited by derived words were more negative-going at the posterior sites. This difference resulted in a reliable interaction between word type and site. At no single site was the difference between word types reliable, but the word type effect at Fz differed reliably from that at Pz.

At the lateral sites there was a main effect of prime type. Whilst word repetition resulted in a negative-going shift, the positive-going shift engendered by partial priming in the earlier epochs persisted into this final epoch. For neither word type were these effects individually reliable when tested using planned comparisons, nor were the differences between word types in each priming condition reliable.

4.2.2.3 ANOVA of the mean rescaled amplitudes of the subtraction waveforms

Within Epoch

Table 4.9 summarises the results of the ANOVAs performed on the rescaled mean amplitude measurements of the subtraction waveforms elicited by each word type and in each priming condition. None of the ANOVAs performed on the rescaled measurements around the N126 and P238 peaks were reliable.

200 - 400 ms

None of the effects involving prime type or word type was reliable. There was however a reliable main effect of chain. The magnitude of the priming effects over the midline was greater than that over the left hemisphere, but was not greater than the magnitude of the priming effect over the right hemisphere. The difference between the right and left hemispheres was marginally non-significant.

400 - 600 ms

There were no reliable effects involving the factors of prime type or word type.

There was a reliable main effect of chain. The magnitude of the priming effects were greater over the midline than over the left hemisphere. Neither of the other pairwise contrasts was reliable.

600 - 800 ms

The interaction between the factors of word type and site was marginally significant ($0.05 < p < 0.10$). The interaction between word type, prime type and chain was reliable. This interaction was further investigated using a series of Scheffé tests. The large negative-going shift in the formal repetition effects over the midline resulted in a reliable difference in the pattern of effects across the midline and right hemisphere between the two formal priming conditions. Similarly, the smaller negative-going shift in the partial derivational priming effects was reflected in a reliable difference in the pattern of partial priming effects seen for the two word types over the midline and left hemispheres.

Across-Epoch

The rescaled analyses of neither the 200 - 400 ms nor the 400 - 600 ms epochs showed any reliable differences in the topographic distribution of the four priming effects, or that the

Table 4.9 Summary of the results of the ANOVAs performed on the rescaled mean amplitude measurements of the subtraction waveforms in each epoch measured in Experiment 1B.

N126	No Significant Differences				
P238	No Significant Differences				
200 - 400	chain	$F(2,22) =$	3.71	$p < 0.05$	$\varepsilon = 0.95$
400 - 600	chain	$F(2,22) =$	5.02	$p < 0.05$	$\varepsilon = 0.71$
600 - 800	prime type x word type x chain	$F(2,22) =$	4.46	$p < 0.05$	$\varepsilon = 0.96$

distribution of these effects were different in the two epochs. Thus analyses of the data across epochs were not performed.

Whilst there may have been topographic differences between the second and third epochs, the change in the polarity of these effects from positive-going in the second epoch to negative-going in the third epoch, means that the interpretation of differences in the topography of the effects is difficult and their interpretation uncertain. Across epoch analyses were therefore not performed across the second and third epochs.

In neither of the experiments reported so far have the across-epoch analyses been useful in showing differences in the pattern of priming effects. In Experiment 1A this was because the interpretation of the significant 4- and 5- way interactions was uncertain. In this experiment, the reversal of the polarity of the effects across the second and third epochs also made the interpretation of the ANOVAs complex. Although across-epoch analyses were performed for Experiments 2,3,4 and 5 to be reported in the following chapters, they were beset by similar interpretational difficulties. The outcomes of these analyses will not, therefore, be reported.

4.3 Discussion

Experiment 1B sought to determine whether the similarities and differences between the formal and derivational partial and repetition priming effects seen in Experiment 1A could be replicated when subjects were less likely to engage in task-specific strategies. When such strategies were discouraged, differences between the two word types may have emerged. Such differences might reflect differences in the functional significance of formal and derivational relationships between words.

As in Experiment 1A, there were reliable effects of partial and repetition priming on both word types throughout most of the interval between 200 ms and 600 ms post-stimulus. Although the repetition effects became larger than the partial priming effects in the second broad epoch, this difference between the effects was reliable only at posterior sites.

There was no evidence that the derivational partial priming effects differed either quantitatively or qualitatively from the formal partial priming effects. Thus even when steps were taken to reduce the degree to which subjects employed task-specific strategies, there was no evidence to suggest that ERPs are sensitive to derivational relationships between words.

There was some evidence of differences in the modulations of ERPs elicited by the two word types. Between 200 and 400 ms post-stimulus onset the waveforms elicited by the derived words were more positive-going than were the waveforms elicited by the formal words. That the two word types were discriminated in the ERPs indicates that ERPs may be sensitive to the morphologically complex nature of derived words. However this difference was additive with the effects of repetition. Thus ERPs do not appear to be sensitive to derivational relationships between words.

The repetition effects for the derived words onset some 100 ms earlier than did the formal repetition effect. Although there was a difference of some 50 ms in the onset latency of the two repetition effects in Experiment 1A, in that experiment it was the formal repetition effects which became reliable first. If this difference between the two experiments was a result of the introduction of the word nonword pairs, then the reason for it is not clear. There was no equivalent change in the relative onset latencies of the partial priming effects across the two experiments with the formal partial effects becoming reliable earlier than the derivational partial priming effects. The inconsistencies between Experiments 1A and 1B with respect to the onset latencies of the priming effects means that the degree to which the onset latency data assist in determining the nature, and dynamics, of the cognitive processes underlying the observed priming effects is limited.

Between 400 and 600 ms post-stimulus onset, the partial priming effects showed a more even distribution from the anterior to the posterior of the head than did the repetition effects. However this difference was not reliable when the data were rescaled. Thus, unlike in Experiment 1A, this difference cannot be ascribed to differences in the sets of generators underlying the repetition and partial priming effects.

Although the priming effects observed showed the right-greater-than-left pattern characteristic of modulations of the N400, the analyses of the rescaled data did not find this difference to be reliable. Nonetheless, the finding that the difference in the magnitude of the priming effect between the midline and left hemisphere was reliable, but the difference in the magnitude of the priming effect between the midline and right hemisphere was not, provides some indirect support for the presence of an hemispheric asymmetry in the distribution of the priming effects.

The changes in the structure of some of the non-critical items in Experiment 1B, compared to those used in Experiment 1A, did not result in the emergence of differences between the ERPs elicited by the two word types. Rather, the most notable result from the first experiment, the topographic difference between the positive-going shifts resulting from repetition and formal priming, was no longer reliable in the second experiment. This result suggests that the inclusion of formally related word-nonword pairs made the processing consequences of repetition and partial priming more similar than they had been in Experiment 1A.

Although the inclusion of the formally related word-non-word pairs was intended to reduce the degree to which subjects used task specific strategies, the extent to which this aim was achieved is open to doubt. This is because of the difficulty in determining whether the inclusion of the 'cool - coolene' pairs did indeed result in subjects processing the whole of the item, rather than attending to only the initial part of the letter string.

One indication that subjects attended to the whole stimulus would have involved an analysis of the number of errors made to the 'coolene' type of item. If subjects had primarily been attending to the initial string, then errors on such items would be more likely. Unfortunately non-words such as 'coolene' may have attracted a higher error rate even if subjects had attended to the whole item. Lexical decisions to non-words that contain embedded words as their initial segment are more difficult than lexical decisions to other non-words (Taft & Forster, 1976), thus more errors on 'coolene'-type items than on non-words of equivalent length which do not contain an embedded word, could simply reflect the presence of the word. Thus the claim that subjects attended to only the initial portion of the stimuli less in Experiment 1B than in Experiment 1A, remains only an assumption.

Experiment 2 investigates further the conditions under which formal and morphological priming effects are observed. Although Experiment 1B attempted to reduce the degree to which subjects selectively attended to a restricted region of the stimulus, no attempt was made to control for subjects using the prime word to anticipate the identity of the probe word. Were subjects to engage in this strategy then this could again result in the partial priming condition being transformed into a *de facto* repetition task. The first encounter with a word would be when it was covertly generated by the subject as a result of the presentation of the prime word. The second encounter would result from the presentation of the probe word itself. One manipulation that may prevent such an anticipatory strategy aiding task performance is to present intervening stimuli between the prime and probe items. The lag between the presentation of prime and probe words has previously been shown to dissociate behavioural consequences of derivational and formal priming (see Section 1.7). Experiment 2, therefore, investigated whether formal and derivational priming effects could also be dissociated using this variable of inter-item lag.

Chapter 5

Experiment 2

ERP repetition, formal and derivational priming effects at lag 6.

5.0 Introduction

In Experiments 1A and 1B, interpretations of the functional significance of the ERP derivational priming effects obtained were compromised by the presence of ERP modulations resulting from purely formal similarity between words, and the similarity of these effects to those resulting from derivational priming.

The inclusion of formally related word-non-word pairs (e.g. 'cool - coolene') in Experiment 1B was an attempt to reduce the degree to which subjects attended to the initial part of the critical words, thereby converting the partial priming condition into a *de facto* repetition condition. To the extent that this was successful, it suggests that the ERP priming effects seen in Experiment 1A did not arise as a result of task-specific strategies. The similarities between the ERP formal and derivational partial priming effects in Experiments 1A and 1B suggests that ERP formal and derivational priming effects reflect changes in the same cognitive process or set of processes. Given the absence of a derivational relationship between the formally related words, it is unlikely that this process is one concerned with the processing of morphological information. Since the only thing common to the derivational and formal word pairs is the formal similarity of the members of each pair, the process underlying the partial priming effects is more likely to be one which is sensitive to formal similarity between words.

Since the repetition condition can be seen as asymptotic formal priming, in which the overlap between prime and probe is 100%, the possibility arises that, in the present experiments at least, the repetition effects can be seen as a stronger example of the partial priming effects. In Experiment 1A the repetition and partial priming effects differed on two counts; firstly the repetition effects had a more posterior distribution than did the partial priming effects and, secondly, the magnitude of the repetition effects after 400 ms post-stimulus onset was greater than the magnitude of the partial priming effects in the same interval. Although the difference in the magnitude could be accounted for as a reflection of the greater degree of formal overlap in the repetition than in the formal priming condition, the distributional differences between the two prime types are less easily accounted for in this way. This is because the distributional differences between conditions were present even after the data had been rescaled; a finding which suggests that the two effects were manifestations of changes in the activity of different neural generators.

This conclusion was not supported by the results of Experiment 1B. In that experiment, when the four priming effects were compared in the subtraction waveforms, no differences between them were found in either magnitude or distribution. One motivation for Experiment 1B was to provide an opportunity for differences between the partial and repetition priming conditions to emerge when the partial priming condition was less likely to be treated as a *de facto* repetition condition. However, in this experiment the waveforms elicited by repetition and partial priming were more like each other than they had been in Experiment 1A. Why this should have been so is unclear, but this result does suggest that either the attempt to prevent subjects using task-specific strategies was unsuccessful, or that these effects are not dependent upon the use of such strategies. In Experiment 2, a further attempt is made to dissociate the effects of formal and derivational partial priming using the variable of inter-item lag.

As reviewed in the Chapter 1, a number of studies have suggested that behavioural priming effects resulting from formal similarity between words is dependent upon the lag between the formally similar items being short. The brevity of formal priming effects contrasts with the effects resulting from morphological relationships between words, which are as persistent as repetition priming effects.

If the ERP partial priming effects parallel the analogous behavioural priming effects, then it would be predicted that whereas ERP derivational priming effects will survive the introduction of a lag between the presentation of the prime and probe items, the ERP formal priming effects will not. However, investigations of the time course of ERP repetition effects, at least as reflected in modulations of the N400, have shown that they do not always parallel those of behavioural repetition effects (e.g. Rugg, 1990). It is, therefore, possible that the introduction of a lag between the prime and probe items will not result in a dissociation of derivational and formal ERP priming effects.

On the other hand, were the persistence over time of the ERP formal and derivational priming effects to be similar, this would provide another example of a dissociation between ERP and behavioural priming effects. It would also further constrain the possible mechanisms underlying the ERP derivational and formal partial priming effects, making it even more likely that these effects arise because of the formal similarity between the members of the word pairs.

5.1 Methods

5.1.1 Subjects

12 right-handed adults (6 female) with a mean age of 22 years (range 17-33 years) participated in the experiment. They were each paid £6.

5.1.2 Materials

The experimental items consisted of the same three sets of words as was used in the previous two experiments. The non-words and word fillers were the same as had been used in Experiment 1B. Each subject saw 40 words in each of the 4 priming conditions; formal repetition priming, formal partial priming, derived repetition priming and derived partial priming.

Two pseudo-random orderings of conditions were constructed such that of the 40 words in each priming condition, 10 were primed at a lag of 5, 10 were primed at a lag of 7 and 20 were primed at a lag of 6 intervening items. Such variation in the lengths of the lags between primes and probes means that the contingent relations between items were minimal. As with the previous Experiment each of 6 blocks of 100 items began with either a word filler or an unrepeated non-word. Experimental items were evenly distributed across blocks, as were the non-words. A total of 6 experimental lists were produced by rotating the items across conditions and assigning them to sequential positions determined by each of the two condition code sequences. Within each list, each word occurred only once, whilst across lists words from a particular pairing occurred in both partial and repetition priming conditions. Each experimental list was seen by two subjects.

5.1.3 Procedure

The Experiment was conducted using the procedure described in Section 3.1.

5.2 Results

5.2.1 Behavioural Data

The overall error rate collapsed across misses and false alarms was 11.4%. Subjects missed on average 18.7% of the targets and made false alarm responses to 7.0% of the real words. The mean reaction time for correct responses was 863.1 ms (sd = 214.7), and the mean standard deviation across subjects of these responses was 208.9 ms (sd = 69.8). False alarm responses were associated with a mean RT of 799.8 ms and had an across subject mean standard deviation of 178.7 ms (sd = 63.1).

5.2.2 Event Related Potentials

As in previous experiments ERPs recorded to the words in all experimental conditions have prominent N99 and P186. These peaks are followed by a slow wave which, apart from a short period around 400 ms post stimulus at some sites, remains positive for the whole of its duration. Across subjects, the peak latency of the N99 ranged between 84 ms and 108 ms, whilst the peak latency of the P186 ranged from 176 ms to 200 ms. Figures 5.1 and 5.2 show the waveforms elicited by the formal and derived word types respectively in each of the presentation conditions. Figure 5.3 shows, at a larger scale, the effects over the midline for each word type and for each presentation condition.

As can be seen in these figures, the effects of priming in this experiment are somewhat smaller than in the previous two. The subtraction waveforms for each word type are shown in Figures 5.4 and 5.5. The small sizes of the priming effects are reflected in the point-by-point t-tests performed on the mean amplitudes of the subtraction waveforms. For each of the priming

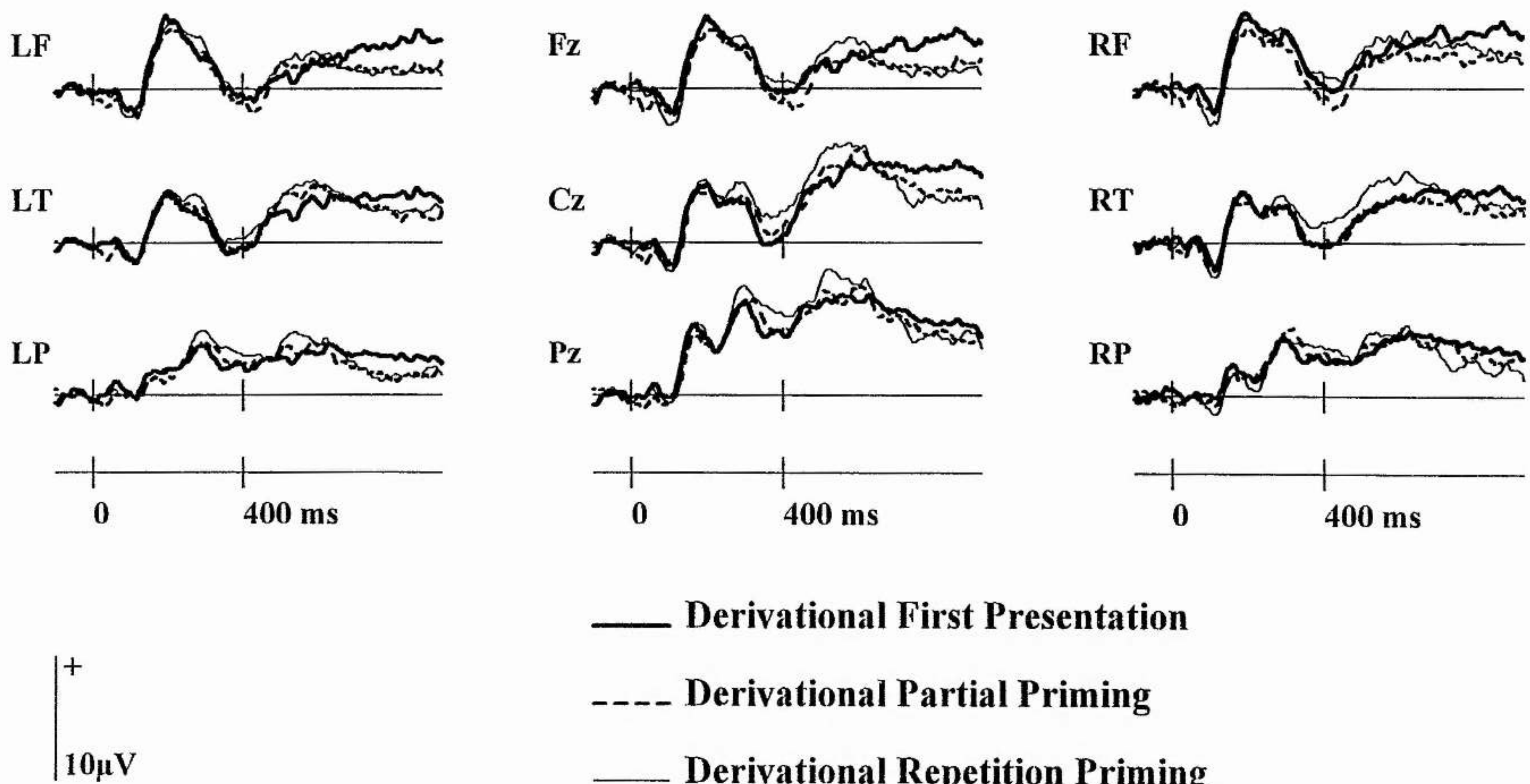


Figure 5.1 ERPs elicited at each electrode site by the first presentations of derived words, by repeated derived words and by derived words primed by their root forms in Experiment 2. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

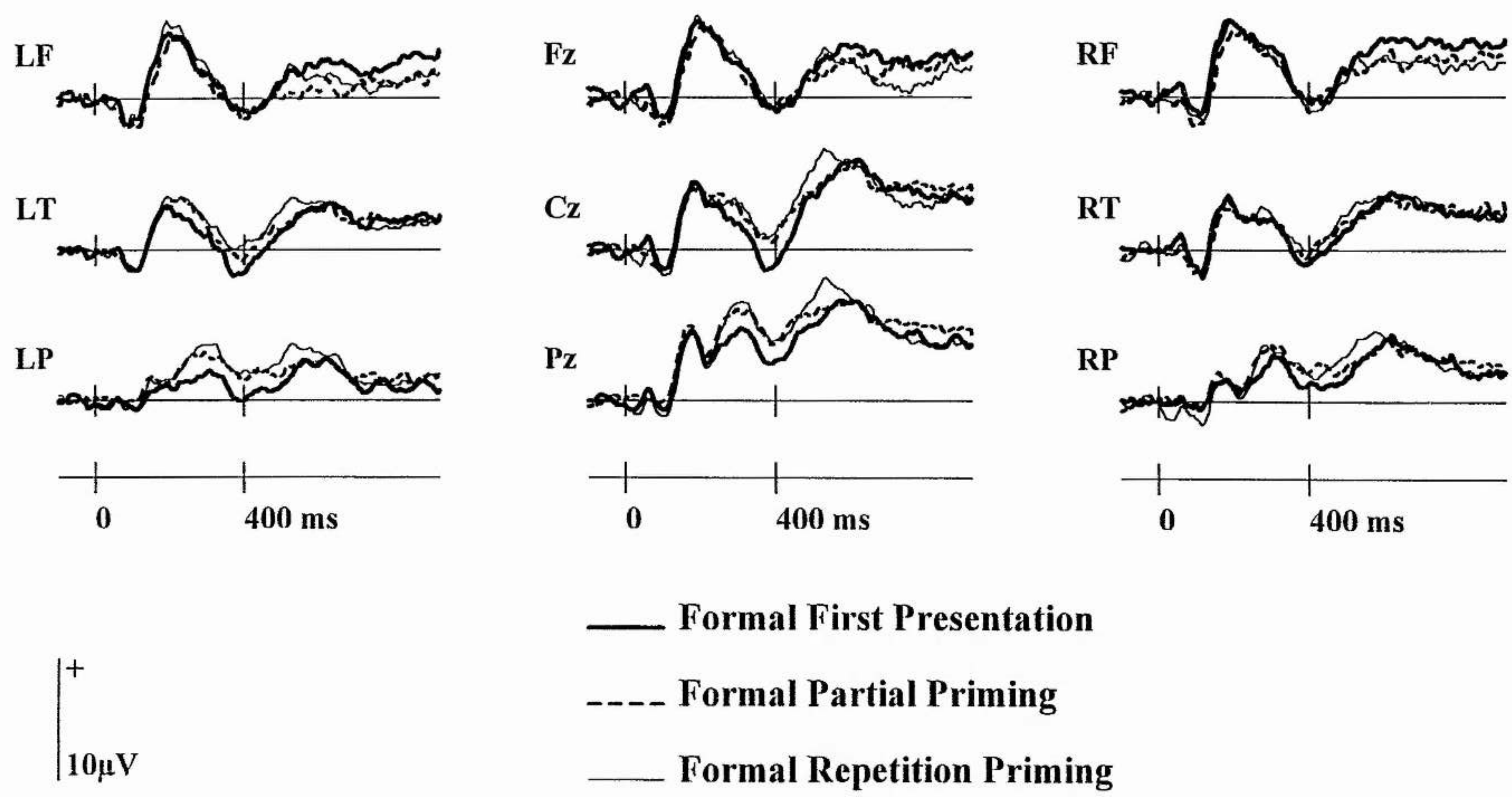


Figure 5.2 ERPs elicited at each electrode site by the first presentations of formal words, by repeated formal words and by formal words primed by their formal root forms in Experiment 2. Electrode sites as in Figure 5.1.

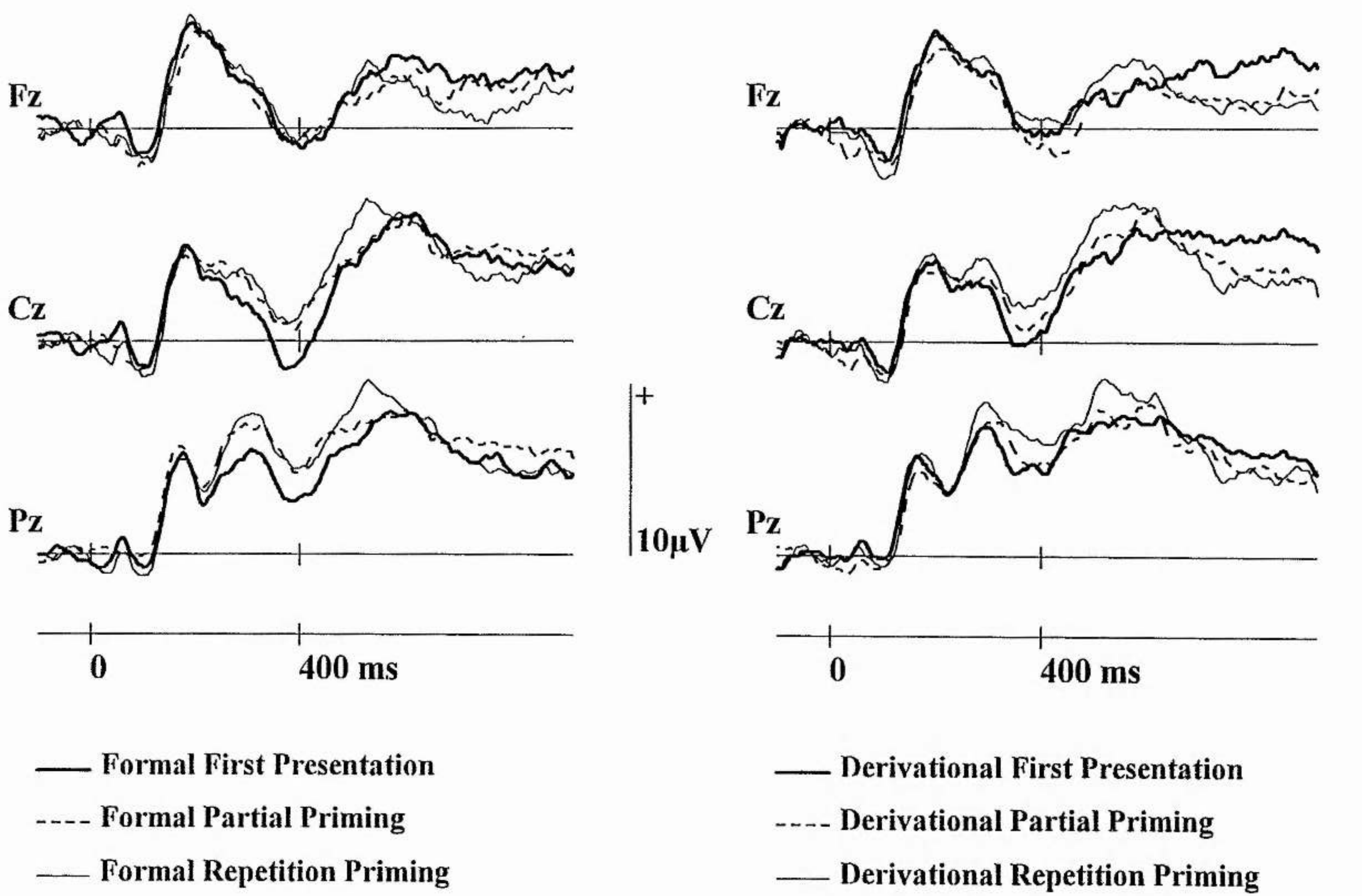


Figure 5.3 ERPs elicited at each midline electrode in each experimental condition and for each word type in Experiment 2. Electrode sites as in Figure 5.1.

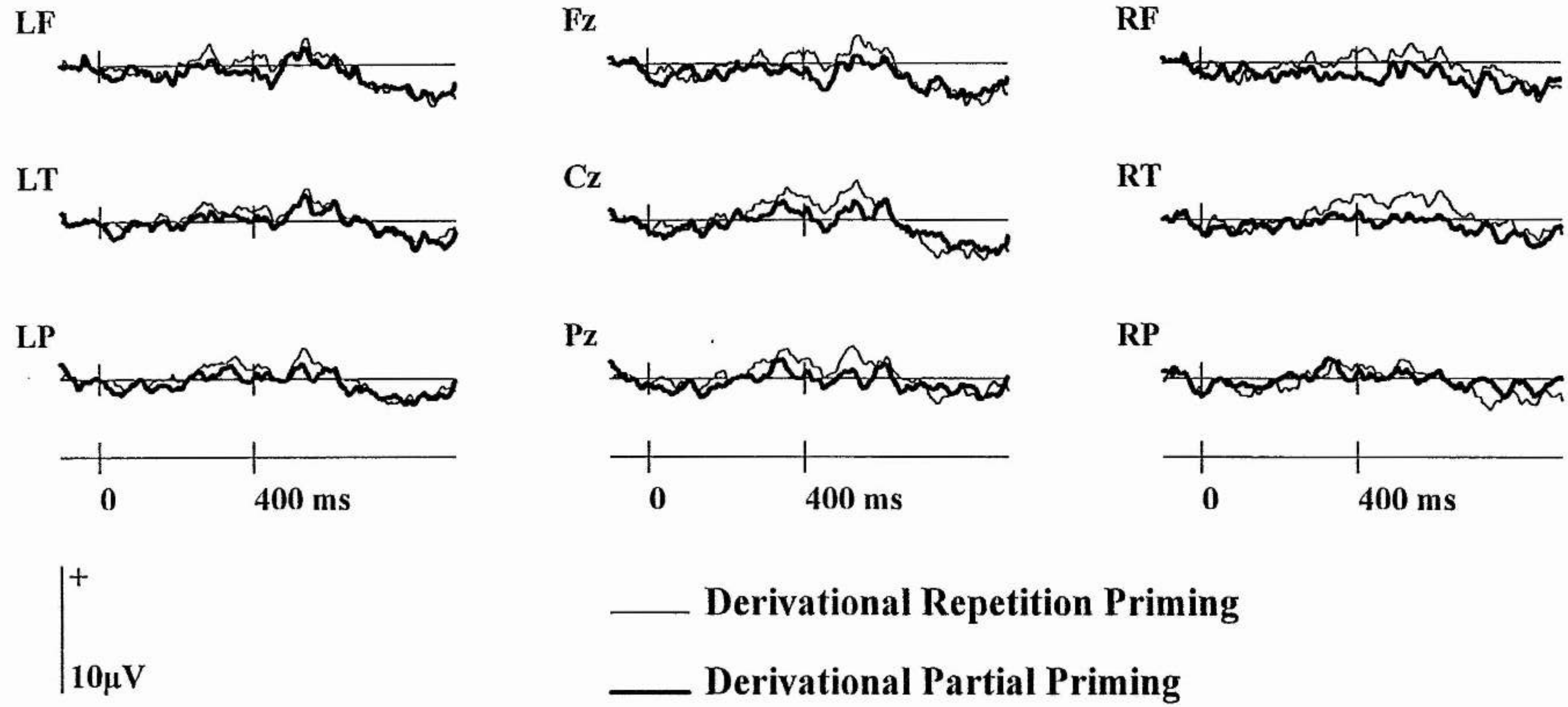


Figure 5.4 Subtraction waveforms for derived word repetition and derivational partial priming conditions at each electrode site in Experiment 2. Electrode sites as in Figure 5.1.

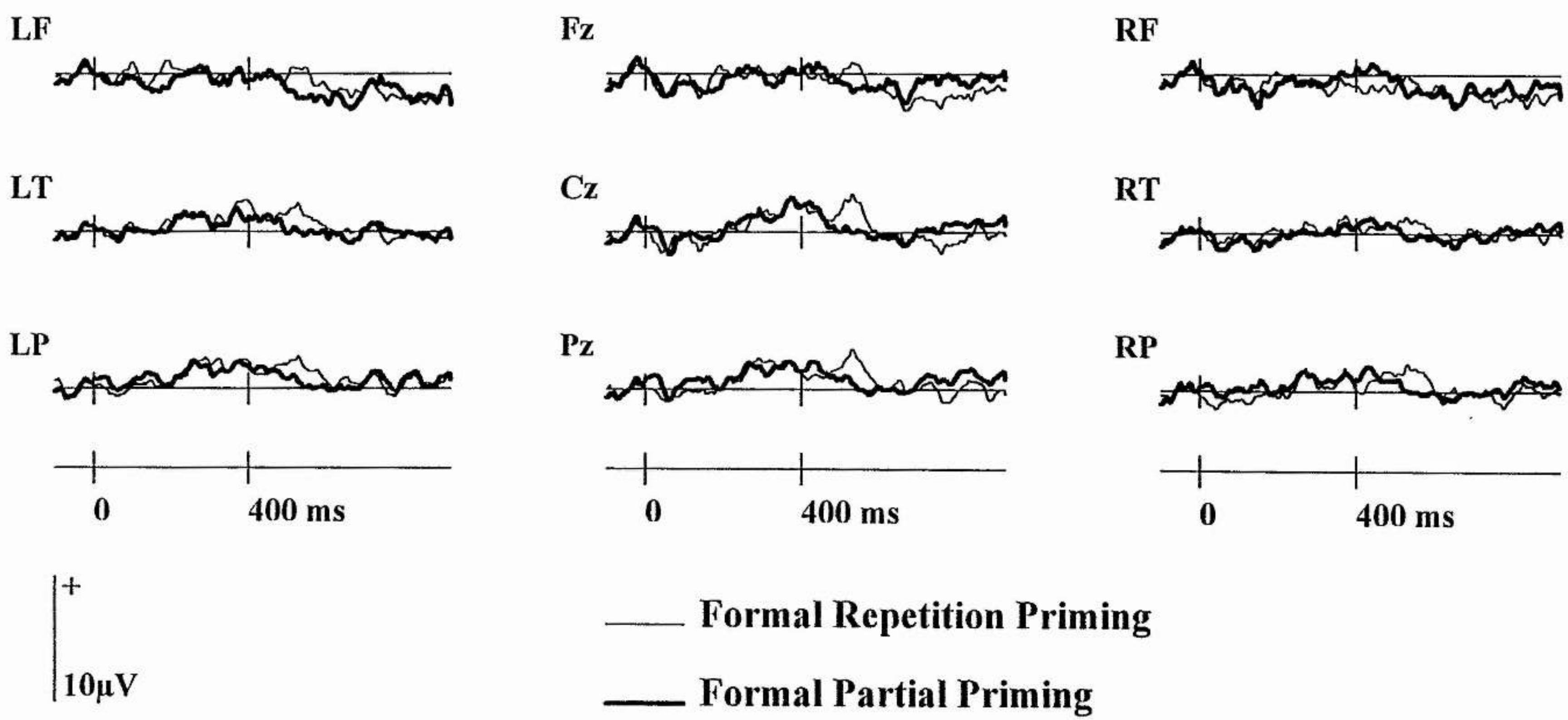


Figure 5.5 Subtraction waveforms for formal word repetition and formal partial priming conditions at each electrode site in Experiment 2. Electrode sites as in Figure 5.1.

conditions there was a period of no more than 40 ms in the interval between 200 ms to 600 ms where the priming effect was consistently reliable.

The mean number of trials contributed by each subject to each experimental condition was 32, 32 and 33 for the formal first presentation, formal partial and formal repetition conditions respectively. The values for the equivalent derived word conditions were 31, 32 and 32. Tables 5.1 - 5.5 show the mean amplitude of the average waveforms at each site and in each condition for the epoch around the N99, the epoch around the P186 and for each of the three 200 ms epochs.

5.2.2.1 ANOVA of the mean amplitude measures of the non-subtracted waveforms

Partial Priming

Table 5.6 summarises the results of the ANOVAs performed on the mean amplitude measurements of waveforms elicited by formal and derived words on their first presentation and when partially primed.

N99

Collapsed over word type, the N99 was more negative-going in the waveforms elicited by partially primed words than in waveforms elicited by words on their first presentation. However, at neither the midline nor the lateral sites did ANOVA reveal a reliable modulation of the N99 as a result of partial priming. Planned comparisons of the amplitudes of the N99 elicited by words of each word type on their first and partially primed presentations also show them not to differ at midline or at lateral sites.

The negative-going partial priming effect was particularly evident at frontal sites. The interaction between presentation type and site was not reliable at midline or lateral sites, although it was nearly so over the midline ($0.05 < p < 0.10$).

P186

Partial priming resulted in a reduction of P186 amplitude. Over the midline ANOVA indicated that this reduction was not reliable. Planned comparisons on the effect for each word type showed the effect was not reliable for either word type. Although the amplitude reduction was largest at the frontal sites, the interaction between presentation type and site was only marginally significant ($0.05 < p < 0.10$).

At lateral sites the main effect of presentation type was not reliable. A planned comparison of the magnitude of the P186, collapsed over lateral sites, also showed the effect not to be reliable. The interaction between presentation type and site was reliable. The reduction in P186 amplitude as a result of partial priming was greatest at the frontal sites. A Newman-Keuls test

Table 5.1 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the N99 peak in Experiment 2.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	-1.17	-1.09	-0.37	-1.73	-1.49	-0.56	-0.98	-1.20	-0.46
Formal Priming	-1.97	-1.44	0.17	-2.19	-1.29	0.05	-1.96	-1.74	-0.26
Formal Repetition	-1.72	-1.80	-0.97	-1.63	-1.29	-0.63	-1.60	-1.63	-1.44
Derived First Pres.	-1.36	-1.26	0.18	-1.51	-1.14	0.26	-1.14	-1.13	0.08
Derivational Priming	-1.87	-1.75	-0.44	-1.76	-1.19	-0.15	-1.71	-1.79	-0.54
Derivational Repetition	-2.64	-1.97	-0.37	-2.23	-1.40	-0.00	-2.51	-2.09	-1.13

Table 5.2 Mean amplitudes of waveforms in each experimental condition and at each electrode site; +/- 24 ms around the P186 peak in Experiment 2.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	5.64	5.07	4.95	4.66	3.33	1.14	5.86	3.79	1.51
Formal Priming	4.72	4.82	5.41	3.76	3.68	1.63	4.71	3.23	1.72
Formal Repetition	5.74	5.02	5.03	5.26	4.00	1.70	5.57	4.05	1.28
Derived First Pres.	4.93	4.45	5.08	5.00	3.68	2.07	5.51	3.81	1.96
Derivational Priming	4.02	4.10	4.53	4.07	3.37	1.37	4.39	3.20	1.67
Derivational Repetition	4.72	4.79	5.35	4.47	3.89	2.05	4.97	3.60	1.40

Table 5.3 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 200 - 400 ms post-stimulus onset in Experiment 2.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	2.56	1.66	4.50	2.03	0.78	1.47	3.34	1.56	2.22
Formal Priming	2.49	3.07	6.11	1.91	1.94	3.10	2.97	1.81	3.23
Formal Repetition	2.94	3.15	6.15	2.53	2.39	3.41	2.85	2.19	2.99
Derived First Pres.	2.72	2.20	5.61	2.40	1.44	2.95	3.46	1.86	3.18
Derivational Priming	2.20	2.79	5.98	2.07	1.77	3.19	2.46	1.85	3.68
Derivational Repetition	3.07	3.58	6.81	2.88	2.35	3.87	3.57	2.64	3.48

Table 5.4 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 400 - 600 ms post-stimulus onset in Experiment 2.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres	1.80	3.99	6.30	0.97	1.37	1.71	2.10	1.77	2.66
Formal Priming	1.39	4.70	7.24	-0.07	1.88	2.67	1.66	2.16	3.37
Formal Repetition	1.76	5.87	8.00	0.87	2.85	3.49	1.28	2.71	4.06
Derived First Pres.	1.47	4.41	7.29	0.72	2.01	3.03	1.92	2.01	3.66
Derivational Priming	0.90	4.86	7.36	0.71	2.72	3.45	1.04	2.02	3.90
Derivational Repetition	2.31	6.17	8.62	1.54	3.27	4.12	2.62	3.71	4.14

Table 5.5 Mean amplitudes of waveforms in each experimental condition and at each electrode site; 600 - 800 ms post-stimulus onset in Experiment 2.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
Formal First Pres.	3.33	5.71	6.48	2.57	2.89	1.96	4.47	3.94	4.25
Formal Priming	2.53	5.71	6.94	1.07	2.82	2.37	3.10	3.72	4.07
Formal Repetition	1.30	5.02	6.40	1.20	2.68	2.32	2.77	3.93	3.99
Derived First Pres.	3.36	6.25	7.08	2.99	3.68	3.58	4.16	4.11	4.82
Derivational Priming	1.93	5.43	6.51	1.82	3.43	2.52	2.58	3.36	4.35
Derivational Repetition	2.05	4.97	6.59	1.77	3.47	2.72	3.68	4.53	3.76

Table 5.6 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the partial priming conditions for each epoch analysed in Experiment 2.

N99	Midline	No Significant Differences			
	Lateral	No Significant Differences			
P186	Midline	No Significant Differences			
	Lateral	presentation type x site	$F(2,22) = 6.61$	$p < 0.05$	$\varepsilon = 0.64$
200 - 400 ms	Midline	presentation type x site	$F(2,22) = 6.96$	$p < 0.05$	$\varepsilon = 0.64$
	Lateral	presentation type x site	$F(2,22) = 4.51$	$p < 0.05$	$\varepsilon = 0.66$
400 - 600 ms	Midline	No Significant Differences			
	Lateral	word type x site	$F(2,22) = 4.61$	$p < 0.05$	$\varepsilon = 0.56$
600 - 800 ms	Midline	No Significant Differences			
	Lateral	presentation type	$F(1,11) = 5.51$	$p < 0.05$	
		hemisphere	$F(1,11) = 5.51$	$p < 0.05$	

indicated that the effect of partial priming on the P186 at the lateral frontal sites, collapsed across hemisphere, was reliable. A Scheffé test indicated that the magnitude of the partial priming effect on the amplitude of the P186 at the frontal and temporal sites was greater than it was at the parietal sites. The difference in the magnitude of the effects between the frontal and temporal sites was not reliable.

200 - 400 ms

For neither midline nor lateral sites did ANOVA reveal reliable effects of presentation type. Planned comparisons of the mean amplitudes of the waveforms elicited by words of each word type on their first and partially primed presentations, also indicated that the differences between the waveforms were not reliable. This was the case at midline and at lateral sites.

There was a reliable interaction between presentation type and site in the midline and lateral analyses. For each word type the partial priming condition produced a negative-going shift in waveforms recorded from frontal sites, and a positive-going shift in waveforms recorded from central or temporal and parietal sites. Scheffé tests revealed that the difference between the priming effects at the frontal sites and the central/temporal sites and between the frontal and parietal sites was reliable in the midline and in the lateral analyses.

When the reliability of the priming effects for each word type were tested separately using Newman Keuls tests, the formal partial priming effects at Cz, Pz and lateral parietal sites were reliable. None of the derivational partial priming effects was reliable.

As described below, the repetition effects were reliable only in the interval between 300 and 400 ms. In order to retain comparability between the analysis of the repetition and partial priming effects, the analogous tests were done on the partial priming effects. The results exactly paralleled those from the broader epoch.

400 - 600 ms

For neither the midline nor lateral sites did ANOVA reveal reliable effects involving the factor of presentation type. Nor were there reliable effects of this factor when it was tested for each word type separately using planned comparisons.

At lateral sites there was a reliable interaction between between word type and site. For both word types, the waveforms became more positive-going towards the back of the head, but this pattern was more pronounced for the derived words than for the formal words. Newman-Keuls tests indicated that at no one site was the difference between the word types reliable. This effect of word type was greater at the lateral parietal sites than it was at lateral frontal sites.

600 - 800 ms

Partial priming in this last epoch resulted in the waveforms recorded at most sites being more negative-going than their corresponding first presentations. Neither ANOVA nor planned comparisons of the magnitude of these negative-going shifts over the midline showed them to be reliable. At lateral sites there was a reliable main effect of presentation type. Planned comparisons indicated that the effect of presentation type was not reliable for either word type, although the effect for derived words approached statistical significance.

The negative-going partial priming effect in this epoch was particularly evident in those waveforms elicited by derived words, and in waveforms recorded at frontal sites. However none of the interaction terms between the factors of presentation type, word type, hemisphere and site was reliable.

There was a main effect of hemisphere which reflected the more positive-going waveforms recorded from right hemisphere electrodes. The interaction between hemisphere and word type was marginally significant ($0.05 < p < 0.10$). This reflected the greater hemispheric asymmetry in the waveforms evoked by formal words than in those evoked by the derived words.

Repetition Priming

Table 5.7 summarises the results of the ANOVAs performed on the mean amplitude measurements of waveforms elicited by formal and derived words on their first presentation and when repeated.

N99

The main effect of presentation type in the ANOVA was not reliable for either the midline or the lateral analysis. Planned comparisons on each word type separately showed that the repetition of neither word type resulted in a reliable increase in the magnitude of the N99 over the midline or at lateral sites.

There was a reliable interaction between presentation type and hemisphere. Scheffé tests indicated that the negative-going shift resulting from repetition was greater over the right hemisphere than over the left. When the effect of presentation type was tested for each hemisphere separately, in neither case was it reliable.

In both the midline and lateral analyses there were reliable interactions between word type and site. At no one site was the difference in the mean amplitude around N99 between the two word types reliable. Over the midline the effect of word type on the N99 was greater at Fz and at Cz than at Pz, with the magnitude of the word type effect at the two more anterior sites not

Table 5.7 Summary of the results of the ANOVAs performed on the mean amplitudes of the ERPs elicited in the first presentation and the repetition priming conditions for each epoch analysed in Experiment 2.

N99	Midline	word type x site	$F(2,22) = 8.41$	$p < 0.01$	$\varepsilon = 0.67$
	Lateral	word type x site	$F(2,22) = 6.74$	$p < 0.05$	$\varepsilon = 0.61$
		presentation type x hemisphere	$F(1,11) = 5.64$	$p < 0.05$	
P186	Midline	word type x site	$F(2,22) = 6.03$	$p < 0.05$	$\varepsilon = 0.92$
	Lateral	No Significant Differences			
200 - 400 ms	Midline	No Significant Differences			
	Lateral	No Significant Differences			
300 - 400 ms	Midline	presentation type x site	$F(2,22) = 6.73$	$p < 0.05$	$\varepsilon = 0.67$
	Lateral	presentation type x site	$F(2,22) = 5.64$	$p < 0.05$	$\varepsilon = 0.68$
400 - 600 ms	Midline	No Significant Differences			
	Lateral	No Significant Differences			
600 - 800 ms	Midline	No Significant Differences			
	Lateral	hemisphere	$F(1,11) = 6.53$	$p < 0.05$	

differing. At lateral sites, the difference between word types was greater at frontal than at parietal sites.

P186

ANOVA revealed that there were no reliable effects of repetition on the mean amplitude around P186, either over the midline or at lateral sites. Planned comparisons of the amplitudes of the P186 showed that for neither word type was the difference between presentation types reliable.

The interaction between word type and site was reliable over the midline. Whereas the amplitude of the P186 elicited by formal words was greatest at Fz and declined towards the back of the head, for the derived words it was greatest at Pz and smallest at Cz. The word type effect at Fz differed reliably from that at Pz. Post hoc tests indicated that at no single site was the effect of word type reliable.

At lateral sites, the P186 was greatest at the front of the head and became smaller towards the back. The interaction between word type and site was marginally significant ($0.05 < p < 0.10$), with the difference between the frontal and parietal sites being greater for the formal words than for the derived words.

200 - 400 ms

The main effect of presentation type was not reliable in the ANOVA. Nor did planned comparisons for each word type separately show the effect of presentation type to be reliable.

The repetition effect for both word types increased in magnitude towards the back of the head. This increase resulted in marginally reliable presentation type by site interactions in the ANOVA of both the midline and lateral data ($0.05 < p < 0.10$ in both cases).

At midline and at lateral sites, the interaction between presentation type and site was reliable when the ANOVA of the mean amplitudes was restricted to the interval between 300 and 400 ms post-stimulus. Over the midline, although the effect of presentation type was not reliable at any one site, the positive-going repetition effects were reliably greater at Cz and Pz than at Fz. At lateral sites the effect of presentation type was also not reliable at any one site. Collapsed over hemisphere, the repetition effects were greater at temporal and parietal sites than at frontal sites. The magnitude of the repetition effects at the temporal and parietal sites did not differ.

There was a reliable main effect of word type. The waveforms elicited by the derived words were more positive-going than those elicited by the formal words.

400 - 600 ms

ANOVA found no reliable effects of repetition in this epoch for either midline or lateral data sets. Planned comparisons on the effects of presentation type for each word type, showed neither to be reliable.

600 - 800 ms

ANOVA on the data from midline and lateral sites showed that the negative-going shifts resulting from repetition in this epoch were not reliable. There was a reliable effect of hemisphere. Waveforms recorded from right hemisphere electrodes were more positive going than were those from the left.

5.2.2.2 ANOVA of the non-rescaled mean amplitudes of the subtraction waveforms

When the ANOVAs were performed on the mean amplitudes of the subtraction waveforms around the P186 peak and in each of the three broad epochs, no reliable differences were found between any of the experimental conditions. Planned comparisons of the mean amplitudes of neither the priming effects for each word type, nor the effects of word type for each prime type, revealed any reliable effects.

Only in the case of the mean amplitudes around N99 were the differences between the waveforms found to be reliable, and only the nature of these differences will be described (see Table 5.8). ANOVAs on mean amplitude measures around the N99 revealed that the main effects of prime type and word type were not reliable. Nor did planned comparisons of the magnitude of the effects of prime type for each word type, or of word type for each prime type, differ reliably.

However, over midline and lateral sites, there was a reliable interaction between prime type, word type and site. Scheffé tests indicated that, over the midline, for the partial priming condition but not for the repetition priming condition, the effect of word type on the N99 at Fz differed from its effect at Pz. Similarly, at lateral sites, the difference in the effect of word type on the amplitude of the N99 between the lateral frontal and lateral parietal sites was reliable, but only in the partial priming condition.

5.2.2.3 ANOVA of the rescaled mean amplitudes of the subtraction waveforms

When the mean amplitude of the waveforms from around the N99 was rescaled and subjected to ANOVA, the only reliable effect was due to differences between electrode chains (see Table 5.8). The N99 was proportionately greatest over the left hemisphere, and smallest over the right. A Newman-Keuls test on these values showed the difference between the left hemisphere

Table 5.8. Summary of the results of the ANOVAs performed on the non-rescaled and rescaled mean amplitudes of the subtraction waveforms in each epoch measured in Experiment 2.

N99

Non-rescaled						
	Midline	prime type x word type x site	$F(2,22) =$	4.69	$p < 0.05$	$\varepsilon = 0.59$
	Lateral	prime type x word type x site	$F(2,22) =$	4.60	$p < 0.05$	$\varepsilon = 0.61$
Rescaled		chain	$F(2,22) =$	4.55	$p < 0.05$	$\varepsilon = 0.93$

chain and each of the other two to be reliable. The rescaled magnitude of the N99 over the midline and right hemisphere chains did not differ from one another.

In none of the other epochs measured was there found to be any reliable effect involving the factors of word type, prime type or chain.

5.3 Discussion

The most immediately apparent feature of the results is the small and temporally restricted repetition and partial priming effects observed in this experiment. For both partial and repetition priming, the effects were restricted to central and parietal sites. The partial priming effects were reliable only between 200 and 400 ms and only for formal words. The repetition effects were even less robust, being manifest only as part of an interaction with electrode site. At no single site in any epoch was the repetition effect found to be reliable.

This result contrasts with the ERP effects found in previous studies in which words have been repeated with a number of items intervening between the first and second presentation of the word (Bentin & Peled, 1990; Karayanidis, et al., 1991; Nagy & Rugg, 1989; Rugg, et al., 1993).

The reason for the small magnitude of the effects in this Experiment is unclear. This is particularly so when the effects of the repetition of the root words is considered. These words were repeated so as to ensure that word length could not act as a cue to whether a word would be repeated. The mean amplitude of the waveforms elicited by the first and second presentations of these words alone were measured and subject to ANOVA. This analysis demonstrated that for these words there were reliable main effects of repetition in the epoch between 200 and 400 ms and in the epoch between 400 and 600 ms[3]

The reliability of these effects with words of comparatively short length suggests that the small magnitude of the effects seen with the longer words is unlikely to have been a consequence of some general feature of the experiment which prevented the occurrence of repetition effects.

The primary purpose of this experiment was to determine whether the partial priming effects, and particularly the formal partial priming effects, would survive the introduction of a lag between the first and second presentation of, on average, six intervening items. Although the effects were small, as in previous experiments, there were reliable effects of partial priming in the interval between 200 and 400 ms post-stimulus onset. Although these partial priming

---

[3] ANOVAs with factors of presentation type (first vs second), hemisphere (for the analysis of lateral sites only) and site, were performed for the 200 - 400 ms epoch and the 400 - 600 ms epoch. For the earlier of the two epochs there were main effects of repetition in both midline and lateral analyses (midline; $F(1,11) = 7.18$, $p < 0.05$: lateral; $F(1,11) = 18.57$, $p = 0.001$). For the later epoch there were also main effects of repetition at midline ($F(1,11) = 6.06$, $p < 0.05$) and lateral sites ($F(1,11) = 13.11$, $p < 0.005$).

effects were more evident for the formal words than for the derived words, there was little statistical evidence that the magnitude of the effects differed for the two word types. Specific tests on the effect of partial priming at individual sites for each word type did indicate that the formal partial priming effects were reliable, whilst the derivational partial priming effects were not. Thus to the extent there were differences between the effects seen with the two word types they arose because of the larger partial priming effects seen with the formal words.

This difference between the two word types could be taken as support for the view that derivational priming effects cannot simply reduce to questions concerning the formal similarity between the items. If this were the case then no differences of any sort should be evident between the two word types. Given the small magnitude of the effects, however, such a conclusion must remain a tentative one. Furthermore, the finding that the derivational partial priming effect was more sensitive to inter-item lag then was the formal partial priming effect was contrary to the experimental hypothesis based upon the analogous behavioural work.

The results of Experiment 2 indicate that partial formal priming effects persisted despite the introduction of an inter-item lag of, on average, 6 items. However, because of the small size of the priming effects, the question of whether the formal priming effects could be dissociated from the derivational priming effects was not unambiguously resolved.

Some of the clearest evidence for differences between the effects of the two word types in this experiment occurred in the earliest interval analysed; the interval around the N99 peak. This change in the amplitude of the N99, which largely consisted of increases in its amplitude, is difficult to account for. Since this effect is occurring prior to the time generally held to be the minimum required to identify a word it seems unlikely that it reflects processes which act at a lexical level of analysis or beyond.

This effect on the amplitude of the N99 could reflect processes occurring prior to word identification. The differences in the effects of repetition priming with derived words and with formal words would then have to be accounted for in terms of differences between the words in their sub-lexical orthographic structure. It is possible that the two word types differed on some dimension of sub-lexical similarity, e.g. bigram frequency, which was not controlled for during the selection of the stimulus materials, but this is a possibility that would need to more systematically investigated.

The investigation of the possible impact of orthographic strucure at this level on the formal and derivational priming effects reported in Experiments 1A, 1B and 2 would be an interesting question to explore further. However the remaining three experiments reported in this thesis will concentrate on the investigation of the conditions under which the formal partial priming effects can be observed.

In Experiments 1A, 1B and 2, formally related words were included as a control condition. Such a control allowed an assessment to be made of the extent to which any derivational partial priming effects observed resulted from the orthographic and phonological similarity of these words. However, none of the three experiments reported so far have provided convincing evidence of a difference between the formal and derivational partial priming effects. These results all suggest that ERPs are not sensitive to morphological relationships between words, but are sensitive to similarities between words which may be only in respect of their formal properties. Furthermore the positive-going modulations of the ERP seen as a result of formal partial priming are similar to those which have typically been observed in semantic and repetition priming experiments. These formal partial priming effects have typically exhibited the centro-parietal, and right-greater than-left distribution of modulations of the N400. This supports the view that these partial formal priming effects are modulations of the N400.

This claim that the N400 can be modulated by formal similarities between stimuli is contrary to some accounts of the cognitive processes which underlie the N400 which were reviewed in the Chapter 1. These have either viewed the N400 solely as a marker of semantic processing (e.g. Nigam, et al., 1992), or have suggested that only when task demands require attention to the formal properties of stimuli will formal similarity between items result in modulations of the N400 (Van Petten, 1993). Given the challenge to these views of the N400 posed by the results reported so far, the following three experiments focus on the conditions under which formal similarities between words result in the modulation of ERPs.

Modulations of the ERP resulting from similarities of rhyme in visually presented words (Kramer & Donchin, 1987; Rugg, 1984; 1985a; Rugg & Barrett, 1987), and from similarities of rhyme and alliteration in spoken words reported by Praamstra and Stegeman (1993) and Praamstra et al (1994), have been linked to the N400. However, with the exception of Praamstra et al (1994, experiment 3), which used the LDT with spoken words, these studies have all used tasks in which the detection of similarities of form have been central to the task which subjects were required to perform. They therefore contrast with the present experiments in which the similarity of form between pairs of stimuli is incidental to the experimental task. However this is no guarantee that subjects will not use such similarities between stimuli if to do so would improve their performance on the experimental task.

The use of a variable inter-item lag of, on average, 6 intervening items, was one means of limiting the degree to which subjects could use incidental properties of the experimental stimuli to aid task performance. The use of such a lag may restrict the extent to which subjects could use the prime word as a cue to enable them to predict the identity of the probe word, and to maintain the identity of the predicted probe word in working memory until its presentation.

The design of Experiment 3 also seeks to reduce the degree to which subjects utilised such incidental properties of the stimuli in performing the task. Thus in this next experiment, the formally related and repeated words were presented as part of an experimental list in which the majority of items were not formally, morphologically or semantically similar to the preceding items. If, when the 'relatedness proportion' (Neely, 1991) is low, subjects were to use each word as a cue to predict a subsequently occurring word, this would only infrequently result in a correct prediction. Under such circumstances, subjects may place less emphasis on the use of such task-dependent strategies than might otherwise be the case.

Reductions in the relatedness proportion of items within experimental lists have also been used to determine the degree to which semantic priming effects are dependent upon the involvement of lexical 'expectancy' based mechanisms. If the ERP formal priming effects are dependent upon a form based expectancy mechanism, analogous to the semantically based expectancy mechanism proposed by Neely (1991) and others, then it is possible that the formal priming effects will be eliminated by the use of low relatedness proportions.

Chapter 6

Experiment 3

Formal and repetition priming with low relatedness proportions.

6.0 Introduction

The use of stimuli such as 'scan' -'scandal' has one major disadvantage; given a word such as 'scan' the number of words which can be formed by adding letters to this 'stem' is limited. In the case of 'scan', discounting inflectional and derivational relatives, only two English words can be generated that begin with the letter string 'scan' (i.e. 'scant' and 'scandal'). Thus in an experiment where the majority of short words act as formal primes, it would be easy for subjects to predict upcoming words. Parallels between the ERP effects of repetition and formal similarity under these conditions may reflect no more than that the formal similarity condition was a *de facto* repetition condition in which subjects used the prime word to anticipate the probe word prior to its occurrence.

One method which has been used to minimise the effects of such anticipatory strategies has been to reduce the proportion of repeating and similar items. In circumstances where the following item is unlikely to be either the same or a similar word, it seems less likely that subjects will use each item as a cue to predict the subsequent one. Tweedy et al., (1977) demonstrated that, in a semantic priming paradigm, the facilitation resulting from preceding a word by a semantically related word decreased as the proportion of related words fell from 87.5% to 12.5%. In a later study Napps and Fowler (1987) found that when they reduced the proportion of formally related items from 75% to 25% or 6.25%, the facilitatory effects seen with higher proportions were abolished. These results suggest that with the higher proportions, subjects were actively predicting subsequent items, resulting in the observed facilitation. When the proportion of related words was lower this was no longer a useful strategy and its abandonment resulted in the abolition of the facilitatory effect.

In the light of these findings, the proportion of related items used in the present study was only 12% of the total number presented. Of these items half were prime words, so the proportion of predictable words was only 6%. With such a small proportion of related items, and where many short words were not followed by formally related words, there would be little benefit to subjects in engaging in anticipatory strategies. Hence similarities and differences between the experimental conditions are likely to reflect processes more generally involved in processing of words, rather than being task specific.

6.1 Methods

6.1.1 Subjects

Sixteen subjects (11 female) with a mean age of 22 years (range 19-34) took part in the experiment; each was paid £6. All but one were right handed.

6.1.2 Materials

The items used in this experiment were of three types:

(i) Formally Related Word Pairs.

The experimental items for the critical conditions of this experiment consisted of 100 formally related monomorphemic word pairs. The mean frequency of the prime words according to the Francis and Kucera (1982) count was 27.6 (sd = 36.1). The frequency of the probe words was 4.5 (sd = 3.9). The primes had a mean length of 4.5 letters (sd = 0.6) and the probe words were on average 6.7 letters long (sd = 1.0). The mean overlap index across all critical pairs was 0.64 (sd = 0.1). The 100 pairs were sub-divided into two sets of 50 pairs such that the mean frequencies and word lengths of the prime words and of the probe words in each set were approximately equal.

(ii) Filler Words

A set of 490 filler words were selected from Francis and Kucera (1982). These words were chosen such that the distribution of their lengths and frequencies approximately matched that of the critical words. 150 of these words were bimorphemic derived words; all the rest were monomorphemic words.

(iii) Non-word targets.

270 non-word targets were constructed, all of which were seen by each subject. They were derived from a set of monomorphemic words and, as with the filler words, the distributions of their lengths and frequencies approximately matched those of the experimental items. 234 of the non-words were constructed by changing 1 or 2 letters of each source word to produce a pronounceable non-word. The remaining 36 non-words were produced by adding a pseudo-suffix to a real word, e.g. 'coolene'. Since the primary purpose of this experiment was to investigate the effects of formal priming on ERPs when the likelihood of subjects anticipating the occurrence of formally related items was minimised, none of the non-words was repeated or preceded by formally similar words or non-words.

The experimental lists were produced by combining each of the items described above into a single list of 810 items. This list was sub-divided into 9 blocks of 90 items per block. The probability of a non-word occurring on a particular trial was 0.33. The probability of a word having been repeated or formally primed was in each case 0.06. Two pseudo-random orderings of experimental conditions were produced, constrained only by the requirements that, first, there were an equal number of non-words in each block, including those having a real word as their initial letter string; second, that each block began with a filler word or a non-word; third, that there were no intervening items between a prime word and the corresponding probe word.

Four experimental lists were produced by using the two orders of conditions and, in each case, rotating the words around the two priming conditions. Thus across each group of four subjects each target word occurred in both repetition and formal priming conditions in each of two sequential positions.

6.1.3 Procedure

The task, stimulus display characteristics and instructions to subjects for this experiment were the same as those used in the previous experiments.

EEG Recording

For this experiment EEG was recorded using the same procedure as used in Experiment 2.

Data Analysis

As in the previous experiments, ERPs were quantified by measuring the mean amplitude with respect to the averaged pre-stimulus baseline of selected regions of the waveform associated with each experimental condition. Measurements of mean amplitudes over the same time intervals were also made on subtraction waveforms.

In this experiment, the absence of the derivational words meant that there was no longer a factor of word type in the statistical analysis. For this reason the form of the analyses used to assess differences between experimental conditions was changed. Initially the presence of reliable priming effects was assessed using ANOVA. One ANOVA was performed on the data from the midline sites and one on the data from the lateral sites. In addition to the topographic factors of electrode site, and, where appropriate, hemisphere, this ANOVA used a single factor of presentation type having three levels; first presentation, formal priming and repetition priming. In both analyses the reliability of the repetition and partial formal priming effects were individually assessed using planned comparisons of the mean amplitude of waveforms elicited in the first presentation condition and each in each priming condition. The magnitude of the priming effects in the two conditions were then compared using a planned comparison of the mean amplitude of the waveforms elicited in the two priming conditions. Reliable interactions were further investigated using Scheffé's procedure.

As in the previous experiments, the scalp distribution of the effects was investigated by performing an ANOVA on the mean amplitudes of the subtraction waveforms after they had been rescaled (McCarthy & Wood, 1985). This analysis of the rescaled data employed factors of prime type (repetition vs formal) and electrode chain (midline, left and right) as well as electrode site.

6.2 Results

6.2.1 Behavioural Data

Correct responses to the non-words were made in a mean RT of 784 ms (sd = 142 ms). 4.0% (sd = 2.7) of the words attracted incorrect responses with a mean RT of 832 ms (sd=158). RTs for incorrect responses were more variable than those for correct responses. The across subject mean standard deviation for correct responses was 170 ms (sd = 55 ms) and for incorrect responses was 246 ms (sd = 64 ms). 6.8% (sd = 4.3) of the non-word targets were missed.

6.2.2 Event Related Potentials

Waveforms recorded from each site overlaid by condition are presented in Figure 6.1. Waveforms recorded at midline sites in each condition are plotted on an expanded scale in Figure 6.2. The mean amplitudes of the waveforms in each epoch subjected to analysis are given in Tables 6.1 and 6.2. The mean number of trials in the subject averages in these conditions were 42, 43 and 44 respectively.

There were prominent N81 (range 80 ms to 84 ms) and P150 (range 148 ms to 152 ms) peaks in all waveforms. Because statistical analysis of these features of the waveforms did not reliably discriminate between the experimental conditions with respect to either amplitude or latency, the results of this statistical analysis will not be described further. In the analysis of both the N81 component and the P150 component, there were main effects of hemisphere which reflected the more negative-going waveforms recorded from electrodes over the left hemisphere.

Both repetition and formal priming resulted in a positive-going modulation of the ERP from around 200 ms post-stimulus onset. These priming effects were greater over the right hemisphere than over the left. Whilst in the first of the analysis epochs the effects of repetition and partial priming were of similar magnitude, they showed a clear divergence in the second, with the repetition effect being the greater. In the final epoch the waveforms in both priming conditions were similar to the control condition.

Subtraction waveforms for the formal priming and repetition conditions are plotted in Figure 6.3. Point-by-point t-tests performed on the subtraction waveforms indicated that in the repetition condition the prolonged positive going shift in the waveform recorded at Cz, became reliable at 308 ms. In the partial priming condition the positive-going shift at the same site became reliable somewhat, at 284 ms, whilst at the right temporal site, the t-tests first became significant even earlier, at 240 ms.

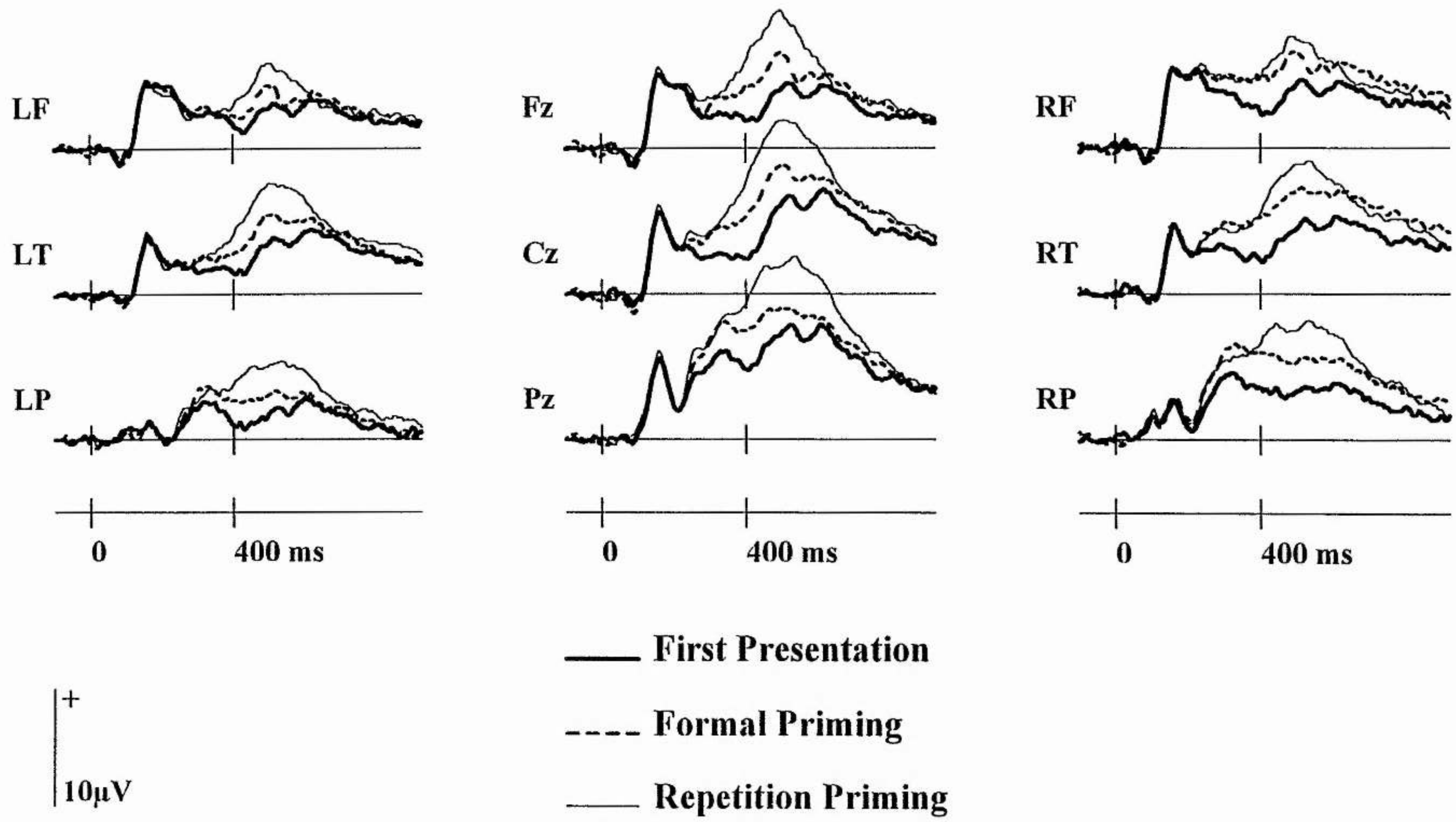


Figure 6.1 ERPs elicited at each electrode site by the first presentations of words, by repeated words and by words primed by their formal root forms in Experiment 3. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

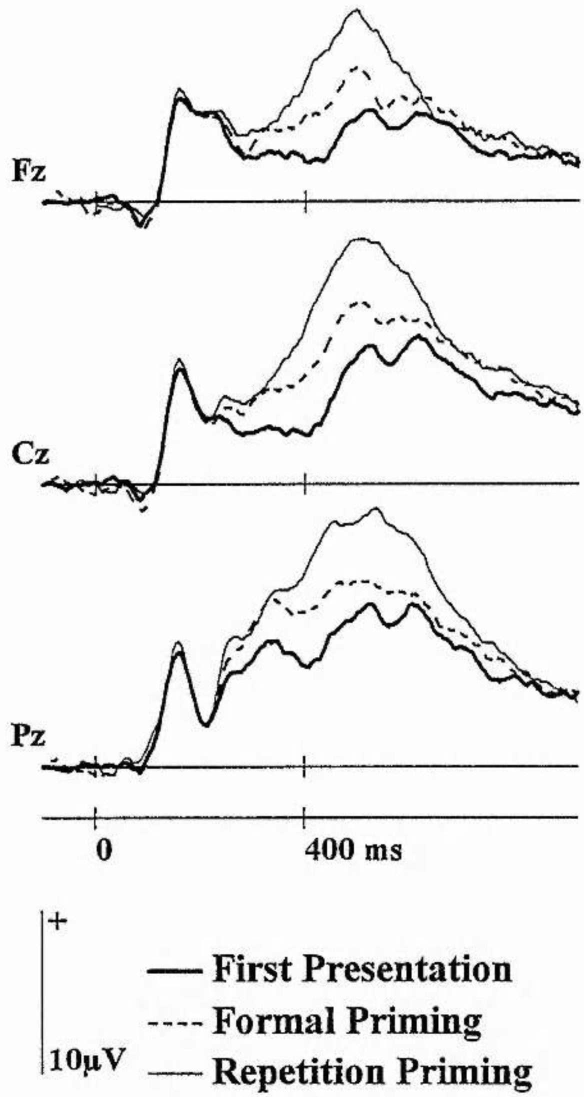


Figure 6.2 ERPs elicited at each midline electrode by word repetition and by formal priming in Experiment 3. Electrode sites as in Figure 6.1.

Table 6.1. Mean amplitudes of ERPs +/- 24 ms around the N81 and P150 peaks at each electrode site for the first presentation, formal priming and repetition conditions of Experiment 3.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
N81									
First Presentation	-0.91	-0.51	0.15	-0.67	-0.28	0.34	-0.59	-0.14	1.05
Formal Priming	-1.18	-1.10	-0.02	-0.93	-0.64	0.21	-0.77	-0.39	1.01
Repetition Priming	-0.59	0.22	0.69	-0.51	-0.19	0.63	-0.42	0.05	1.52
P150									
First Presentation	4.53	5.15	5.53	4.00	3.20	0.94	4.70	3.90	2.53
Formal Priming	4.42	4.99	5.50	3.91	3.26	0.80	4.86	4.23	2.52
Repetition Priming	4.99	5.55	5.92	4.31	3.45	0.53	5.01	4.10	2.29

Table 6.2. Mean amplitudes for each of the three 200 ms measurement intervals and for each electrode site for the first presentation, formal priming and repetition conditions of Experiment 3.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
200 - 400 ms									
First Presentation	3.47	3.51	5.92	3.58	2.39	1.97	4.86	3.65	4.13
Formal Priming	4.36	5.13	7.65	3.68	2.99	2.82	6.13	5.52	6.18
Repetition Priming	5.17	6.04	8.30	3.44	3.23	2.96	6.17	5.25	5.91
400 - 600 ms									
First Presentation	4.23	6.62	8.49	2.96	3.84	2.19	4.55	5.16	4.32
Formal Priming	6.47	9.61	10.73	4.06	5.76	3.75	6.92	8.26	7.08
Repetition Priming	9.60	13.40	14.53	5.84	8.32	6.23	8.10	10.17	9.61
600 - 800 ms									
First Presentation	3.99	6.90	7.29	3.34	4.52	2.18	4.63	5.54	3.67
Formal Priming	4.90	8.19	8.13	3.79	5.19	2.61	6.36	7.82	5.59
Repetition Priming	4.79	8.65	9.65	3.58	5.68	3.50	5.53	7.42	6.41

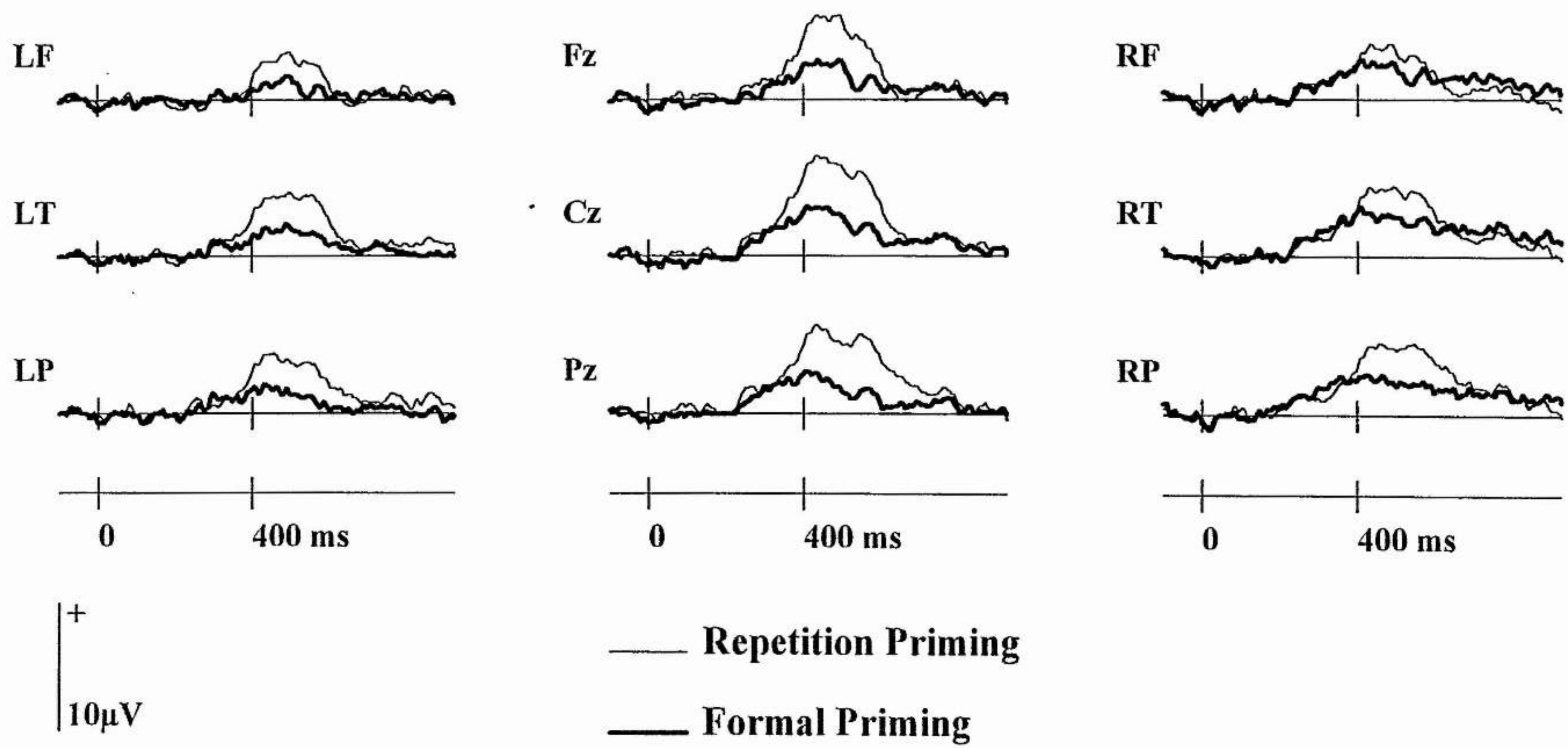


Figure 6.3 Subtraction waveforms for word repetition and formal priming conditions at each electrode site in Experiment 3. Electrode sites as in Figure 6.1.

6.2.2.1 ANOVA of the mean amplitude measures of the non-subtracted waveforms

The results of the ANOVAs performed on the non-subtracted waveforms are given in Table 6.3.

200 - 400 ms

This epoch coincides with that period in which the formal and repetition effects appear to be most similar. Over midline sites ANOVA resulted in a reliable main effect of presentation type. Planned comparisons showed that the positive-going shift was reliable for each priming condition separately, but that the magnitudes of the two priming effects did not differ from one another. At the lateral sites there were reliable main effects of presentation type and hemisphere, and a reliable interaction between presentation type and hemisphere. Planned comparisons showed both priming effects to be reliable but not to differ between themselves. Post-hoc tests indicated that both repetition and formal priming effects were larger over the right hemisphere than over the left.

400 - 600 ms

ANOVA performed on the midline data confirmed that there was a reliable difference between the three presentation types. Planned comparisons indicated that the waveforms evoked in formal and repetition priming conditions were significantly more positive-going than were those evoked in the first presentation condition. In addition the difference between the waveforms evoked by word repetition and those evoked by formal priming was also reliable. At the lateral sites, the ANOVA gave rise to reliable main effects of presentation type and of hemisphere. Planned comparisons showed that each condition differed reliably from the other two. There was also a significant interaction between presentation type and electrode site. Post-hoc tests indicated that the repetition effects were significantly greater at the temporal sites than at the frontal sites. None of the other contrasts between electrode sites was reliable.

600 - 800 ms

Although the ANOVAs failed to reveal any reliable differences in this epoch over the midline sites, a planned comparison between the repetition and first presentation conditions showed that they continued to differ reliably. The analogous test on the formal priming effect was not significant. At the lateral sites, ANOVA revealed main effects of presentation type and hemisphere. Planned comparisons showed both the repetition and formal priming effects to still be reliable but not to differ from one another. There were also reliable interactions between presentation type and hemisphere, and between presentation type and electrode site. Post-hoc tests indicated that the former interaction was a result of the repetition and formal priming effects being greater over the right hemisphere than over the left, whilst the latter was a result of the repetition effect being greater at the parietal electrodes than at the frontal electrodes.

Table 6.3 Summary of the results of ANOVA performed on the mean amplitudes of ERPs elicited by the words on their first presentation, when repeated and when formally primed in Experiment 3.

N81	Midline	No Significant Differences			
	Lateral	hemisphere	$F(1,15) = 4.92$	$p < 0.05$	
P150	Midline	No Significant Differences			
	Lateral	hemisphere	$F(1,15) = 9.76$	$p < 0.01$	
200 - 400 ms	Midline	presentation type	$F(2,30) = 5.95$	$p = 0.01$	$\varepsilon = 0.87$
	Lateral	presentation type	$F(2,30) = 4.14$	$p < 0.05$	$\varepsilon = 0.95$
		presentation type x hemisphere	$F(2,30) = 5.34$	$p = 0.01$	$\varepsilon = 0.95$
		hemisphere	$F(1,15) = 90.48$	$p < 0.05$	
400 - 600 ms	Midline	presentation type	$F(2,30) = 38.63$	$p < 0.001$	$\varepsilon = 0.87$
	Lateral	presentation type	$F(2,30) = 32.43$	$p < 0.001$	$\varepsilon = 0.96$
		presentation type x site	$F(4,60) = 4.15$	$p < 0.05$	$\varepsilon = 0.49$
		hemisphere	$F(1,15) = 63.45$	$p < 0.001$	
600 - 800 ms	Midline	No Significant Differences			
	Lateral	presentation type	$F(2,30) = 4.07$	$p < 0.05$	$\varepsilon = 0.85$
		presentation type x hemisphere	$F(2,30) = 4.39$	$p < 0.05$	$\varepsilon = 0.77$
		presentation type x site	$F(4,60) = 3.60$	$p < 0.05$	$\varepsilon = 0.59$
		hemisphere	$F(1,15) = 58.18$	$p < 0.001$	

6.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms

The results of the ANOVAs performed on the rescaled mean amplitudes are given in Table 6.4.

200 - 400 ms

There was a reliable main effect of chain and a significant interaction between prime type and chain. Post-hoc tests revealed that in the formal priming condition the priming effects over the midline and right hemisphere were greater than over the left hemisphere, but in the repetition condition the only reliable difference was between the midline and left hemisphere electrode chains. The differing topographic profiles of the two effects can be seen in Figure 6.4 A.

400 - 600 ms

There was a main effect of electrode chain and a reliable interaction between prime type and electrode chain. The topographic profile across the three chains can be seen in Figure 6.4 B. Whilst the repetition effects were greatest over the midline, the formal priming effects were greatest in waveforms recorded over the right hemisphere. Post hoc tests showed that the formal priming effects in waveforms from the midline and right hemisphere were greater than the effects in waveforms recorded over the left hemisphere, but only between the midline and the left hemisphere was there a reliable difference in the repetition effects.

600 - 800 ms

There was a main effect of chain, a reliable interaction between prime type and chain and a reliable interaction between prime type and site. The magnitude of the formal priming effect was greater over the right hemisphere than over the left hemisphere. Post hoc tests showed that the distribution of the parietal maximum repetition priming effect differed reliably from the temporal maximum formal priming effect.

6.3 Discussion

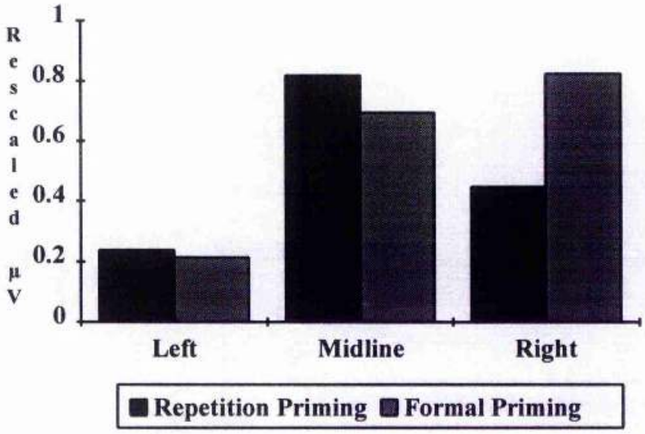
This experiment sought to resolve two questions; firstly, could a further demonstration of the modulation of ERPs by formal priming be provided even when subjects were unlikely to predict the occurrence of formally similar items? Secondly, if so, would such formal priming show similarities to, and/or differences from, word repetition effects?

The answer to the first question is clear. Formal priming resulted in reliable modulation of the ERP throughout the period normally associated with semantic and repetition priming effects. With respect to the second question, the formal and repetition priming effects had some features in common but also showed some differences. Both effects onset at approximately 200 ms post-stimulus and were of similar magnitude for some 150 ms thereafter. Subsequently the amplitude of the repetition effect became significantly greater. Both formal and repetition

Table 6.4 Summary of the results of ANOVA performed on the rescaled mean amplitudes of the subtraction waveforms in Experiment 3.

200 - 400 ms	chain	$F(2,30) = 9.24$	$p < 0.005$	$\varepsilon = 0.82$
	prime type x chain	$F(2,30) = 3.61$	$p < 0.05$	$\varepsilon = 0.93$
400 - 600 ms	chain	$F(2,30) = 7.37$	$p = 0.005$	$\varepsilon = 0.81$
	prime type x chain	$F(2,30) = 5.19$	$p < 0.05$	$\varepsilon = 0.92$
600 - 800 ms	chain	$F(2,30) = 5.08$	$p < 0.05$	$\varepsilon = 0.85$
	prime type x chain	$F(2,30) = 4.31$	$p < 0.05$	$\varepsilon = 0.92$
	prime type x site	$F(2,30) = 4.52$	$p < 0.05$	$\varepsilon = 0.67$

A



B

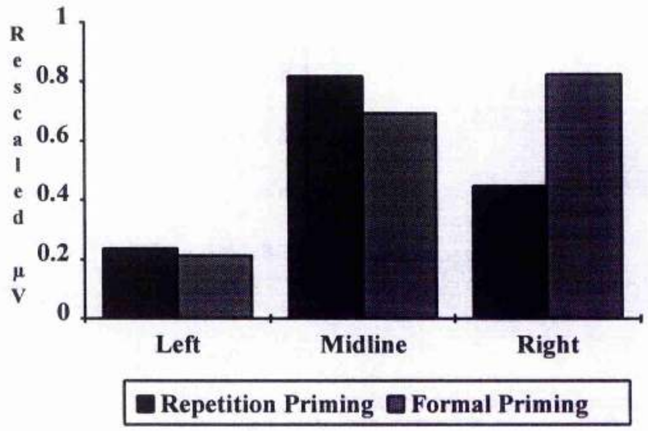


Figure 6.4. Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus in Experiment 3.

priming effects were greater over the right hemisphere and the midline than over the left hemisphere. However, whereas the formal priming effects were greatest in waveforms recorded from electrodes over the right hemisphere, the repetition effects were greatest in waveforms recorded at midline sites. This topographic difference between the repetition and formal priming effects was common to both the first and second of the analysis epochs. A discussion of the possible functional significance of the repetition and formal priming effects and the relation between them will be deferred until the General Discussion. Prior to that, two more experiments will be described which seek to constrain the possible interpretation of these effects.

The repetition condition differs from the formal priming condition in several ways. Firstly, whilst repetition involves the re-accessing of the same lexical representations, formally related word pairs are commonly held to have separate, although possibly linked, lexical representations. Secondly, whilst in the repetition condition lexical and semantic information is repeated, this is not the case in the formal priming condition. Thirdly, the repetition condition involves a greater degree of formal similarity between prime and probe words than does the formal priming condition itself. Thus whilst the formally similar word pairs had a similarity rating of some 60%, the repeated pairs were, by definition, 100% similar. Differences between the effects of repetition and formal priming may have been a reflection of any of these differences in formal, lexical or semantic overlap between prime and probe encounters.

Experiment 4 attempts to dissociate the effects resulting from the difference in degree of formal similarity, from those resulting from the difference in lexical and semantic overlap between the prime and probe enconters in the two priming conditions. The question of whether the processing of orthographically legal non-words results in the activation of the lexical and semantic information associated with orthographically similar words is controversial. Nonetheless, a demonstration of a similar pattern of repetition and formal priming with such stimuli to that seen with words would strongly support the view that repetition and formal priming effects are not dependent upon the activation of lexical and semantic information.

Chapter 7

Experiment 4

Formal and repetition priming with non-words

7.0 Introduction

Experiment 3 confirmed the findings of the previous experiments that although before approximately 400 ms post-stimulus onset the repetition and formal ERP priming effects were of equivalent magnitude, subsequently the repetition effects became larger than the formal priming effects. In addition, Experiment 3 found that whilst the repetition effects were greatest over the midline, the formal priming effects were greatest in waveforms recorded from electrodes positioned over the right hemisphere.

Either or both of these differences between the priming effects could have resulted from variations in the degree of semantic, lexical or formal overlap between the prime and probe encounters in the two conditions. The next experiment attempts to determine whether semantic or lexical overlap is a necssary condition for the demonstration of formal priming effects by investigating formal priming with non-words. On the assumption that the amount of semantic and lexical information activated by non-words is limited, differences between repetition and formal priming in non-words equivalent to those found using real words would suggest that these effects are not dependent upon the repetition of lexical or semantic characteristics of the stimuli. The degree to which non-words activate such representations of orthographically or phonologically similar words is controversial, but it is unlikely that any ERP formal priming effects seen with non-words in the present experiment would be lexically mediated. This is because for each of the non-word pairs used, the word from which the non-word probe is derived is not a close neighbour of the non-word prime. Thus the non-word probe 'buple' is derived from the word 'bugle'. The prime non-word paired with 'buple' is 'bup' which has a number of word neighbours which are orthographically closer to it than is 'bugle' (e.g. bug, bud, bun, bus, but, buy, bull, bust). In these circumstances, for the ERP formal priming effect to be a result of partial activation of lexical representations, such partial activation would have to spread a considerable distance through an orthographic neighbourhood. Although the dynamics of partial activation resulting from the presentation of a non-word are not known, it seems unlikely that it would extend to such distant neighbours. To the extent that the non-word ERP repetition effect is similar to the non-word ERP formal priming effect, then the ERP non-word repetition effect is also unlikely to be lexically mediated.

A demonstration of formal priming effects in non-words would also indicate that these priming effects were not generated as a result of subjects predicting the identity of the probe item. This is because for any non-word prime (e.g. 'bup'), there is a large number of equally possible formally related non-words (e.g. 'buple', 'bupper', 'bupine' etc). Consequently predictions about the identity of the probe item would likely be incorrect.

7.1 Methods

7.1.1 Subjects

Sixteen subjects, having a mean age of 20 years (range 18-24 years), were each paid £6 to participate in the experiment. Ten subjects were female and all but one were right handed.

7.1.2 Materials

Eighty pairs of formally related words were selected. The first members of these pairs had a mean length of 4.2 letters and a mean frequency of 29.3 counts per million (Francis & Kucera, 1982), whilst their mates had a mean length of 6.5 letters and a mean frequency of 4.9. Using the same index of formal similarity as was used in Experiment 1A, the mean value of similarity between members of a formally related word pair was 0.65. These 80 related pairs were sub-divided into two sets of 40 pairs. The two sets were approximately balanced with respect to mean lengths in letters and mean word frequencies.

These formally related word pairs were transformed into formally related non-word pairs by changing one or two of the letters that were common to both members of the pair. Thus the pair 'poise' - 'poison' was changed to 'poile' - 'poilon'. In addition to these critical non-words, 312 non-words were used as filler items. Of these, 272 were constructed in the same way as the critical non-words. The remaining 40 non-words were constructed by removing one or more terminal letters from a real word. This resulted in a formally related non-word - real word pair, e.g. 'punge' - 'pungent'. In addition to the words used in these pairs, 64 more words were selected, of which 32 were similar in length to the non-word formal primes and 32 were similar in length to the non-word targets. 24 words, half of each length, were selected to form a group of repeating words, whilst the remainder formed a group which were presented only once.

For each subject, one sub-set of formally related non-word pairs was presented in a formal priming condition, whilst the second sub-set was presented in a repetition priming condition. In each case prime and probe items were presented on immediately succeeding trials, i.e. at a lag of 0. The formally related non-word-word pairs and the repeating word targets were also presented at a lag of 0. The experimental list of 600 items was sub-divided into 6 blocks of 100 items. The probability of a target occurring on a given trial was 0.21. The probability of an item being a repeated or formally primed non-word was, in each case, 0.07. The 128 target words were distributed over the blocks so that 2 blocks contained 22 targets and 4 blocks contained 21 targets. Including the non-word-word pairs, there were 20 formally related pairs per block. The words and non-words were combined in a pseudo-random order to produce one experimental list in which each block began with a filler item. A second list was produced by using a second pseudo-random sequence of experimental conditions. Finally two further lists were produced by rotating the two sub-sets of critical pairs around the two priming conditions.

7.1.3 Procedure

The equipment and the parameters for stimulus presentation and the EEG recording were the same as those used in Experiment 3. Subjects were requested to decide as quickly and accurately as possible whether the string of letters presented on the computer screen was a real word in English. They were asked to press a microswitch with the index finger of their right hand whenever they decided that a real word had been presented and to refrain from responding whenever a non-word was presented.

Data Analysis

The analysis of the data from this experiment will largely follow the same approach as that adopted for Experiment 3. Because the formal priming and repetition priming effects in Experiment 3 were shown to have different scalp distributions, planned comparisons of the mean rescaled amplitudes across electrode chains were performed for each priming condition separately. In addition, differences in the amplitudes of the N1 and P2 deflections across experimental conditions were assessed as in Experiment 1A.

7.2 Results

7.2.1 Behavioural Data

Subjects failed to detect 11.5% (sd = 8.85) of the real words, and incorrectly responded to 2.1% (sd = 1.5) of the non-words. The mean response time for correctly identified words was 675 ms (sd = 85 ms), while for incorrectly assigned non-words it was 772 ms (sd = 174 ms). The means of the standard deviations of these response times were 184 ms (sd = 50 ms) for the words and 246 ms (sd = 153 ms) for the non-words.

7.2.2 Event-Related Potentials

The grand average waveforms recorded at each site are presented in Figure 7.1, whilst the waveforms from the midline sites sre presented at larger scales in Figure 7.2. The mean number of trials per subject in the first presentation, formal priming and repetition priming conditions is 33, 34 and 34 respectively. Mean amplitudes in each epoch measured are presented in Tables 7.1 and 7.2. The subtraction waveforms for each priming condition are presented in Figure 7.3.

There are prominent N80 and P160 deflections in all conditions. Following these peaks there is a period during which the formal and repetition priming conditions are of similar magnitude and this in turn is followed by a period in which the repetition effects appear to be the greater. Prior to these effects the waveforms evoked by repeated non-words appear to show an early onsetting negative-going shift especially at midline sites. This shift results in larger N80 and smaller P160 deflections than are found in the formal priming condition. The differences in the

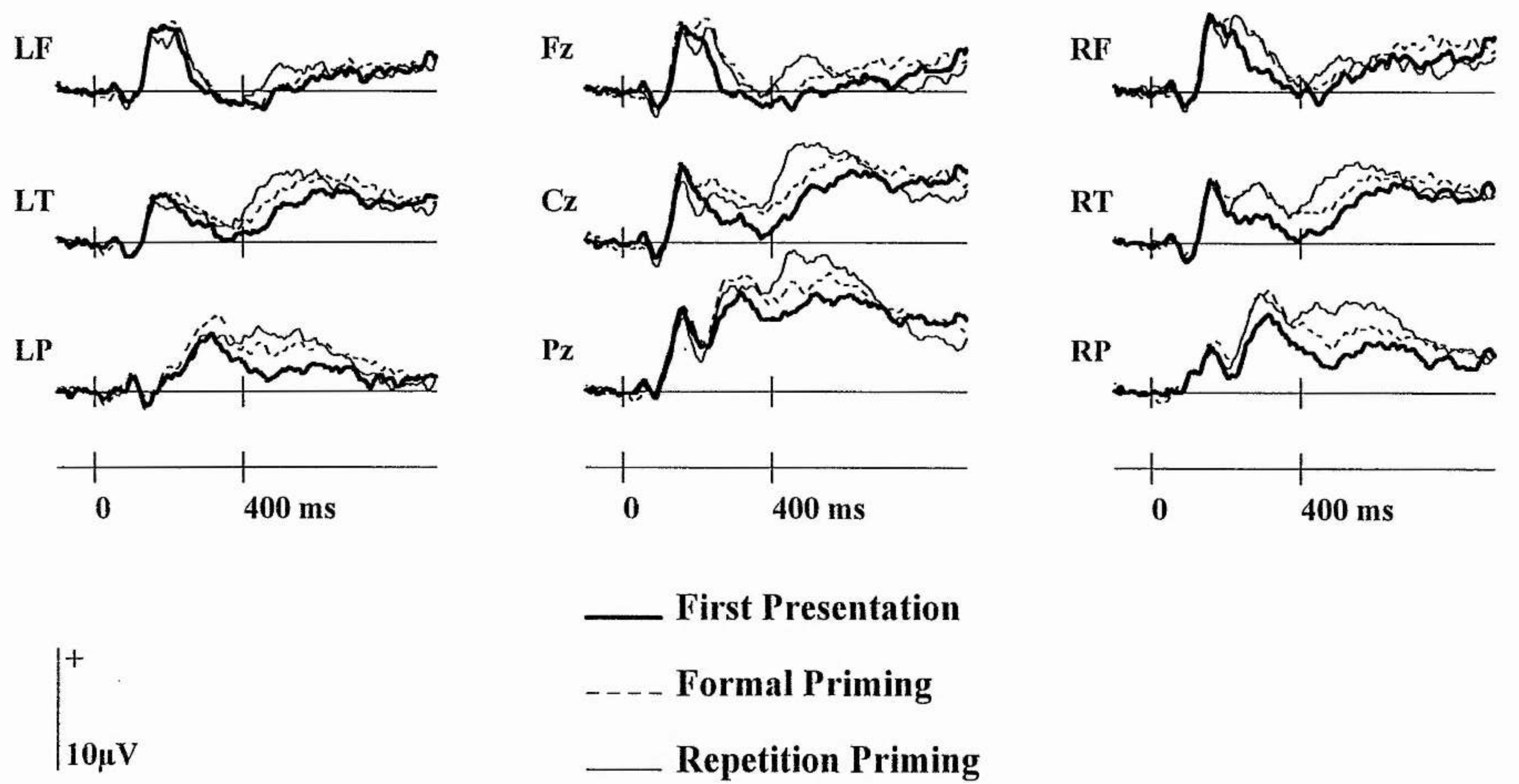


Figure 7.1 ERPs elicited at each electrode site by the first presentations of non-words, by repeated non-words and by non-words primed by their formal root forms in Experiment 4. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

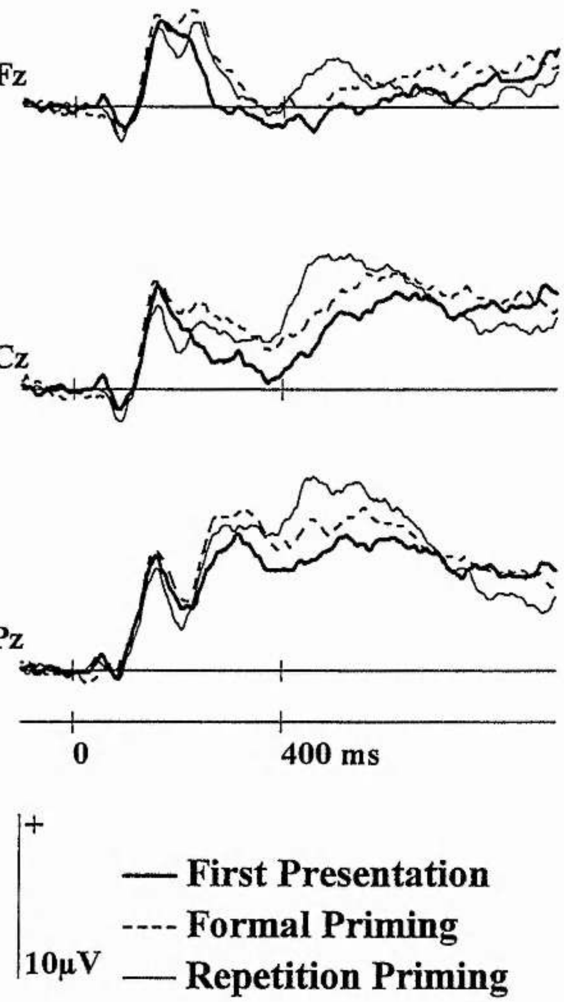


Figure 7.2 ERPs elicited at each midline electrode by non-word repetition and by formal priming in Experiment 4. Electrode sites as in Figure 7.1.

Table 7.1. Mean amplitudes of the N80 and P160 peaks at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 4

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
N80									
First Presentation	-0.74	-0.56	0.36	-0.44	-0.74	0.52	-0.61	-0.81	0.63
Formal Priming	-1.26	-0.90	0.56	-1.01	-0.79	0.91	-0.74	-0.57	0.92
Repetition Priming	-1.34	-1.29	-0.01	-0.75	-0.68	0.35	0.96	0.77	0.69
P160									
First Presentation	4.18	5.16	6.08	4.16	2.98	-0.41	5.11	4.14	3.25
Formal Priming	4.96	5.83	6.58	4.44	3.42	0.20	5.45	4.60	3.82
Repetition Priming	4.01	4.14	5.23	3.84	2.68	-0.55	4.67	3.81	3.04

Table 7.2. Mean amplitudes over each of the 200 ms measurement intervals at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 4.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
200 - 400 ms									
First Pres.	0.54	1.94	6.33	0.91	1.55	3.08	1.98	1.71	4.38
Formal	2.42	4.01	8.00	1.55	2.61	4.89	3.78	3.79	6.27
Repetition	1.82	3.34	7.39	1.32	2.26	3.64	3.59	3.69	6.06
400 - 600 ms									
First Pres.	-0.36	3.74	7.36	-0.19	2.47	1.77	0.73	2.36	3.21
Formal	0.91	5.45	8.93	0.02	3.93	3.70	1.55	3.88	5.03
Repetition	1.90	7.37	10.90	1.21	5.08	4.79	2.13	5.54	7.31
600 - 800 ms									
First Pres.	1.01	5.29	6.98	1.40	3.80	1.57	2.68	4.45	3.45
Formal	2.24	6.29	7.56	2.01	4.98	2.94	3.80	5.46	4.47
Repetition	0.61	5.35	7.40	1.59	4.16	2.28	2.13	5.09	5.41

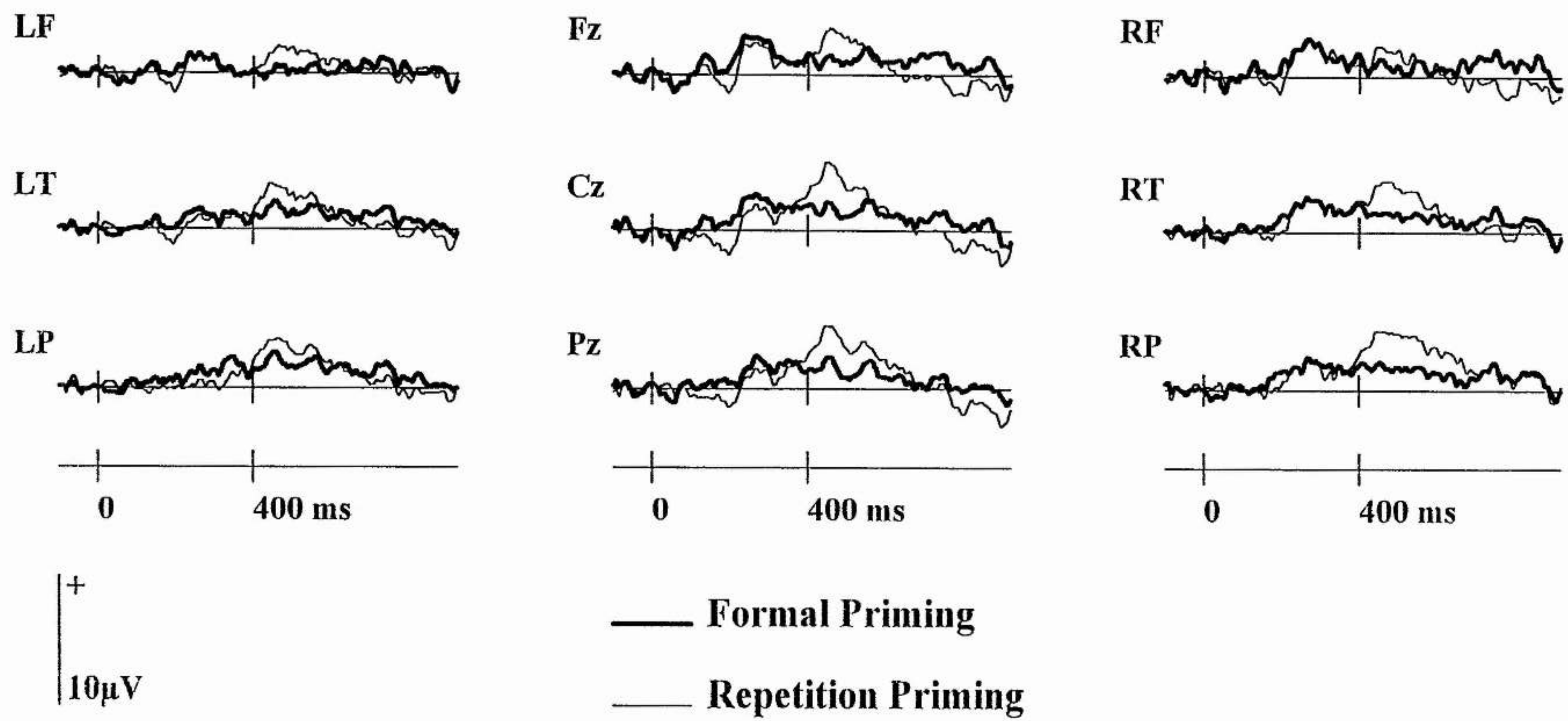


Figure 7.3 Subtraction waveforms for non-word repetition and formal priming conditions at each electrode site in Experiment 4. Electrode sites as in Figure 7.1.

amplitude of the N80 deflection were not reliable, but ANOVA on the mean amplitudes of the P160 deflection did result in a reliable effect of presentation type. Planned comparisons showed that the amplitude of the P160 in each of the priming conditions differed reliably from the first presentation condition, and also from one another.

7.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms

Table 7.3 summarises the results of the ANOVAs performed on the non-subtracted waveforms.

200 - 400 ms

ANOVA revealed a main effect of presentation type over midline sites. Planned comparisons showed that the magnitude of each priming effect was reliable, but that they did not themselves differ. At lateral sites there was a main effect of presentation type. As at the midline, the magnitude of the two priming effects were each reliable but the difference between them was not. ANOVA also revealed a reliable interaction between presentation type and hemisphere. Whilst in all three conditions waveforms recorded over the right hemisphere were more positive-going than were those recorded from over the left, post-hoc Scheffé tests indicated that this asymmetry was greater for the formal and repetition priming conditions than for the first presentation condition. The difference between the two priming conditions was not reliable.

400 - 600 ms

As in the previous epoch the overall ANOVA revealed a reliable effect of presentation type at midline sites. Planned comparisons indicated that formal and repetition priming effects were both reliable. In addition the repetition priming effect was reliably greater than the formal priming effect. At lateral sites there was a main effect of presentation type and also an interaction between presentation type and electrode site. Planned comparisons showed that the waveforms in each presentation condition differed reliably from those in the other two conditions. Post hoc tests indicated that the repetition effect was greater at temporal and parietal sites than at the frontal sites.

600 - 800 ms

The main effect of presentation type was reliable in neither the midline nor the lateral analysis, nor did planned comparisons indicate that either priming effect was reliable when tested separately. In the ANOVA of lateral sites there was a reliable 3-way interaction between the factors of presentation type, hemisphere and site. The positive-going repetition effect at the right parietal site differed reliably from the small negative-going effect at the right frontal site.

Table 7.3 Summary of the results of ANOVAs performed on the mean amplitudes of the waveforms elicited by the non-words on their first presentation when partially primed and when repeated in Experiment 4.

N80	Midline	No Significant Differences			
	Lateral	No Significant Differences			
P160	Midline	presentation type x site	$F(2,30) = 5.54$	$p < 0.01$	$\varepsilon = 0.94$
	Lateral	hemisphere x site	$F(2,30) = 10.32$	$p < 0.01$	$\varepsilon = 0.59$
200 - 400 ms	Midline	presentation type	$F(2,30) = 8.04$	$p < 0.01$	$\varepsilon = 0.73$
	Lateral	presentation type	$F(2,30) = 9.79$	$p = 0.001$	$\varepsilon = 0.83$
		presentation type x hemisphere	$F(2,30) = 4.53$	$p < 0.05$	$\varepsilon = 0.84$
400 - 600 ms	Midline	presentation type	$F(2,30) = 10.88$	$p < 0.001$	$\varepsilon = 0.87$
	Lateral	presentation type	$F(2,30) = 14.73$	$p < 0.001$	$\varepsilon = 0.74$
		hemisphere	$F(1,15) = 4.69$	$p < 0.05$	
		presentation type x site	$F(4,60) = 4.37$	$p < 0.05$	$\varepsilon = 0.65$
600 - 800 ms	Midline	No Significant Differences			
	Lateral	hemisphere	$F(1,15) = 8.46$	$p < 0.05$	
		presentation type x hemisphere x site	$F(4,60) = 5.59$	$p = 0.005$	$\varepsilon = 0.59$

7.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms

200 - 400 ms

There was a main effect of chain ($F(2,30)=6.13$, $p<0.01$, $\varepsilon = 0.99$). Planned comparisons indicated that the formal and repetition priming effects were each greater over the right hemisphere than over the left hemisphere. This difference between chains is evident in Figure 7.4 A.

400 - 600 ms

There were no reliable effects. The more even distribution of the priming effects across electrode chains in this epoch compared to the previous epoch can be seen by comparing Figure 7.4 B with 7.4 A.

600 - 800 ms

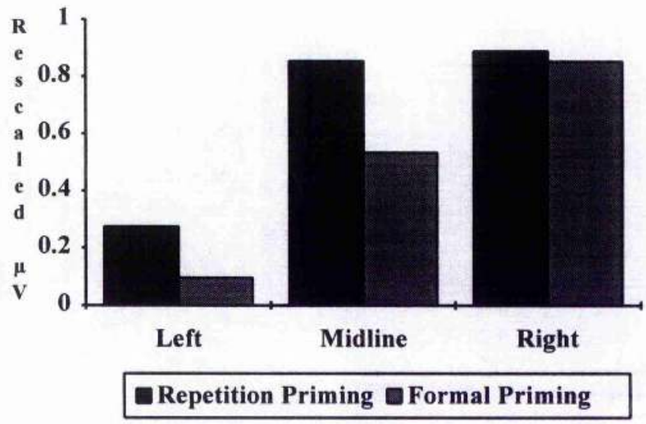
There were no reliable differences between priming conditions or between electrode chains in this epoch.

7.3 Discussion

The results of Experiment 4 show some notable similarities with the results of Experiment 3 but also some differences. In the current experiment there was a reduction in the amplitude of the P160 in the non-word repetition condition. The functional significance of this modulation of the ERP is not known. While the reports by Rugg (1987) and Nagy and Rugg (1989) of a similar reduction in the amplitude of this deflection as a result of immediate repetition strongly suggests this manipulation is implicated in eliciting this modulation, the many reports of repetition effects which do not result in such an effect (e.g. Bentin & McCarthy, 1994; Rugg, et al., 1988) suggests that stimulus repetition is not a sufficient condition.

This experiment sought to determine whether the differences in magnitude and topography between formal and repetition priming observed in Experiment 3 were best seen as a result of the differences in degree of formal overlap, or as a result of the repetition of semantic and lexical information that occurred in the repetition condition but not in the formal priming condition. Repetition and formal priming with non-words allowed the manipulation of the degree of formal similarity whilst minimising the effects of lexical or semantic processing. Under these conditions, differences between the non-word repetition and formal priming effects are unlikely to have arisen as a result of the differential involvement of lexical and semantic representation. Rather, such differences more likely arose as a result of the differences in the degree of formal similarity between prime and probe stimuli.

A



B

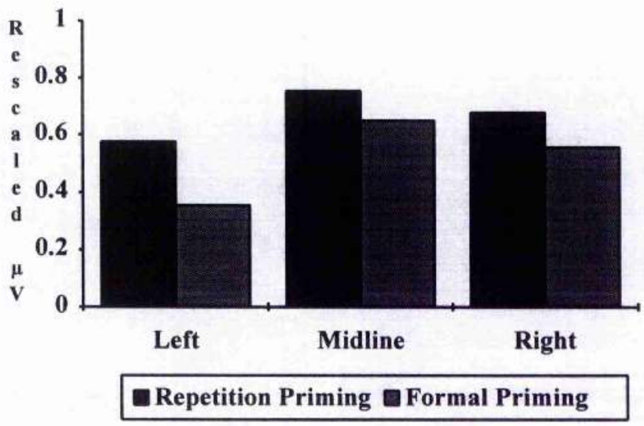


Figure 7.4. Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus onset in Experiment 4.

This reasoning suggests that the differences between the magnitudes of the formal and repetition priming effects seen with non-words was due to differences in degree of formal similarity between the prime and probe stimuli. This pattern of priming effects between 200 ms and 600 ms post stimulus, in which a period of equivalent repetition and formal priming effects was followed by a period during which the magnitude of the two effects differ is similar to the pattern of effects observed in the earlier experiments. This similarity in the pattern of relative magnitudes pre- and post- 400 ms across experiments using words and non-words suggests that the reason for these differences was the same in each case. Given the impoverished lexical and semantic information associated with non-words, it seems likely that the differences in the magnitudes of the repetition and formal priming effects arose as a result of differences in the degree of formal similarity between prime and probe encounters in the two priming conditions.

The conclusions which can be drawn from this experiment on the basis of topography are less clear. Between 200 and 400 ms post-stimulus, when the topographic profiles of the repetition and formal priming effects did not differ, the effects over the midline and right hemisphere were reliably greater than were those over the left hemisphere. They therefore appear to have a distribution similar to that found for the formal priming of words in Experiment 3. The change in the topographic profiles of the repetition effects between the two experiments may suggest that to the extent that the contribution of lexical and semantic information is minimised, and similarity is based purely of the formal properties of stimuli, the effects shift towards the right hemisphere. Such changes in topography across experiments must however be treated with caution. The topography of repetition effects can vary between experiments even when there is little difference in the nature of the stimuli repeated or in the conditions under which the repetition takes place. A stronger test of the possible differences in topography between word and non-word repetition and formal priming effects would require that these conditions be contrasted within the same experiment. Taken at face value however, the shift in the early part of the repetition effect away from a midline maximum with words, towards the right hemisphere with non-words, can plausibly be seen as resulting from a change in the representational substrate on which repetition-sensitive processes operate.

This interpretation does not however provide a satisfactory account of why the topographic profile of both the non-word repetition and non-word formal priming effects is more even with respect to electrode chain between 400 ms and 600 ms post-stimulus. However, this distribution may have been due to the influence of the left hemisphere maximum Late Positive Component which, it has been suggested, is sensitive to explicit, recollective aspects of memory (Van Petten, et al., 1991; Wilding, et al., 1995). Since this component tends to be somewhat greater over the left hemisphere than over the right, the effect of it being superimposed on the right-greater-than-left N400 effect, would be to produce a waveform more symmetric with respect to hemisphere. Why this Late Positive Component should be more evident in this experiment than in the previous one is unclear. One possibility is that since non-words are novel stimuli, having no pre-existing representations, successful task performance is more dependent on the use of explicit recollection when the stimuli are non-words than when they are words. We will return to this issue in the discussion of Experiment 5 which further investigates the nature of formal priming effects with word stimuli.

In each of the experiments reported thus far, the sets of formally related stimuli used consisted mainly of stimulus pairs which were similar with respect to both visual form and phonology. Thus whilst it appears that ERPs are sensitive to formal similarity, it is unclear from the experiments reported so far whether similarity of visual form and phonology are equally potent in modulating ERPs. Experiment 5 attempts to resolve this issue by dissociating these two dimensions of formal similarity.

Chapter 8

Experiment 5

The contribution to formal priming effects of orthographic and phonological similarity

8.0 Introduction

Ideally, the effects of similarity of visual form and of phonology should be investigated using stimuli which factorially combine these variables, as in Rugg and Barrett (1987). Where the overlap between words is in their initial segments, however, the materials to produce such a design are not available in English. Specifically, there are insufficient word pairs in which one member of the pair is a heterographic homophone of the initial segment of its mate to allow the employment of word pairs which are similar with respect to phonology, but dissimilar with respect to their visual form. Because of this constraint, Experiment 5 investigates formal priming effects for word pairs which share both initial visual form and phonology (e.g. 'scan' - 'scandal'), with pairs in which there is a change in the orthographic-to-phonological mapping of first vowel, and which therefore share only initial visual form (e.g. 'ball' - 'ballast').

If the formal priming effects found in the previous experiments are a result only of similarity of visual form or orthography, then the formal priming effects for the two types of word pairs should be equivalent. On the other hand, should phonological similarity be a necessary condition for ERP formal priming effects to be observed, then such effects should be confined to the 'scan' - 'scandal' word pairs.

8.1 Methods

8.1.1 Subjects

16 adults (6 female, all right handed) aged between 18 and 27 years (mean age 21 years) were each paid £6 for participating in the experiment.

8.1.2 Materials

The critical items for this study consisted of two sets of 80 pairs of formally related words. In one set the paired words were similar in both visual form and phonology ('scan' - 'scandal'), and these will be referred to as PH+ words. Members of formally related pairs in the second set differed in their phonologies, as defined by the pronunciation of the initial vowel ('lathe' - 'lather'), but were as similar to each other in respect of their visual form as were the PH+ words. The words in this second set will be referred to as the PH- words. In the PH+ group the first members of the pairs had a mean length of 4.6 letters and a mean frequency of 23.6 occurrences per million (Francis & Kucera, 1982), whilst their formally related mates had a mean length of 6.5 letters and a mean frequency of 4.4. The equivalent values for the PH- group were 4.1, 27.7, 6.0 and 3.9 respectively. Using the index of similarity employed in the previous experiments the PH+ word pairs had a mean score of 0.68 and the PH- word pairs a mean score of 0.64. The PH+ and PH- pairs were each subdivided into two sub-sets of 40 pairs. The sub-sets were approximately balanced with respect to length, frequency and score on the similarity index.

The critical items were combined with 270 non-word targets and 310 filler words producing a total of 900 items in each list. As in the previous two experiments, items which had been primed constituted a relatively small proportion of the total number of items. 9% of all items were repeated words, and 9% were words which had been formally primed. The proportion of targets in each list was 30%.

The non-word targets were all orthographically legal and pronounceable and were constructed by replacing one or two letters in words similar in length and frequency range to the critical items and fillers. Of the non-words presented during the experiment, 195 were presented only once, 15 were repeated, 15 were preceded by a formally related non-word, ('glip' - 'glipse'), and 15 were preceded by a formally related word, ('throne' - 'thronce'). The non-words were constructed such that their lengths mirrored the distribution of the lengths of the critical items.

Of the 310 filler words, 15 were designated as formal primes for non-word targets as described above, leaving 295 filler words to be selected. As with the non-word targets, this was done so as to ensure that the distribution of the word lengths over the filler words as a whole reflected the distribution found in the critical items.

In each experimental list, the second member of each of the formally related pairs from one sub-set of PH+ items and one sub-set of PH- items was repeated at a lag of 0. For the second sub-sets of PH+ and PH- words, the second member of each of the pairs was immediately preceded by its formally related mate. These conditions will be referred to as the 'formal PH+' and 'formal PH-' conditions. The experimental items were combined, in a pseudo-random order, with the target non-words and filler items to produce the final list of 900 items. This was done such that when the list was subdivided into 10 blocks of 90 items, equal numbers of critical items, and equal numbers of words and non-words, appeared in each block. A total of four such lists were produced by generating a second pseudo-random ordering of experimental conditions, and rotating each of the PH+ and PH- word groups between the repetition and formal priming conditions. Each list was seen by four subjects.

8.1.3 Procedure

The equipment and the parameters, both for stimulus presentation and the recording of EEG, were the same as those in used in Experiment 4. Subjects received the same instructions as had been given to subjects in Experiment 3.

Data Analysis

Mean amplitudes of the waveforms were measured +/- 24 ms around the N90 and P160 peaks and in the three successive 200 ms epochs beginning at 200 ms post stimulus onset. Because both PH+ and PH- words appear in a repetition condition, initial analyses determined whether the waveforms evoked by the two word types differed either on their first or second presentation. No differences were found and the waveforms elicited in the repetition conditions were collapsed across word type. Subsequent ANOVAs had a single factor of presentation type with four levels; first presentation, formal PH-, formal PH+ and repetition, in addition to the factors of electrode site and, in the analysis of data from lateral sites, hemisphere. Planned comparisons were then used to assess the reliability of each of the priming effects and to compare their magnitudes.

The scalp distributions of the priming effects were analyzed using ANOVA of the rescaled mean amplitudes of the subtraction waveforms from all three priming conditions and all 9 sites. As in the previous experiments, the 9 sites were sub-divided into three chains of three electrodes. Because of the *a priori* interest in differences in topography between the formal priming effects and the repetition priming effects, subsidiary ANOVAs were performed to compare each of the formal priming conditions with the repetition condition.

8.2 Results

8.2.1 Behavioural Data

The overall error rate was 5.2% (sd = 2.2). 7.8% (sd = 0.54) of the non-words were missed, whilst 4.1% (sd = 0.05) of the real words received incorrect responses. Mean reaction times for correctly detected non-words was 763 ms (sd = 118 ms), with a standard deviation across subjects of 171 ms (sd = 45 ms).

8.2.2 Event Related Potentials

Waveforms evoked in the first presentation and three priming conditions at each site are presented in Figure 8.1. Waveforms recorded at midline sites in each condition are shown at an expanded scale in Figure 8.2. Mean amplitudes of waveforms in the first presentation, formal priming and repetition priming conditions, for each epoch, are given in Tables 8.1 and 8.2. The mean number of trials per subject in the first presentation, PH-, PH+ and repetition conditions is 64, 32, 31 and 65 respectively. Subtraction waveforms generated using the collapsed first presentation and repetition waveforms are shown in Figure 8.3.

After prominent N90 and P160 peaks, which do not differentiate the experimental conditions, waveforms in each condition are characterised by a prolonged slow positive wave. Between approximately 200 ms and 600 ms post-stimulus, waveforms evoked in each of the priming conditions are more positive-going than are those evoked in the first presentation condition. This positive going shift is once again initially of approximately equal magnitude in the repetition and formal priming conditions. Subsequently the positive going shift in waveforms evoked by repeated words is greater in magnitude than that evoked in the formal priming condition. The magnitude of this shift diminishes after approximately 500 ms post-stimulus. At most sites however, the waveforms evoked by formally primed and repeated words remain

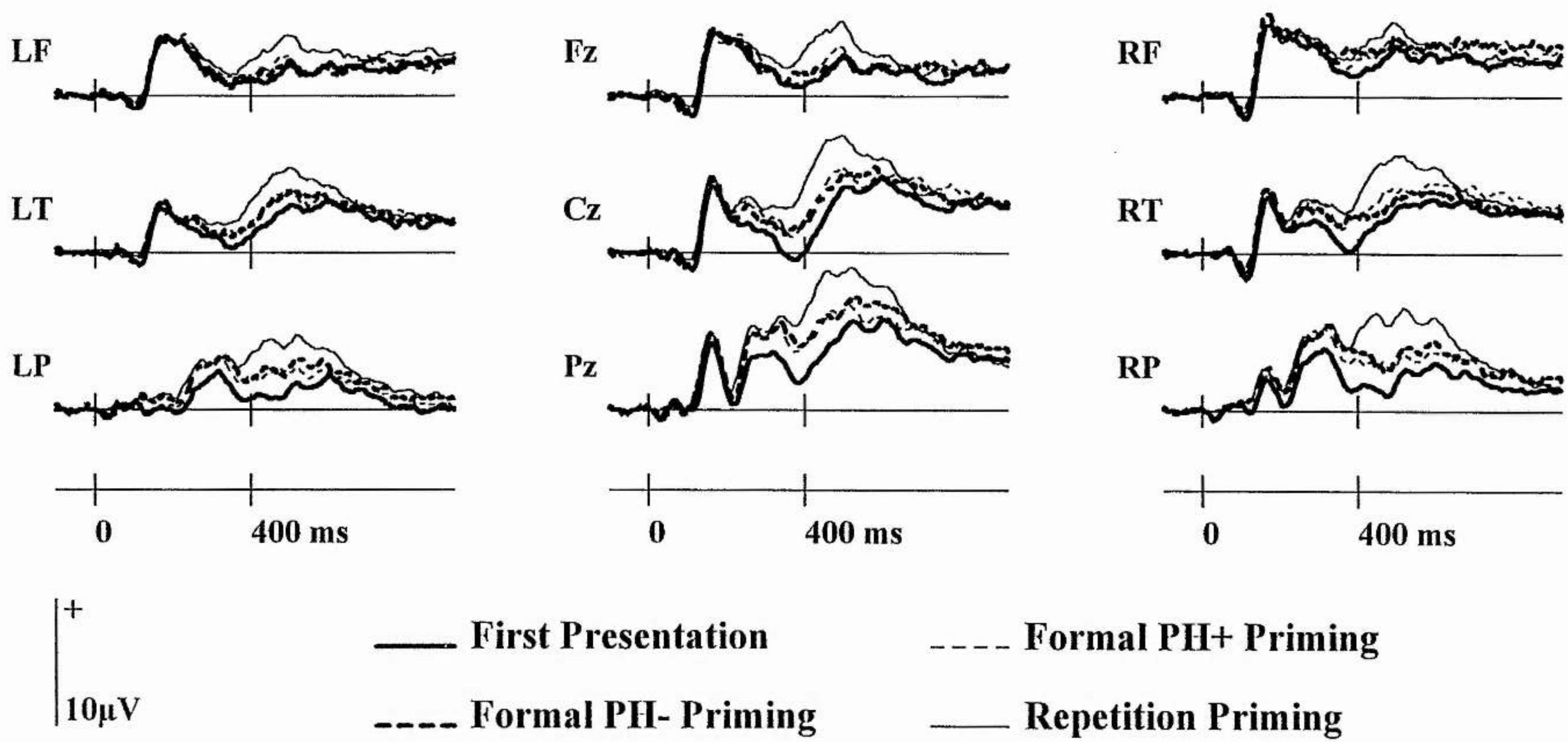


Figure 8.1 ERPs elicited at each electrode site by the first presentations of words, by repeated words and by words primed by their formal PH+ or formal PH- root forms in Experiment 5. Fz, Cz and Pz refer to centro-frontal, mid-central and centro-parietal electrode sites respectively. LF, RF, LT, RT, LP and RP refer to left (L) and right (R) frontal (F), temporal (T) and parietal (P) sites.

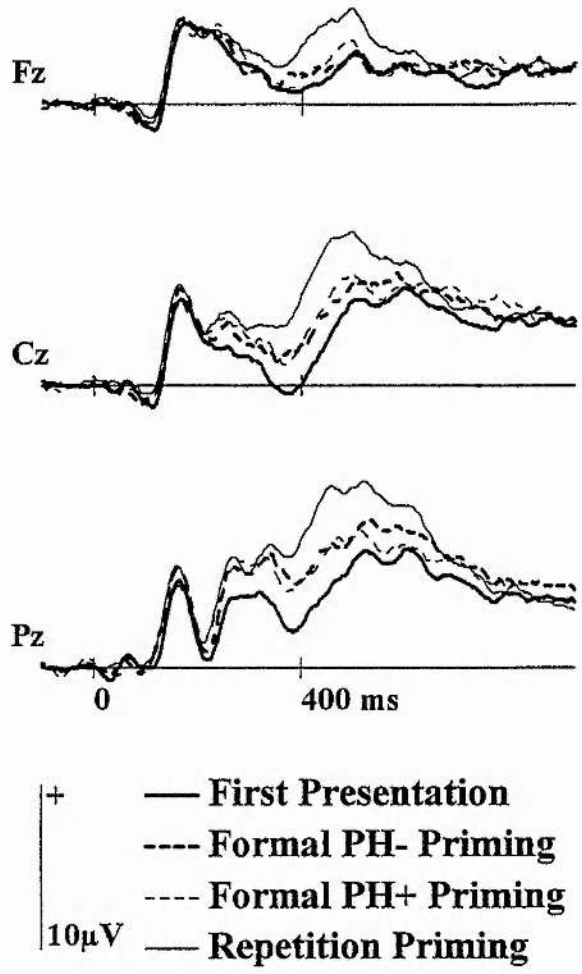


Figure 8.2 ERPs elicited at each midline electrode by word repetition and by formal priming in Experiment 5. Electrode sites as in Figure 8.1.

Table 8.1. Mean amplitudes of the N90 and P160 peaks at each electrode site for the first presentation, formal and repetition priming conditions of Experiment 5.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
N90									
First Pres.	-1.13	-0.88	0.10	-0.80	-0.55	0.42	-1.15	-1.07	0.44
PH-	-0.97	-0.83	0.07	-0.63	-0.36	0.54	-0.74	-0.62	0.66
PH+	-1.16	-0.81	0.05	-0.93	-0.66	0.26	-0.80	-0.86	0.47
Repetition	-0.50	-0.29	0.46	-0.23	-0.08	0.69	-0.67	-0.68	0.73
P160									
First Pres.	3.41	3.98	4.27	3.15	2.57	-0.01	4.07	3.06	1.79
PH-	4.11	4.71	5.06	3.65	3.14	0.85	5.12	3.94	2.66
PH+	3.70	4.29	4.34	3.19	2.58	-0.08	4.14	3.21	2.16
Repetition	4.23	5.18	5.34	3.73	3.31	1.05	4.56	3.91	2.92

Table 8.2. Mean amplitudes over each of the three 200 ms measurement intervals for each electrode site and for the first presentation, formal PH, formal PH+ and repetition priming conditions of Experiment 5.

	Fz	Cz	Pz	LF	LT	LP	RF	RT	RP
200 - 400 ms									
First Pres.	2.34	1.28	3.18	2.19	1.47	1.57	3.30	1.81	3.12
PH-	2.69	2.66	5.02	2.36	2.11	2.91	4.26	2.97	4.72
PH+	2.47	2.65	4.89	2.40	2.01	2.49	3.59	3.07	4.51
Repetition	3.40	4.03	5.86	2.90	2.78	3.34	4.01	3.73	5.32
400 - 600 ms									
First Pres.	2.04	3.98	5.67	1.65	3.11	1.63	2.93	3.20	2.51
PH-	2.36	5.42	7.72	1.97	4.08	3.43	3.89	4.06	4.22
PH+	2.35	5.31	7.03	2.08	3.83	2.76	3.65	4.52	3.93
Repetition	4.33	8.12	10.33	3.79	5.80	5.17	4.60	6.90	7.36
600 - 800 ms									
First Pres.	1.60	4.37	5.48	2.06	3.03	1.35	2.74	3.71	2.74
PH-	2.43	5.36	6.83	2.49	3.41	2.23	4.27	4.29	3.67
PH+	2.21	5.59	6.11	2.36	3.51	1.77	4.16	5.09	3.67
Repetition	2.16	5.34	6.78	3.10	3.68	2.56	3.04	4.95	4.65

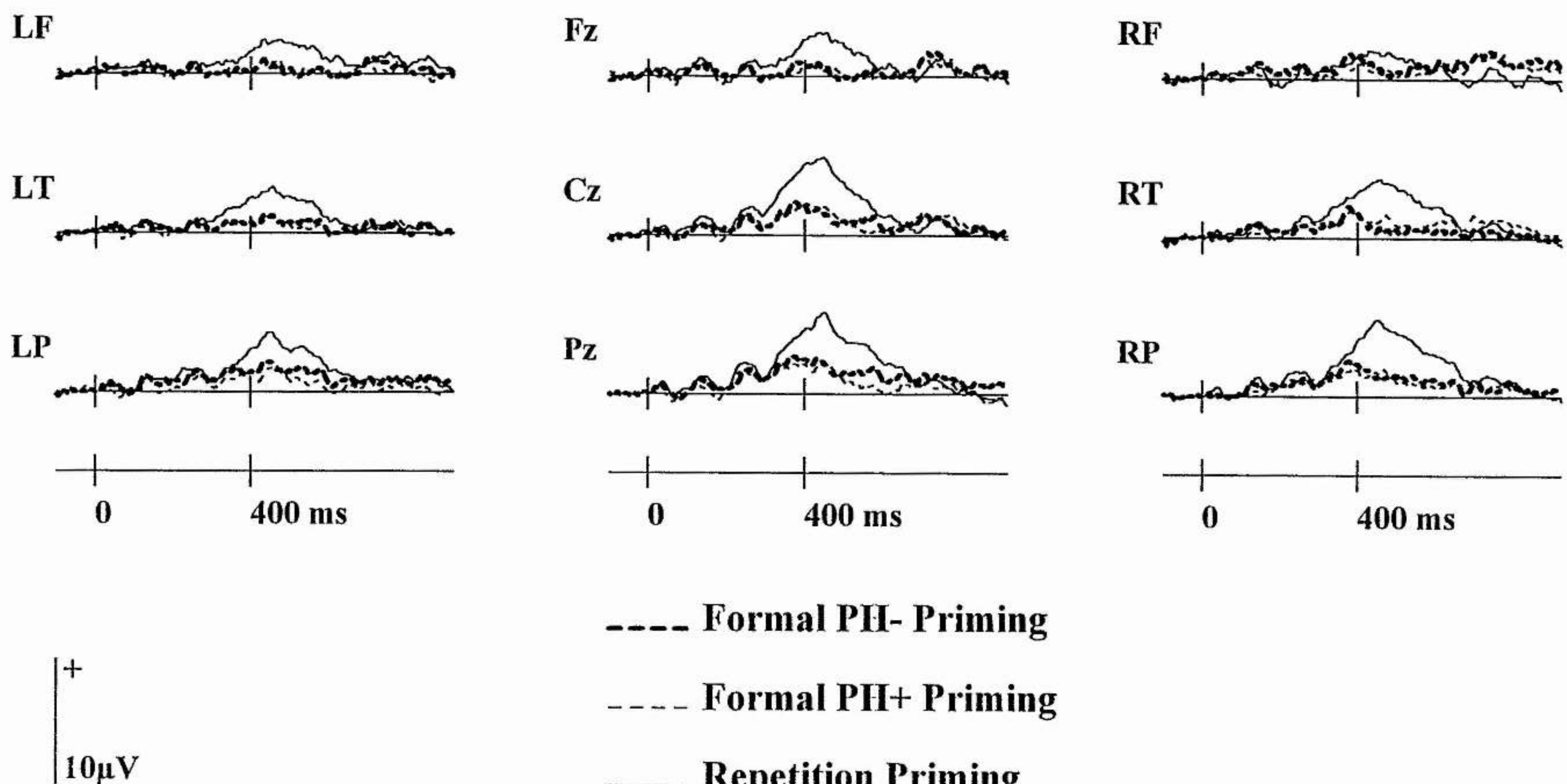


Figure 8.3 Subtraction waveforms for word repetition and formal priming conditions at each electrode site in Experiment 5. Electrode sites as in Figure 8.1.

more positive going than those evoked by words on their first presentation for the remainder of the recording epoch. Notably, the waveforms evoked by formally primed PH+ and PH- words overlay each other for most of the recording epoch.

8.2.2.1 ANOVA of the mean amplitudes of the non-subtracted waveforms

A summary of the results of the ANOVAs performed on the mean amplitude measurements of the waveforms elicited in each experimental condition is given in Table 8.3.

200 - 400 ms

The initial ANOVA on the measurements of the raw waveforms evoked by all four word types revealed reliable effects of presentation type over both midline and lateral sites. Over the midline, planned comparisons indicated that all three priming conditions differed from the first presentation condition. In addition the repetition effect was reliably greater than the two formal priming effects. This result was in contrast to the analogous results from the previous experiments. When the analysis was restricted to the interval between 200 and 300 ms post-stimulus onset, the formal and repetition priming conditions were each reliable but did not differ between themselves. This pattern of equivalent priming effects was found at the lateral sites regardless of the interval chosen for analysis.

There were also significant interactions between presentation type and electrode site. Over the midline, all three priming effects were greater at Pz than at Fz, whilst in the repetition and PH+ conditions the priming effects were also greater at Cz than at Fz. At the lateral sites, only in the repetition condition were there reliable differences in the sizes of the effects at different sites, with the repetition effect being larger at the parietal than at the frontal sites.

400 - 600 ms

The overall ANOVA on the data from midline sites resulted in a main effect of presentation type. Planned comparisons showed that only the formal PH- and repetition priming effects were reliable, and that the repetition effect was larger than either of the formal priming effects. There was also a reliable interaction between presentation type and site. The repetition effect was greater at Cz and Pz than at Fz and the formal PH- effect was larger at Pz than at Fz.

At lateral sites there was a reliable effect of presentation type. As at the midline, planned comparisons showed the formal PH- and the repetition effects to be reliable, and the repetition effect to be greater than either of the formal priming effects. There were reliable interactions between presentation type and site, and between presentation type, hemisphere and site. Post hoc tests showed that the repetition effects were larger at parietal than at frontal sites. Although the repetition effects were seemingly larger at the right parietal than at the left parietal site, this difference was not reliable in a post-hoc test.

Table 8.3 Summary of the results of ANOVAs performed on the mean amplitudes of the waveforms elicited by the non-words on their first presentation when partially primed and when repeated in Experiment 5.

200 - 400 ms	Midline	presentation type	$F(3,45) = 10.73$	$p < 0.001$	$\varepsilon = 0.89$
		presentation type x site	$F(6,90) = 5.68$	$p = 0.001$	$\varepsilon = 0.55$
	Lateral	presentation type	$F(3,45) = 7.35$	$p = 0.001$	$\varepsilon = 0.91$
		presentation type x site	$F(6,90) = 2.95$	$p < 0.05$	$\varepsilon = 0.64$
400 - 600 ms	Midline	presentation type	$F(3,45) = 15.37$	$p < 0.001$	$\varepsilon = 0.84$
		presentation type x site	$F(6,90) = 5.15$	$p < 0.005$	$\varepsilon = 0.54$
	Lateral	presentation type	$F(3,45) = 15.07$	$p < 0.001$	$\varepsilon = 0.77$
		presentation type x site	$F(6,90) = 6.35$	$p < 0.001$	$\varepsilon = 0.61$
		presentation type x hemisphere x site	$F(6,90) = 4.09$	$p = 0.005$	$\varepsilon = 0.68$
600 - 800 ms	Midline	No Significant Differences			
	Lateral	presentation type x hemisphere x site	$F(6,90) = 4.25$	$p = 0.005$	$\varepsilon = 0.63$

600 - 800 ms

There were no significant effects involving prime type over the midline, and nor did planned comparisons on the individual priming effects show them to be reliable. At lateral sites only the 3-way interaction between presentation type, hemisphere and electrode site was reliable. The repetition effect was larger at the right parietal site than at other sites, whilst the formal priming effects were of approximately equal magnitude over the anterior-posterior line.

8.2.2.2 ANOVA of the rescaled mean amplitudes of the subtraction waveforms

200 - 400 ms

Figure 8.4 A shows the distribution of the priming effects across the three electrode chains for each priming condition. Although the formal priming effects were proportionately greater over the right hemisphere than were the repetition effects, when all three conditions were included in the analysis there were no reliable effects involving the factors of prime type or of chain. When the analysis was restricted to the PH- and repetition conditions the interaction between prime type and chain was marginally significant ($0.05 < p < 0.10$). Post-hoc analysis showed that although the difference in the size of the effects at each chain was not reliable, the pattern of effects between the midline and right hemisphere chains was different in the two priming conditions.

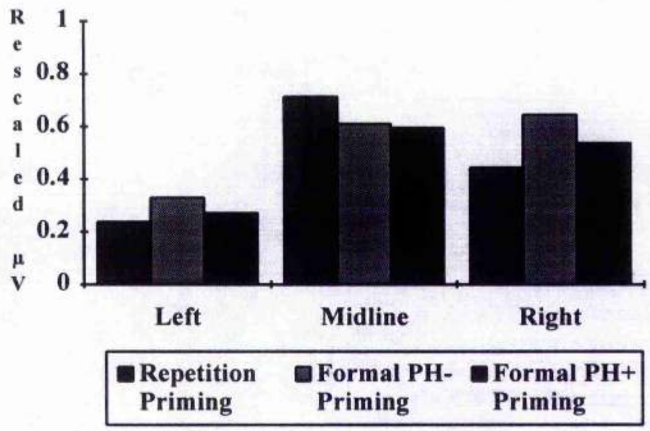
400 - 600 ms

The distribution of the priming effects across the three chains is shown in Figure 8.4 B. There were no reliable effects in the analysis of the rescaled data from all three conditions. When the analysis was restricted to the formal PH- and repetition conditions, there was a reliable 3-way interaction between prime type, chain and site ($F_{4,60} = 5.43$, $p < 0.005$, $\varepsilon = 0.68$). This reflected the more posterior distribution over the right hemisphere of the repetition priming effect compared to the formal priming effect. The interaction with site complicates the investigation of differences in the pattern of formal and repetition priming effects across chains. However there was no evidence of a difference in the pattern of effects across chain as a function of prime type at frontal, central/temporal or at parietal electrode sites.

600 - 800 ms

There was a reliable interaction between prime type, chain and site ($F_{8,120} = 3.18$, $p < 0.05$, $\varepsilon = 0.59$). This interaction reflected the differences between the right hemisphere, where there were frontally distributed PH+ and PH- effects and a parietally distributed repetition effect, and the left hemisphere, where each of the effects were distributed evenly over the head.

A



B

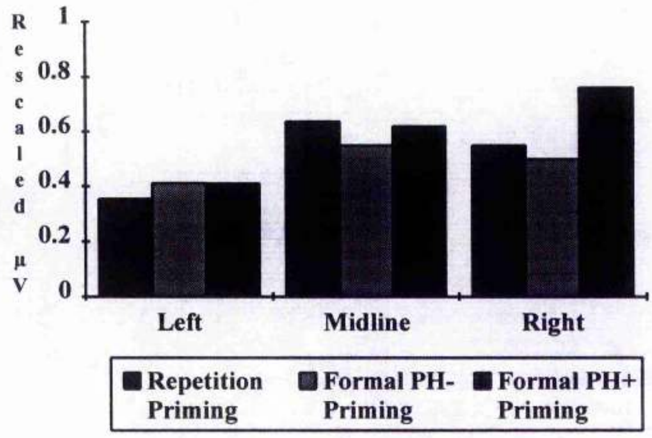


Figure 8.4. Mean rescaled amplitudes of repetition and formal priming effects for each electrode chain collapsed over sites between (A) 200 -400 ms and (B) 400 - 600 ms post-stimulus in Experiment 5.

8.3 Discussion

In respect of both their timing and their relative magnitudes, the formal priming and repetition effects in this experiment parallel the effects seen in the previous ones. Once again the formal priming effects onset at essentially the same latency as the effects of repetition, and initially were of similar magnitude. Subsequently, the magnitude of the repetition effects increased relative to the magnitude of the formal priming effects.

The major conclusion to be drawn from this experiment is clear. The addition of phonological similarity to similarity of visual form has no effect on the ERP formal priming effect in terms of onset latency, magnitude or scalp distribution. Clearly this would not be surprising if ERPs were insensitive to the processing of phonology. However, the evidence from cross-modality studies (Anderson & Holcomb, 1995; Rugg, et al., 1993), and from studies using orthographically and semantically unrelated rhyming words (Praamstra, et al., 1994; Rugg & Barrett, 1987) shows that this is not the case.

There was once again some evidence that the formal priming effects were more asymmetrically distributed in favour of the right hemisphere than were the repetition effects. This effect was reliable however only in the formal PH- condition and only between 200 and 400 ms post-stimulus onset. The limited reliability of these effects in this experiment provide only qualified support for the view proposed in Section 7.3 that when priming effects are based on formal similarity then they tend to be largest at right hemisphere sites.

As in the Experiment 4, the more symmetrical distribution of the repetition and formal priming effects post- 400 ms may reflect the influence of the left hemisphere maximum Late Positive Component. However, if this is the case then it suggests that lexical status is not an important determinant of the degree to which the post-400 ms effects are influenced by the presence of this component. Although Experiment 3 used words and Experiment 4 non-words, the waveforms in the two experiments had similar topographies after 400 ms post-stimulus. Furthermore, while waveforms from Experiments 3 and 5 differed in scalp topography, both experiments used words as the critical items.

The present results suggest that similarity of visual form is sufficient for the generation of ERP formal priming effects. Whether such similarity of visual form is a necessary condition, or whether phonological similarity would also be sufficient is impossible to tell from the present experiments. If Monsell (1985) and Rugg et al (1993) are correct in suggesting that the auditory presentation of words results in the generation of phonological but not orthographic codes, the possibility arises of using a cross-modality priming paradigm to address this question.

Chapter 9

General Discussion

9.0 Introduction

In this final chapter I will summarise the results of all six experiments which have been reported here. I will then discuss the extent to which these experiments are relevant to the debate over the functional significance of the N400 and their relevance to other recent studies which have investigated the representation of visual word forms.

9.1 A summary of the main findings

The first three experiments investigated whether ERPs are sensitive to a derivational relationship between words in the same or similar manner to that which has been demonstrated for word repetition and semantic similarity. Such derivational priming effects were compared with priming effects due to repetition or resulting from a purely formal similarity between words. The repetition condition acted as a 'benchmark' against which the magnitude of any morphological priming effects could be assessed. Combining some models of word recognition with some hypotheses concerning the functional significance of modulations of the N400 component of the ERP leads to the prediction of equivalent effects in the derivational and repetition priming conditions, at least with respect to modulations of the N400. The formal priming condition acted as a control for the formal similarity between the 'regular' derivationally related words used in the present experiments. Only effects found in the derivational priming condition but not in the formal priming condition could be taken as possibly resulting from the morphological similarity between words.

Experiment 1A provided a number of results that provided a basis for the subsequent experiments. Firstly, although there was a highly reliable positive-going shift in the ERP as a consequence of derivational priming, this effect was paralleled by a similar positive-going shift as a consequence of formal priming. Any differences between word types that were observed seemed to result from the earlier onset of the formal partial priming effects. Secondly, the partial and repetition priming effects were of similar magnitude initially, but differed in their topography. Thirdly, in a subsequent period of the waveform the partial and repetition priming effects differed in both magnitude and topography, with the repetition effects being the greater. Finally, there were some differences in the onset latencies between the various conditions. The priming effects with formal words onset earlier than the equivalent effects with derived words in the repetition and in the partial priming conditions.

The results of Experiment 1B were similar to those of Experiment 1A in a number of respects. Once again formal and derivational partial priming effects were indistinguishable. The repetition priming effects were again initially of similar magnitude to the partial priming effects but subsequently became somewhat larger. The results of Experiments 1A and 1B differed with respect to the distribution of the partial and repetition effects. Unlike in

Experiment 1A, in Experiment 1B there was no evidence of a difference in the scalp distributions of the two effects.

Experiment 2 attempted to distinguish between the priming effects seen with the two word types using the variable of inter-item lag. For reasons which are unclear, the magnitude of the effects found in this experiment were small and as a consequence the results were inconclusive. There were reliable formal priming effects in the region before 400 ms post-stimulus onset, but the repetition effects were reliable only as part of an interaction with the factor of site. The small size of the effects in this experiment mean that the importance of inter-item lag in demonstrating formal priming effects cannot be ruled out, but the fact that it was this effect which remained reliable, rather than the repetition effect, suggests that inter-item lag is not a critical variable. Nonetheless until the experiment is repeated with a more powerful design this conclusion must remain tentative.

The persistence of the partial formal priming effect across all three experiments led me to focus more closely on this effect and to postpone further studies of the sensitivity of ERPs to morphological relationships between words. Focussing on the formal priming effects allowed me to both increase the number of items used in the formal priming condition and to reduce of the proportion of related items in the experimental lists. Increasing the number of critical items was intended to produce an increase in the signal-to-noise ratio of the averaged ERPs, whilst the reduction of the relatedness proportion was intended to emphasise the role of automatic lexical processing. Each of the remainder of the experiments used a relatively low proportion of related items.

Experiment 3 demonstrated that the formal priming effect could be observed when the proportion of related items was much reduced. As in Experiments 1A and 1B, the amplitude of the partial and repetition priming effects were initially of the same magnitude, but subsequently the amplitude of the repetition effect became greater than the amplitude of the formal priming effect. As in Experiment 1A, the topographies of the two effects differed. Whereas in the earlier experiment this difference was expressed as a difference between the two priming conditions in the distribution of the effects over the anterior-posterior line, in Experiment 3 the difference was between the proportion of the effects found at left hemisphere, midline and right hemisphere sites. The formal priming effect was proportionately greatest at right hemisphere sites, whilst the repetition effect was greatest at the midline.

Experiment 4 investigated the extent to which the formal priming effects found in the previous experiments were dependent upon lexical processing by using non-words rather than words as the experimental items. In respect of their amplitudes, the formal priming effects with non-words were similar to the effects seen with words. The formal and repetition priming effects were again of similar amplitude before approximately 400 ms, after which the repetition effects were greater than the formal priming effects. Unlike the results of Experiment 3, however, the formal and repetition priming effects were similar in topography. In both cases the priming effects were greatest over the right hemisphere and smallest over the left.

Finally, in Experiment 5, I sought to determine the relative importance of phonological and orthographic similarity in demonstrations of formal priming effects. Formal priming effects resulting from similarity on orthographic and phonological dimensions were essentially equivalent to those resulting from orthographic similarity alone. The comparison of formal and repetition priming effects revealed a now familiar pattern of results. The repetition effect was initially the same magnitude as the formal effects but subsequently increased in magnitude whilst the formal effects declined in magnitude. The evidence for a difference in topography between the formal and repetition priming effects was less convincing in this experiment than it was in Experiment 3. Nonetheless in each of the two epochs between 200 and 600 ms there was a trend for the formal priming effects to be proportionately greater over the right hemisphere than over the midline, with the repetition effects showing the opposite pattern.

9.2 The component structure of the ERP repetition and formal priming effects

The question of the functional significance of the ERP components modulated in each of the experimental conditions will be discussed in detail in Sections 9.4- 9.6. For now it is sufficient to ask how the modulations observed in the present experiments relate to those found in previous investigations of ERP priming effects.

As noted in Section 2.3, some studies of the ERP consequences of repetition have found that the P2 component is attenuated by item repetition. In the present experiments, only in Experiment 4 was there a reliable attenuation of the P2 component as a result of repetition. This modulation of the P2 was elicited by the repetition of non-words, a result which replicates the finding of Rugg (1987), and reinforces his conclusion that the processes reflected by this modulation are not sensitive to the lexical status of the repeating item. However the precise nature of the functional significance of this modulation remains to be determined.

More central for this thesis is the question of whether the present experimental effects included a modulation of the N400, which, it has been argued, reflects lexical processing (see Section 2.5). Modulations of this component have been characterised as having a centro-parietal maximum and as being generally larger over the right hemisphere than over the left. Where there were reliable ERP modulations in the present experiments, they were generally larger at central and posterior sites. This difference in anterior-posterior distribution of the priming effects was not always reliable in the analysis of the non-subtracted waveforms (as in Experiments 3 and 4), and was reliable in the rescaled waveforms only in Experiment 1A. With regard to the distribution of the priming effects over hemispheres, in each of the present experiments the positive-going shift in the waveform resulting from the various priming conditions were greater over the right hemisphere than over the left. This was true both for the repetition and the formal priming effects. These differences were not always reliable when the data were rescaled.

The generally centro-parietal and right-greater-than-left pattern of priming effects seen in the present experiments, particularly in the 200 - 400 ms epoch, is consistent with that which has been claimed to be characteristic of modulations of the N400. It seems likely therefore that the both the partial and repetition priming conditions resulted in the modulation of this component of the waveform. In Sections 9.5 and 9.6 I will consider further the implications of this result for views of the functional significance of the N400.

Finally, the somewhat greater magnitude of the repetition effects compared to the formal priming effects, and the more symmetric topography of the effects after approximately 400 ms, is consistent with the presence of a left-greater-than-right Late Positive Component in this epoch. The functional significance of this effect will be discussed further in Section 9.4

9.3 ERPs and derivational relations between words

In Experiments 1A and 1B there was little evidence that ERPs were sensitive to specifically derivational relationships between words. What evidence there was seemed largely to depend upon differences in the onset latency of the partial priming effects. In Experiment 1A differences in the partial priming effects for the two word types were a result of the later onset of the derivational partial priming effects. The formal partial priming effects also onset later than the derivational partial priming effects in Experiment 2, but this delay was not sufficient to result in a reliable interaction equivalent to that seen in Experiment 1A.

Although this difference in onset latency could have reflected differences in the processing of the two words, as noted in Section 4.3, the differences between the onset latencies of the repetition priming effects for the two word types were not consistent across Experiments 1A and 1B. This lack of consistency means that differences in the onset latency of the partial priming effects cannot readily be used to support claims that the ERP differences reflect differences in the processing of the two word types. Thus although differences in the timing of the derivational, formal and repetition priming effects were potentially informative, this potential was not fulfilled.

In Experiment 1B there was also little evidence that ERPs are sensitive to derivational relationships between words. Nonetheless, the reliable effects of word type indicate that ERPs may be sensitive to the differences between the processing accorded monomorphemic and bimorphemic words. There was also a reliable main effect of word type on the amplitude of the P191 in the analysis of the partial priming effects of Experiment 1A, which may be accounted for in the same way. However, there were no similar effects in any of the other epochs analysed in either Experiment 1A or Experiment 1B. The lack of generality of these differences between the formal and derivational words means that any claim that ERPs are sensitive to the morphemic structure of words is in need of further substantiation.

Experiment 2 also failed to provide convincing evidence of a difference in the pattern of effects seen in the formal and derivational partial priming conditions. The absence of reliable repetition effects was surprising given, firstly, the previous reports of reliable ERP repetition effects over similar lags (e.g. Bentin & Peled, 1990; Nagy & Rugg, 1989) and secondly that a post-hoc analysis of the effects of the repetition of the short filler words did reveal reliable repetition effects. In the absence of reliable repetition effects the interpretation of the difference between the partial priming conditions is uncertain and thus cannot count as evidence that ERPs are sensitive to derivational relationships between words.

If it is the case that ERPs in general and the N400 component in particular are not sensitive to derivational relationships between words, then what does this tell us about the functional significance of these ERP modulations? In Section 1.10 I reviewed the evidence that suggests that demonstrations of behavioural priming effects between morphologically related words could be taken as evidence that there was a domain of lexical representations in which morphological relationships between words were explicitly represented. If so then the apparent absence of modulations of the ERP which result from a derivational relationship between words suggests that ERPs do not, either directly or indirectly, reflect processes operating at a lexical level of representation.

This conclusion is reinforced by the similarity of the repetition and formal priming effects seen with words and non-words. As discussed in Section 7.0, non-word repetition effects may occur because of the partial activation of lexical representations of orthographically similar words. Thus the existence of ERP non-word repetition effects does not unequivocally rule out a role for lexical or semantic processes in the generation of such repetition effects. The similarity of non-word formal and repetition priming effects, however, makes the involvement of lexical and semantic processes less likely. ERP non-word formal priming occurs between non-words whose nearest word neighbours are not themselves close orthographic neighbours. For these effects to be lexically or semantically mediated would require the partial activation of an implausibly large neighbourhood of orthographically similar words.

The conclusion that ERPs do not reflect lexical processes does not, of course, deny that there are such processes. In Section 1.0, I referred to the materialist account of the relation between psychological and neural processes under which any distinction which has psychological reality must be based in differences in neural processing. Thus there cannot be a 'many-to-one' mapping between psychological states and physiological states (e.g. Cacciopo & Tassinary, 1990) in which the distinction between only formally similar words such as 'scan' and 'scandal' is represented by the same physiological state as is the distinction between the morphologically-related words such as 'ruin' and 'ruinous'. The absence of ERP modulations specific to derivational relationship between words is likely therefore to be a consequence of the limitations of ERP methodology in detecting activity which occurs asynchronously or in generators with unfavourable orientations (see Section 2.1.1). At present it is not possible to ascribe the insensitivity of ERPs to derivational relationships to one or other of these accounts. This problem would be more tractable if the cerebral location of a lexicon in which morphological information may be represented could be determined. Identifying the location of such a lexicon would provide evidence concerning the orientation of the relevant neural generators. However, although a number of studies have attempted to localise lexica concerned with the recognition of printed words, these studies have produced conflicting results (see Section 9.5). Thus the reason for the failure of ERPs in the present series of experiments to show a sensitivity to derivational relationships remains to be determined.

9.4 Formal and repetition priming effects after 400 ms post-stimulus onset

Before concentrating on the nature of the processes underlying the formal priming effects, I will briefly outline a number of possible hypotheses to account for why the repetition effects increase in magnitude after 400 ms compared to the formal priming effects. This difference in magnitude indicates that, for whatever reason, the activity of some neural generators change markedly at this time as a consequence of stimulus repetition. As already noted, the similarity of the effect seen with non-words to that seen with words makes it unlikely that this amplitude change is a reflection of the processing of lexical or semantic information in the word repetition condition. It suggests instead that the relevant factor is the degree of formal overlap between the prime and probe words. It is not clear however exactly what processes are affected by such differences in overlap. Although there are a number of possible accounts, each has its weaknesses.

One possibility is that the differences between the two priming conditions reflect the different subjective probabilities of the two conditions. The P3 component is known to be sensitive to subjective probability (see Pritchard, 1981). By this proposal, the greater positivity in the repetition condition than in the formal priming condition would result from the large late positivity elicited by the relatively infrequent repetitions. Although the formal priming condition occured as infrequently as the repetitions, subjects may have noticed the formal similarities only relatively infrequently. Were this the case, then although a large late positivity would have been elicited on a few trials when the formal similarity was noticed, this effect would be diluted by the larger number of trials when the formal similarity was not noticed. This proposal is difficult to evaluate since it requires an estimation of the frequency with which subjects were aware of the similarities between words without drawing attention to these similarities.

Another possibility, already noted in Sections 7.3 and 8.3, is that the later effect is a reflection of processes associated with the recollection of an event. The differences between the formal and repetition conditions would then reflect the strength of the recollection engendered by exact repetition compared to that engendered by an event similar to a previous one in respect of only part of its visual form. Such an account however requires the assumption that these recollection-sensitive processes act in a graded, rather than an all or none, fashion. It has recently been argued that, although the experience of recollection may be 'all-or-none', the informational content which provides the basis for such experience may indeed be graded (Rugg, Cox, Doyle, & Wells, 1995). According to this view the amplitude of the Late Positive Component of the ERP reflects the extent to which information underlying conscious recollection has indeed been retrieved.

A somewhat different account of the post 400 ms effect depends upon the argument that information from printed words is taken up from left to right (Marcel, 1980; Segui & Zubizaretta, 1985; Taft & Forster, 1975). Under this account the early part of the ERP modulation reflects the processing of that part of a probe word which has been primed both by the same word and by a formally related word, whilst the later modulation reflects processing of that part of a word primed only in the repetition condition. Neural activity occurring in the formal priming condition is attenuated as it becomes apparent that the probe word is not a true repeat of the prime word. One question for this account is why the magnitude of the repetition effect appears to increase in magnitude after 400 ms, rather than the magnitude of the formal priming effect declining. Furthermore, although the present experiments do not address the question of whether formal priming effects are dependent upon the position of the formal overlap between words, Doyle, Rugg and Wells (1994) reported that for word pairs which share letters at the end of the word (e.g. 'sweat' - 'bleat'), repetition and formal priming effects show a similar pattern to that found in the present experiments.

The present findings are also consistent with a view of the N400 as reflecting processes involved with contextual integration (see Section 2.4). Under this interpretation, the difference in magnitudes of the repetition and formal priming effects post-400 ms reflect differences in the degree to which contextual integration is facilitated by similarity between prime and probe items. Any topographic differences between the two priming conditions would again be seen as resulting from differences in the source of the information facilitating the integration process. But it is unclear why this contextual integration hypothesis would predict that the effects of formal and repetition priming would be initially similar in magnitude.

In this section I have considered a number of plausible hypotheses concerning the processes reflected by the large ERP repetition effects found after 400 ms. One of these hypotheses seems to sit uneasily with the available data, but further work is needed so that the others can be more rigorously evaluated. Nonetheless the recent work which has linked a late positivity with processes involved in recollection, suggests that the post-400 ms differences may be related to differences in the extent to which the repetition and formal priming conditions serve as a basis for recollection.

9.5 ERP formal priming effects and the functional significance of modulations of the N400

If the ERP modulations seen as a result of partial priming do not reflect lexical processes then what sorts of processes do they reflect? The conditions under which the formal priming effects were observed in Experiments 3, 4, and 5 provides a considerable body of evidence as to what these processes might be. The remainder of this discussion will focus on the results of these experiments but I will refer to the partial priming effects seen in Experiments 1A, 1B and 2 to see if the conclusions that I wish to draw on the basis of the later experiments are consistent with the results of the earlier experiments.

The direct comparison of formal and repetition priming effects provide an opportunity to assess the degree to which these two priming effects reflect changes in the same cognitive processes or set of processes. In Section 9.1 I argued that on distributional grounds there was at least one ERP component, the N400, which was modulated by both repetition and by formal priming. This view of the formal and repetition priming effects modulating the same ERP component is reinforced by the similarity in the onset latency of the two effects. It is generally assumed (e.g. Van Petten, 1993) that the onset of ERP effects can be seen as an indicator of the time at which processing is modified as a consequence of a prior event, whereas the magnitude of the effects indicates the degree to which such modification occurs. Under these assumptions, repetition and formal priming result in changes in processing which are manifest at the same latency and initially to the same degree. Whilst this may most parsimoniously be interpreted as a consequence of repetition and formal priming initially modulating the same process and in the same manner, this conclusion conflicts with that which could be drawn on the basis of the topographic differences between the effects.

Topographic differences between experimental conditions are often taken to indicate differences not only in the pattern of neural activity between conditions, but also in the cognitive processes invoked in the different conditions. However, as noted in Section 2.1.5, Rugg and Coles (1995) have argued that topographic differences are not sufficient to permit this conclusion. They argued that if ERPs are sensitive to the content as well as to the identity of a cognitive operation, and if the representations of differing contents do not overlap anatomically, then topographic differences may arise when the same operation is applied to the different representations. Thus differences in topography between conditions may indicate a difference not of cognitive operation, but rather in the nature of the information to which such cognitive operations are applied. Word repetition may result in the modifications of operations performed on lexical and semantic representations, as well as on representations of visual form and phonology. In contrast, non-word repetition and word and non-word formal priming may result only in modifications of cognitive operations performed on representations of visual form and/or phonology.

The trend for the ERP formal priming effects to be greatest at midline and right hemisphere sites is perhaps analogous to the strongly lateralised effects found by Rugg and Barrett (1987) in the rhyme-matching task. When Rugg and Barrett (1987) had subjects make rhyme judgements on word pairs, the difference between the ERPs elicited by rhyming and non-rhyming pairs was almost entirely lateralised to the waveforms recorded over the right hemisphere. The account of the topographic differences in the present data in terms of the same processes operating on a different representational substrate is essentially the same as that given by Rugg and Barrett (1987). They suggested that their rhyme-sensitive 'N450' component was homologous with the N400, but that the N450 reflected orthographic and phonological, rather than semantic, similarity. The present results additionally suggest that similarity of visual form can result in modulations of the N400 even when the task does not encourage explicit processing of such similarity.

The results of a number of recent studies have suggested that the N400 may not be a unitary component, but instead consists of a number of sub-components (e.g. Nobre & McCarthy, 1994; McCarthy, Nobre, Bentin & Spencer, 1995; Guillem, N'Kaoua, Rougerie & Claverie, 1995). If this is the case then it may be possible to show that these sub-components are differentially sensitive to similarity in different domains.

However if the modulations of the ERP seen in the formal priming conditions of the present experiments are taken to be modulations of a unitary N400 component, then modulations of the N400 cannot be seen as a marker of specifically semantic processing. Furthermore if the N400 can be modulated by types of similarity other than semantic similarity, this raises questions over the interpretation of demonstrations of the sensitivity of ERPs to semantic similarity. It is not clear that demonstrations of ERP effects as a consequence of semantic similarity can be taken as reflecting specifically semantic processing rather than processing that reflects a more general recognition of the similarity of two items. The ERP modulations seen as a result of semantic and formal priming may instead reflect the operation of a generic similarity-sensitive process which acts on representations of different properties of experimental items.

The question of the manner in which such a mechanism operates is addressed by the results of Experiment 5 in which formal priming engendered by words orthographically similar to one another was compared with that engendered by orthographic and phonological similarity. The equivalence of the formal priming effect in the two cases can be accounted for in a number of ways. This result may be taken to suggest that these effects are sensitive to similarities of orthography only. However, on the assumption that the presentation of a picture only minimally activates an orthographic representation of the picture's name, the demonstration by Barrett and Rugg (1990) of largely right-hemisphere effects in a rhyme-matching task with picture stimuli suggests that this suggestion is unlikely to be correct.

An alternative possibility is that the proposed similarity-sensitive mechanism may act in all-or-none manner and to not be sensitive to gradations of similarity between items. This suggestion may be tested by comparing the formal priming effects found between items with differing degrees of orthographic similarity. Furthermore, as noted in Section 8.3, a cross-modal priming paradigm may shed light on whether phonological similarity in the absence of orthographic similarity would also produce similar formal priming effects. However if the formal priming effect does indeed turn out to be all-or-none, then this raises the question of the degree of similarity required between two stimuli before the effect is observed.

Another question raised by this 'similarity' hypothesis concerns whether the similarity-sensitive operation acting on representations of different properties of words is in fact the same operation. Evidence that the ERP effects elicited by semantic and formal properties of words responded in a similar manner to experimental manipulations would suggest that the same operation was being applied in each case. Although there is no direct comparison of the effects of formal and semantic similarity, there are some indications that the two operations may differ. Experiment 1B demonstrated that formal priming effects, although small, were still reliable even with a lag of, on average, 6 intervening items. Although there are no data available on the longevity of ERP semantic priming effects, semantic priming effects on behavioural measures are known not to demonstrate such persistence (see Section 1.5.4). On the other hand behavioural formal priming effects also seem to be more transient than the equivalent ERP effect. A direct comparison of formal and semantic priming effects would inform the question of whether the same operation was engaged in the two cases.

Although the results of Experiments 3, 4 and 5 were relatively consistent in showing right-hemisphere maximum priming effects, these results contrasted with the formal priming effects found in Experiments 1A, 1B and 2. In these experiments the formal priming effects showed a midline maximum, as did the repetition effects. This lack of consistency between experiments might be considered to be problematic for any attempt to identify the types of processes reflected by the ERP formal priming effects. However the first three experiments differed from the second three experiments in a number of ways. Firstly, whilst the earlier experiments included the partial derivational condition this manipulation was absent from the later experiments. Secondly, the earlier experiments had a somewhat higher proportion of related or repeated words than did the later experiments.

Why should these differences between experiments have produced the observed differences in scalp distribution of the formal priming effects? One possibility is that the LPC onset earlier in Experiment 1A and 1B than it did in the later experiments. The high proportion of related items may have resulted in subjects attempting to explicitly remember the appearance or other characteristics of previous items, a strategy which may have led to the earlier onset of the recollection-sensitive LPC. Thus it is at least plausible that the differences in scalp distribution arose from changes in the onset latency of the LPC.

A second possibility is that the change in the distribution reflected the use by subjects of a strategy more dependent upon semantic processing. I (see Section 9.4) and others (e.g. Barrett & Rugg, 1990) have argued that a more symmetrical modulation of the ERP may reflect semantic similarity between experimental items, whilst asymmetric modulations of the ERP may result from formal similarity. It is not immediately clear why this change to a 'semantic' strategy should have occurred. Had the proportions of words and non-words changed markedly the observed effect may have arisen as a result of subjects increasing the extent to which they made their lexical decisions on the basis of a detection of semantic content. However there was little difference in the proportions of words and non-words between the earlier and later experiments, only a change in the number that were repeated or partially primed.

9.6 The neuroanatomical basis for formal priming effects

Because ERPs reflect not only the location but also the orientation of neural generators, drawing conclusions concerning localisation of function on the basis of ERPs is difficult (Rugg, Kok, Barrett, & Fischler, 1986). However this enterprise has recently been aided by a number of studies which have employed Positron Emission Tomography (PET) functional imaging techniques to investigate the loci of processing involving visually presented words.

Petersen (1990) presented subjects with words, legal and illegal non-words and strings of non-letter 'false-font' characters. They observed an increase in activation of left medial extra-striate cortex with the word and legal non-word stimuli only and suggested that this region of the brain constituted a lexicon of visual word forms. Howard (1992) also investigated the locus of a lexicon of word forms. In contrast to Petersen (1990), Howard (1992) suggested that such a lexicon could be localised to the posterior part of the left middle temporal gyrus (see also Price, Wise, Watson, Patterson, Howard, & Frackowiak, 1994). Although conflicting in respect of the specific locus of a lexicon of word forms, these studies are consistent in placing it within the left hemisphere. As Howard et al (1992) note, such a locus is also consistent with neuropsychological evidence concerning the deficits in the processing of visually presented words seen in surface dyslexia (see Marshall & Newcombe, 1973; Vanier & Caplan, 1985).

Because of the highly convoluted nature of the cortical surface, the larger right hemisphere formal priming effects reported in the present experiments are not necessarily inconsistent with their generator(s) being within the left hemisphere. This is particularly possible if the generators are located on a medial surface. Nonetheless, the tendency for the formal priming effects seen in the present experiments to be larger over the right hemisphere seems more consistent with proposals that the processes underlying form-specific priming of words are lateralised to that hemisphere (Marsolek, et al., 1992; Marsolek, et al., 1994; Squire, Ojemann, Miezin, Petersen, Videen, & Raichle, 1992 but see Buckner, Petersen, Ojemann, Miezin, Squire, & Raichle, 1995). However these same authors have suggested that there is a form non-specific system located within the left hemisphere. It remains an open question as to why the

ERP formal priming effects may have reflected the operation of a form specific system more than the operation of a form non-specific system.

The link between visual word priming and processes occurring within the right hemisphere was also the subject of the study by Swick (in press). They compared repetition effects for words and non-words in patients suffering from lesions of the right temporal-occipital cortex as a result of infarctions of the posterior cerebral artery, and in normal control subjects. They reported that although the normal controls exhibited the expected positive-going shift in the ERP as a result of item repetition, the patient group did not show an ERP repetition effect. However, these results are far from definitive on two counts. Firstly, Swick (in press) included only three subjects in the patient and control groups. Consequently the signal-to-noise ratio of the waveforms, particularly in the patient group, was poor. Secondly, Swick (in press) used as control subjects normal lesion-free individuals. A control group of individuals who had lesions at locations other than in the right temporal-occipital cortex would have been more appropriate. Nonetheless, these results are consistent with the view that repetition effects with visually presented items reflect, at least in part, processes occurring within the right hemisphere.

If the ERP formal priming effect does reflect form-specific processing in the right hemisphere then the distribution of the effect suggests that it does so in a fairly direct manner. However the late onset and the persistence of the effect seems to be inconsistent with it being a direct reflection of the operation of a form-specific representational system as proposed by Squire and his colleagues. Alternatively, the effect may be an indirect reflection of such processing and result from processes which are themselves dependent upon the output of a form specific system. However if this is the case then it is unclear what sort of processes these are that operate functionally 'downstream' of a structural description of a visual input but which also may be localised in the right hemisphere. One possibility is that such a process operates upon representations embodied within the same neural systems as are utilised in the initial process of word recognition. Whatever these processes are, they occur in contexts where there are few related items; a criterion which has been associated with automatic processing which is not under strategic control.

Form-specific components of priming should prove to be sensitive to manipulations of visual similarity. If this is the case then the ERP formal priming effect may be abolished or much reduced as a result of differences in presentation format. Such changes in presentation format may include changes in letter case, changes in letter font or changes across visual and auditory modalities between encounters with formally-related words. Alternatively, if the formal priming effect reflects processing of form-independent representations of visual stimuli, then it may be attenuated when priming is across-modality but not across manipulations of case or font. Thus a number of studies would assist in further determining the conditions under which the ERP formal priming effect, as described in this thesis, can be observed.

9.7 Conclusions

ERPs were found to be modulated by derivational and formal priming, as well as by word and non-word repetition. A number of components of the ERP were most likely modulated by these experimental manipulations, including the N400.

The failure of ERPs to exhibit a sensitivity to derivational relationships between words, together with the similarity of the ERP priming effects with word and non-words, suggests that ERPs do not reflect, directly or indirectly, activity within a morphologically-structured lexicon.

If the ERP formal priming effect does reflect a modulation of the N400 component, a component also thought to be modulated by repetition and semantic priming and in rhyme matching tasks, then this component may reflect the operation of a generic similarity-sensitive mechanism. According to this hypothesis, the N400 is not a reflection of the operation of specifically semantic processes.

The equivalence of the effect resulting from similarity in orthographic and phonological domains to that resulting from orthographic similarity alone suggests that this similarity-sensitive mechanism may operate in an all-or-none fashion rather than being sensitive to gradations of similarity.

References

Allison, T., Wood, C. C. & McCarthy, G. (1986). The Central Nervous System. In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), Psychophysiology: Systems, Processes and Applications. (pp. 5-25). New York: Guilford Press.

Allport, D. A. (1977). On knowing the meanings of words we are unable to report: The effects of visual masking. In S. Dornic (Eds.), Attention and Performance Vol. 6. Hillsdale, NJ.: Lawrence Erlbaum.

Anderson, J. E. & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus onset asynchronies: An event related potential study. Psychophysiology, 32, 177-190.

Andrews, S. (1989). Frequency and neighbourhood effects on lexical access: Activation or search? Journal of Experimental Psychology: Learning, Memory and Cognition, 15(5), 802-814.

Andrews, S. (1992). Frequency and neighbourhood effects on lexical access: Lexical similarity or orthographic redundancy? Journal of Experimental Psychology: Learning, Memory and Cognition, 18(2), 234-254.

Aronoff, M. (1976). Word formation in generative grammar. Cambridge, MA.: MIT Press.

Bainbridge, J. V., Lewandowsky, S. & Kirsner, K. (1993). Context effects in repetition priming are sense effects. Memory and Cognition, 21(5), 619-626.

Balota, D. A. & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. Journal of Experimental Psychology: Human Perception and Performance, 10(3), 340-357.

Balota, D. A. & Chumbley, J. I. (1985). The locus of word frequency effects in the pronunciation task: Lexical access and/or production? Journal of Memory and Language, 24, 89-106.

Baron, J. (1973). Phonemic stage not necessary for reading. Quarterly Journal of Experimental Psychology, 25, 241-246.

Barrett, S. E. & Rugg, M. D. (1990). Event-related potentials and the phonological matching of picture names. Brain and Language, 38, 424-437.

Basilli, J. N., Smith, M. C. & MacLeod, C. M. (1989). Auditory and visual word stem completion: Separating data-driven and conceptually driven processing. Quarterly Journal of Experimental Psychology, 41A(3), 439-453.

Bavelier, D., Prasadam, S. & Segui, J. (1994). Repetition blindness between words: Nature of the orthographic and phonological representations involved. Journal of Experimental Psychology: Learning, Memory and Cognition, 20(6), 1437-1455.

Beauvillain, C. & Segui, J. (1992). Representation and processing of morphological information. In R. Frost & L. Katz (Eds.), Orthography, Phonology, Morphology and Meaning. (pp. 377-389). Elsevier Science Publishers.

Beauvillian, C. (1994) Morphological structure in visual word recognition: Evidence from prefixed and suffixed words. Language and Cognitive Processes, 9(3), 317-339.

Becker, C. A. (1976). Allocation of attention during visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 2, 556-566.

Becker, C. A. (1980). Semantic context efects in visual word recognition. Memory and Cognition, 8, 493-512.

Becker, C. A. (1985). What do we really know about semantic context effects during reading? In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), Reading Research: Advances in Theory and Practice Vol. 5, (pp. 1-82). New York: Academic Press.

Becker, C. A. & Killion, T. H. (1977). Interaction of visual and cognitive effects in visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 3, 389-401.

Bentin, S., McCarthy, G. & Wood, C. (1985). Event-related potentials, lexical decision and semantic priming. Electroencephalography and Clinical Neurophysiology, 60, 343-355.

Bentin, S. & Moscovitch, M. (1988). The time course of repetition effects for words and unfamiliar faces. Journal of Experimental Psychology: General, 117(2), 148-160.

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

Bentin, S. & Feldman, L. B. (1990). The contribution of morphological and semantic relatedness to repetition priming at short and long lags: Evidence from Hebrew. Quarterly Journal of Experimental Psychology, 42A(4), 693-711.

Bentin, S. & McCarthy, G. (1994). The effects of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. Journal of Experimental Psychology: Learning, Memory and Cognition, 20(1), 130-149.

Bentin, S., Kutas, M. & Hillyard, S. A. (1995). Semantic processing and memory for attended and unattended words in dichotic listening: Behavioural and electrophysiological evidence. Journal of Experimental Psychology: Human Perception and Performance, 21(1), 54-63.

Bergman, M. W., Hudson, P. T. W. & Eling, P. A. T. M. (1988). How simple complex words can be: Morphological processing and word representations. Quarterly Journal of Experimental Psychology, 40A(1), 41-72.

Besner, D. & Swan, M. (1982). Models of lexical access in visual word recognition. Quarterly Journal of Experimental Psychology, 34A(313-325).

Besner, D. & Smith, M. C. (1992). Models of word recognition: When obscuring the stimulus yields a clearer view. Journal of Experimental Psychology: Learning, Memory and Cognition, 18(3), 468-482.

Besson, M. & Macar, F. (1987). An event-related potential analysis of incongruity in music and other non-linguistic contexts. Psychophysiology, 24(1), 14-25.

Besson, M. & Kutas, M. (1993). The many facets of repetition: A cued recall and event-related potential analysis of repeating words in the same versus different sentence contexts. Journal of Experimental Psychology: Learning, Memory and Cognition, 19(5), 1115-1133.

Besson, M., Kutas, M. & Van Petten, C. (1992). An event-related potential (ERP) analysis of semantic congruity and repetition effects in sentences. Journal of Cognitive Neuroscience, 4(2), 132-149.

Blaxton, T. A. (1985) Investigating dissociations among memory measures: Support for a transfer appropriate processing framework. PhD, Purdue University.

Blaxton, T. A. (1989). Investigating dissociations among memory measures: Support for a transfer-appropriate processing framework. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(4), 657-668.

Boddy, J. (1986). Event-related potentials in chronometric analysis of primed word recognition with different stimulus onset asynchronies. Psychophysiology, 23(2), 232-245.

Borowsky, R. & Besner, D. (1991). Visual word recognition across orthographies: On the interaction between context and degradation. Journal of Experimental Psychology: Learning, Memory and Cognition, 17(2), 272-276.

Borowsky, R. & Besner, D. (1993). Visual word recognition: A multistage activation model. Journal of Experimental Psychology: Learning, Memory and Cognition, 19(4), 813-840.

Bowers, J. S. (1993). Does implicit memory extend to legal and illegal nonwords? Journal of Experimental Psychology: Learning, Memory and Cognition, 20(3), 534-549.

Bowey, J. A. (1990). Orthographic onsets and rimes as functional units of reading. Memory and Cognition, 18, 419-427.

Bowey, J. A. (1993). Orthographic rime priming. Quarterly Journal of Experimental Psychology, 46A(2), 247-271.

Bradley, D. (1980). Lexical representation of derivational relation. In M. Aronoff & M.L. Keane (Eds.), Juncture. MIT Press: Cambridge, Mass.

Bradley, D. C. & Forster, K. I. (1987). A reader's view of listening. Cognition, 25, 103-134.

Brooks, L. (1978). Non-analytic concept formation and memory for instances. In E. Rosch & B. B. Lloyd (Eds.), Cognition and Categorisation (pp. 170-216). Hillsdale, NJ.: Lawrence Erlbaum.

Brown, A. S., Neblett, D. R., Jones, T. C. & Mitchell, D. B. (1991). Transfer of processing: Some inappropriate findings. Journal of Experimental Psychology: Learning, Memory and Cognition, 17(3), 514-525.

Brown, C. & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. Journal of Cognitive Neuroscience, 5, 34-44.

Brown, H., Sharma, N. K. & Kirsner, K. (1984). The role of script and phonology in lexical representation. Quarterly Journal of Experimental Psychology. 36A, 491-505.

Bruce, V., Burton, M. & Craw, I. (1992). Modelling face recognition. Philosophical Transactions of the Royal Society of London - Series B, 335(1273), 121-128.

Buckner, R. L., Petersen, S. E., Ojemann, J. G., Miezin, F. M., Squire, L. & Raichle, M. E. (in press). Functional anatomical studies of explicit and implicit memory retrieval tasks. Journal of Neuroscience 15(1), 12-29.

Burani, C. & Carammaza, A. (1988). Representation and processing of derived words. Language and Cognitive Processes, 2(3/4), 217-227.

Burani, C. & Laudanna, A. (1992). Units of representation for derived words in the lexicon. In R. Frost & L. Katz (Eds.), Orthography, Phonology, Morphology and Meaning. (pp. 361-376). Elsevier Science Publishers.

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Eds.), Language Production London: Academic Press.

Bybee, J. L. (1985). Morphology: A study of the relation between meaning and form. Amsterdam: John Benjamin.

Cacciopo, J. T. & Tassinary, L. G. (1990). Psychophysiology and psychophysiological inference. In J. T. Cacciopo & L. G. Tassinary (Eds.), Principles of Psychophysiology (pp. 3-33). Cambridge: Cambridge University Press.

Caramazza, A., Laudanna, A. & Romani, C. (1988). Lexical access and inflectional morphology. Cognition, 28, 297-332.

Caramazza, A., Miceli, G., Silveri, M. C. & Laudanna, A. (1985). Reading mechanisms and the organisation of the lexicon: Evidence from acquired dyslexia. Cognitive Neuropsychology, 2(1), 81-114.

Carr, T. H. & Pollatsek, A. (1985). Recognizing printed words: A look at current models. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), Reading Research: Advances in Theory and Practice Vol. 5. (pp. 1-82). New York: Academic Press.

Carr, T. H., Brown, J. S. & Charalambous, A. (1989). Repetition and reading: Perceptual encoding mechanisms are very abstract but not very interactive. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(5), 763-778.

Carroll, M. & Kirsner, K. (1982). Context and repetition effects in lexical decision and recognition memory. Journal of Verbal Learning and Verbal Behaviour, 21, 55-69.

Cave, C. B. & Squire, L. R. (1992). Intact and long-lasting repetition priming in amnesia. Journal of Experimental Psychology: Learning, Memory and Cognition, 18, 509-520.

Cermak, L. S., Talbot, N., Chandler, K. & Wolbarst, L. R. (1985). The perceptual priming phenomenon in amnesia. Neuropsychologia, 23(5), 615-622.

Cermak, L. S., Verfaille, M., Milberg, W., Lettourneau, L. & Blackford, S. (1991). A further analysis of perceptual identification priming in alcoholic Korsakoff patients. Neuropsychologia, 29(8), 725-736.

Challis, B. H. & Brodbeck, D. R. (1992). Level of processing affects priming in word fragment completion. Journal of Experimental Psychology: Learning, Memory and Cognition, 18(3), 595-607.

Challis, B. H. & Sidhu, R. (1993). Dissociative effects of massed repetition on implicit and explicit measures of memory. Journal of Experimental Psychology: Learning, Memory and Cognition, 19, 115-127.

Clarke, R. & Morton, J. (1983). Cross modality facilitation in tachistoscopic word recognition. Quarterly Journal of Experimental Psychology, 35A, 79-96.

Cohen, N. J. & Squire, L. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of "knowing how" and "knowing that". Science, 210, 207-209.

Coles, M. G. H., Gratton, G., Kramer, A. F. & Miller, G. A. (1986). Principles of signal acquisition and analysis. . In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), Psychophysiology: Systems, Processes And Applications, (pp. 183-221). New York: Guilford Press.

Coles, M. G. H. & Rugg, M. D. (1995). Event-related brain potentials: an introduction. In M. D. Rugg & M. G. H. Coles (Eds.), Electrophysiology of Mind (pp 1 - 26). New York: Oxford University Press.

Coles, M. G. H., Smid, H. G. O. M., Scheffers, M. & Otten, L. (1995). Mental chronometry and the study of human information processing. In M. D. Rugg & M. G. H. Coles (Eds.), Psychophysiology of Mind, (pp. 86-131). New York: Oxford University Press.

Colombo, L. (1986). Activation and inhibition with orthographically similar words. Journal of Experimental Psychology: Human Perception and Performance, 12, 226-234.

Coltheart, M., Besner, D., Jonassen, J. T. & Davelaar, E. (1977). Phonological encoding in the lexical decision task. Quarterly Journal of Experimental Psychology, 31, 489-507.

Craik, F. I. M. & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behaviour, 11, 671-684.

Craik, F. I. M., Moscovitch, M. & McDowd, J. M. (1994). Contributions of surface and conceptual information to performance on implicit and explicit memory tasks. Journal of Experimental Psychology: Learning, Memory and Cognition., 20(4), 864-875.

Cristoffanini, P. M., Kirsner, K. & Milech, D. (1986). Bilingual lexical representation: The status of English-Spanish cognates. Quarterly Journal of Experimental Psychology, 38A, 367-393.

Curran, T., Tucker, D. M., Kutas, M. & Posner, M. I. (1993). Topography of the N400: Brain electrical activity reflecting semantic expectancy. Electroencephalography and Clinical Neurophysiology, 88, 188-209.

Cutler, A., Hawkins, J. A. & Gilligan, G. (1985). The suffixing preference: A processing explanation. Linguistics, 23, 723-758.

Dannenbring, G. L. & Briand, K. (1982). Semantic priming and word repetition in the lexical decision task. Canadian Journal of Psychology, 36, 335-344.

De Groot, A. M. B. & Nas, G. L. J. (1991). Lexical representation of cognates and non-cognates in compound bilinguals. Journal of Memory and Language, 30, 90-123.

Deacon, D., Breton, F., Ritter, W. & Vaughan, H. G. (1991). The relationship between the N2 and the N400: Scalp distribution, stimulus probability and task relevance. Psychophysiology, 28(2), 185-200.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. Psychological Review, 93, 285-321.

Den Heyer, K., Goring, A. & Dannenbring, G. L. (1985). Semantic priming and word repetition: The two effects are additive. Journal of Memory and Language, 24, 699-716.

Den Heyer, K. & Benson, K. (1988). Constraints on the additive relationship between semantic priming and word repetition and the interactive relationship between semantic priming and stimulus quality. Canadian Journal of Psychology, 42(4), 399-413.

Dixon, N. F. (1971). Subliminal perception: The nature of a controversy. New York: McGraw Hill.

Donchin, E., Ritter, W. & McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S. H. Koslow (Eds.), Brain Event-Related Potentials in Man, (pp. 349-411). New York: Academic Press.

Donchin, E. & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? Behavioural and Brain Sciences, 11, 355-372.

Dorfman, J. (1994). Sublexical components in implicit memory for novel words. Journal of Experimental Psychology: Learning, Memory and Cognition, 20(5), 1108-1125.

Doyle, M. C., Rugg, M. D. & Wells, T. (1994). Using ERPs to investigate the orthographic processing of words. European Journal of Neuroscience, Supplement No. 7.

Drewnowski, A. & Healy, A. F. (1980). Phonetic factors in letter detection: A re-evaluation. Memory and Cognition, 10, 145-154.

Drews, E. & Zwitserlood, P. (1995). Morphological and orthographic similarity in visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 21(5), 1098-1116.

Duchek, J. M. & Neely, J. H. (1989). A dissociative word frequency x levels of processing interaction in episodic recognition and lexical decision tasks. Memory and Cognition, 17(2), 148-162.

Dunn, J. C. & Kirsner, K. (1989). Implicit memory: Task or Process? In S. Lewandowsky, J. C. Dunn, & K. Kirsner (Eds.), Implicit Memory: Theoretical Issues. (pp. 17-32). Hillsdale, NJ.: Lawrence Erlbaum Associates.

Durgunoglu, A. Y. & Neely, J. H. (1987). On obtaining episodic priming in a lexical decision task following paired associate learning. Journal of Experimental Psychology: Learning, Memory and Cognition, 13(2), 206-222.

Durgunoglu, A. Y. (1988). Repetition, semantic priming and stimulus quality: Implications for the interactive-compensatory reading model. Journal of Experimental Psychology: Learning, Memory and Cognition, 14(4), 590-603.

Durso, F. T. & Johnson, M. K. (1980). The effects of orienting tasks on recognition, recall and modality confusion of pictures and words. Journal of Verbal Learning and Verbal Behaviour, 19, 416-429.

Emmorey, K. (1989). Auditory morphological priming in the lexicon. Language and Cognitive Processes, 4, 73-92.

Evett, L. J. & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. Quarterly Journal of Experimental Psychology, 33A, 325-350.

Feldman, L. B. (1991). The contribution of morphology to word recognition. Psychological Research, 53, 33-41.

Feldman, L. B. (1994). Beyond orthography and phonology: Differences between inflections and derivations. Journal of Memory and Language, 33, 442-470.

Feldman, L. B. & Fowler, C. A. (1987). The inflected noun system in Serbo-Croatian: Lexical representation of morphological structure. Memory and Cognition, 15(1), 1-12.

Feldman, L. B. & Moskovljevic, J. (1987). Repetition priming is not purely episodic in origin. Journal of Experimental Psychology: Learning, Memory and Cognition, 13(4), 573-581.

Feldman, L. B. & Andjelkovic, D. (1992). Morphological analysis in word recognition. In R. Frost & L. Katz (Eds.), Orthography, Phonology, Morphology and Meaning. (pp. 343-361). Elsevier Science Publishers.

Ferrand, L. & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. Quarterly Journal of Experimental Psychology, 45A, 353-372.

Ferrand, L. & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. Quarterly Journal of Experimental Psychology, 47A(2), 365-382.

Ferrand, L., Grainger, J. & Segui, J. (1994). A study of masked form priming in picture and word naming. Memory and Cognition, 22(4), 431-441.

Feustel, T. C., Shiffrin, R. M. & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. Journal of Experimental Psychology: General, 112(3), 309-346.

Fischler, I. & Raney, G. E. (1991). Language by eye: Behavioural and electrophysiological approaches to reading. In J. R. Jennings & M. G. H. Coles (Eds.), Handbook of Cognitive Psychology: Central And Autonomic Nervous System. New York: Wiley.

Forbach, G. B., Stanners, R. F. & Hochhaus, L. (1974). Repetition and practice effects in lexical decision. Memory & Cognition, 2(2), 337-339.

Forster, K. I. (1976). Accessing the mental lexicon. In R. J. Wales & E. Walker (Eds.), New Approaches to Language Mechanisms. Amsterdam: North-Holland.

Forster, K. I. (1987). Form priming with masked primes: The best match hypothesis. In M. Coltheart (Ed) Attention and Performance XII (pp 127-146): Hillsdale , NJ. Lawrence Erlbaum.

Forster, K. I. & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. Journal of Experimental Psychology: Learning, Memory and Cognition, 10(4), 680-698.

Forster, K. I., Davis, C., Schoknecht, C. & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? Quarterly Journal of Experimental Psychology, 39A, 211-251.

Forster, K. I. & Davis, C. (1991). The density constraint on form-priming in the naming task: Interference effects from a masked prime. Journal of Memory and Language, 30, 1-25.

Forster, K. & Taft, M. (1994). Bodies, antibodies and neighbourhood density effects in masked form priming. Journal of Experimental Psychology: Learning, Memory and Cognition, 20(4), 844-863.

Fowler, C. A., Napps, S. E. & Feldman, L. (1985). Relations among regular and irregular morphologically related words in the lexicon as revealed by repetiton priming. Memory and Cognition, 13(3), 241-255.

Fowler, C. A., Wolford, G., Slade, R. & Tassinary, L. (1981). Lexical access with and without awareness. Journal of Experimental Psychology: General, 110(3), 341-362.

Francis, W. N. & Kucera, H. (1982). Frequency Analysis of English Usage: Lexicon and Grammar. Boston, MA: Houghton Mifflin Company.

Fromkin, D. (1973). Speech Errors as Linguistic Evidence. The Hague: Mouton.

Funnell, E. (1987). Morphological errors in acquired dyslexia. Quarterly Journal of Experimental Psychology, 39A, 497-539.

Gabrieli, J. D. E., Keane, M. M., Stanger, B. Z., Kjelgaard, M. M., Corkin, S. & Growdon, J. H. (1994). Dissociations among structural-perceptual, lexical-semantic and event-fact memory systems in Alzheimer, amnesic and normal subjects. Cortex, 30, 75-103.

Garnsey, S. (1993). Event-related brain potentials in the study of language: An introduction. Language and Cognitive Processes, 8(4), 337-356.

Garrett, M. (1982). Production of speech: Observations from normal and pathological language. In A. W. Ellis (Eds.), Normality and Pathology in Cognitive Function. (pp. 179-220). London: Academic Press.

Gibson, E. J. & Guinet, L. (1971). Perception of inflections in brief visual presentations of words. Journal of Verbal Learning and Verbal Behaviour, 10, 182-189.

Glushko, R. J. (1979). The organisation and activation of orthographic knowledge in reading aloud. Journal of Experimental Psychology: Human Perception and Performance, 5, 674-691.

Graf, P. & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. Journal of Verbal Learning and Verbal Behaviour, 23, 553-568.

Graf, P., Squire, L. R. & Mandler, G. (1984). The information that amnesic patients do not forget. Journal of Experimental Psychology: Learning, Memory and Cognition, 10, 164-178.

Graf, P. & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. Journal of Experimental Psychology: Learning, Memory and Cognition, 11(3), 501-518.

Graf, P., Shimamura, A. P. & Squire, L. R. (1985). Priming across modalities and priming across category levels: Extending the domain of preserved function in amnesia. Journal of Experimental Psychology: Learning, Memory and Cognition, 11(2), 386-396.

Graf, P. & Ryan, L. (1990). Transfer-appropriate processing for implicit and explicit memory. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(6), 978-992.

Grainger, J. (1990). Word frequency and neighbourhood frequency effects in lexical decision and naming. Journal of Memory and Language, 29, 228-244.

Grainger, J. (1992). Orthographic neighborhoods and visual word recognition. In R. Frost & L. Katz (Eds.), Orthography, Phonology, Morphology and Meaning. Amsterdam: Elsevier Science Publishers .

Grainger, J., O'Regan, J. K., Jacobs, A. M. & Segui, J. (1989). On the role of competing word unit in visual word recognition: The neighbourhood frequency effect. Perception and Psychophysics, 45(3), 189-195.

Grainger, J. & Segui, J. (1990). Neighbourhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. Perception and Psychophysics, 47, 191-198.

Grainger, J., Cole, P. & Segui, J. (1991). Masked morphological priming in visual word recognition. Journal of Memory and Language, 30, 370-384.

Grainger, J. & Jacobs, A. M. (1993). Masked partial-word priming in visual word recognition: Effects of positional letter frequency. Journal of Experimental Psychology: Human Perception and Performance, 19(5), 951-964.

Guillem, F., N'Kaoua, B., Rougerie, A. & Claverie, B. (1995) Intra-cranial topography of event-related potentials (N400/P600) elicited during a continuous recognition memory task. Psychophysiology, 32(4), 382-392

Haist, F., Musen, G. & Squire, L. R. (1991). Intact priming of words and non-words. Psychobiology, 19, 275-285.

Halgren, E. & Smith, M. E. (1987). Cognitive evoked potentials as modulatory processes in human memory formation and retrieval. Human Neurobiology, 6, 129-139.

Hamann, S. B. (1990). Level of processing effects in conceptually driven implicit tasks. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(6), 970-977.

Hamberger, M. & Friedman, D. (1992). Event-related potential correlates of repetition priming and stimulus classification in young, middle-aged and older adults. Journals of Gerontology, 47(6), 395-495.

Hashtroudi, S., Ferguson, S. A., Rappold, V. A. & Chrosniak, L. D. (1988). Data-driven and conceptually-driven processes in partial-word identification and recognition. Journal of Experimental Psychology: Learning, Memory and Cognition, 14(4), 749-757.

Hayman, C. A. G. & Jacoby, L. L. (1989). Specific word transfer as a measure of processing in the word-superiority paradigm. Memory and Cognition, 17(2), 125-133.

Hayman, C. A. G. & Rickards, C. (1995). A dissociation in the effects of study modality on tests of implicit and explicit memory. Memory and Cognition, 23(1), 95-112.

Henderson, L. (1985). Towards a psychology of morphemes. In A. W. Ellis (Eds.), Progress in The Psychology of Language, Vol. 1. (pp. 357-391). Hillsdale, NJ.: Lawrence Erlbaum.

Henderson, L. (1989). On mental representation of morphology and its diagnosis by measures of visual access speed. In W. Marslen-Wilson (Eds.), Lexical Representation and Process. (pp 357-391). Cambridge, MA: MIT Press.

Henderson, L., Wallis, J. & Knight, D. (1984). Morphemic structure and lexical access. In Attention and Performance. X (pp. 211-224). Hillsdale, NJ: Lawrence Erlbaum.

Hillinger, M. L. (1980). Priming effects with phonemically similar words: The encoding bias hypothesis reconsidered. Memory and Cognition, 8, 115-123.

Hintzman, D. L. (1990). Human learning and memory: Connections and dissociations. Annual Review of Psychology., 41, 109-139.

Holcomb, P. & Osterhout, L. (1995). ERPs and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), Electrophysiology of Mind. (pp. 171-215). New York: Oxford University Press.

Holcomb, P. J. (1988). Automatic and attentional processing: An event-related brain potential analysis of semantic priming. Brain and Language, 35(1), 66-85.

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. Psychophysiology, 30, 47-61.

Holcomb, P. J. & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. Language and Cognitive Processes, 5(4), 281-312.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision and visual masking: A survey and appraisal. Behavioural and Brain Sciences, 9, 1-23.

Howard, D., Patterson, K., Wise, R., Douglas Brown, W., Friston, K., Weiller, C. & Frackowiak, R. (1992). The cortical localisation of the lexicons. Positron Emission Tomography evidence. Brain, 115, 1769-1782.

Humphreys, G. W. (1985). Attention, automaticity and autonomy in visual word processing. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), Reading Research: Advances in Theory and Practice Vol. 5. New York: Academic Press.

Humphreys, G. W., Evett, L. J. & Taylor, D. E. (1982). Automatic phonological priming in visual word recognition. Memory and Cognition, 10, 576-590.

Humphreys, G. W. & Evett, L. (1985). Are there independent lexical and non-lexical routes in word processing? An evaluation of the dual-route theory of reading. Brain and Behavioural Sciences, 8, 689-740.

Humphreys, G. W., Evett, L. J., Quinlan, P. & Besner, D. (1987). Orthographic priming: Qualitative differences between priming from identified and unidentified primes. In Attention and Performance XII (pp 105-126). Hillsdale , NJ. Lawrence Erlbaum.

Humphreys, G. W., Besner, D. & Quinlan, P. T. (1988). Event perception and the word repetition effect. Journal of Experimental Psychology: General, 117(1), 51-67.

Humphreys, G. W., Evett, L. J. & Quinlan, P. T. (1990). Orthographic processing in visual word identification. Cognitive Psychology, 22(517-560).

Jacoby, L. L. (1983a). Perceptual enhancement: Persistent effects of an experience. Journal of Experimental Psychology: Learning, Memory and Cognition, 9(1), 21-38.

Jacoby, L. L. (1983b). Remembering the data: Analyzing interactive processes in reading. Journal of Verbal Learning and Verbal Behaviour, 22, 485-508.

Jacoby, L. L. & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. Journal of Experimental Psychology: General, 110(3), 306-340.

Jacoby, L. L. & Witherspoon, D. (1982). Remembering without awareness. Canadian Journal of Psychology, 36(2), 300-324.

Jacoby, L. L. & Hayman, C. A. G. (1987). Specific visual transfer in word identification. Journal of Experimental Psychology: Learning, Memory and Cognition, 13(3), 456-463.

Jacoby, L. L., Woloshyn, V. & Kelley, C. (1989). Becoming famous without being recognized: Unconscious influences of memory produced by dividing attention. Journal of Experimental Psychology: General, 118(2), 115-125.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. Journal of Memory and Language, 30, 513-541.

Jacoby, L. L., Toth, J. P. & Yonelinas, A. P. (1993). Separating conscious and unconscious influences of memory: Measuring recollection. Journal of Experimental Psychology: General, 122(2), 129-154.

Jacoby, L. L., Toth, J. P., Yonelinas, A. P. & Debner, J. A. (1994). The relationship between conscious and unconscious influences: Independence or redundancy? Journal of Experimental Psychology: General, 123(2), 216-219.

Jarvella, R. J. & Meijers, G. (1983). Recognizing morphemes in spoken words: Some evidence for a stem-organized mental lexicon. In G. B. Flores d'Arcais & R. J. Jarvella (Eds.), The Process of Language Understanding New York: John Wiley.

Jasper, H. H. (1958). The ten-twenty electrode system of the International Federation. Electroencephalography and Clinical Neurophysiology, 10, 371-375.

Johnson, M. K. & Hasher, L. (1987). Human learning and memory. Annual Review of Psychology, 38, 631-688.

Johnson-Laird, P. N. (1983). Mental Models. Cambridge, MA.: Harvard University Press.

Jordan, T. R. (1986). Testing the BOSS hypothesis: Evidence for position-insensitive orthographic priming in the lexical decision task. Memory and Cognition, 14(6), 523-532.

Karayanidis, F., Andrews, S., Ward, P. B. & McConaghy, N. (1991). Effects of inter-item lag on word repetition: An event-related potential study. Psychophysiology, 28(3), 307-318.

Katz, L., Rexer, K. & Lukatela, G. (1991). The processing of inflected words. Psychological Research.(53), 25-32.

Kay, J. & Bishop, D. (1987). Anatomical differences between nose, palm and foot, or the body in question: Further dissection of the processes of sub-lexical spelling-sound translation. In M. Coltheart (Ed.), Attention and Performance XII. (pp 449-470). Hillsdale, NJ.: Lawrence Erlbaum.

Keane, M. M., Gabrieli, J. D. E., Fennema, A. C., Growden, J. H. & Corkin, S. (1991). Evidence for a dissociation between perceptual and conceptual priming in Alzheimer's Disease. Behavioural Neuroscience, 2105(2), 326-342.

Kelliher, S. & Henderson, L. (1990). Morphologically based frequency effects in the recognition of irregularly inflected verbs. British Journal of Psychology, 81, 527-539.

Kempley, S. T. & Morton, J. (1982). The effects of priming with regularly and irregularly related words in auditory word recognition. British Journal of Psychology, 73, 441-454.

Kirsner, K. & Smith., M. C. (1974). Modality effects in word identification. Cognition, 2(4), 637-640.

Kirsner, K., Milech, D. & Standen, P. (1983). Common and modality specific processes in the mental lexicon. Memory and Cognition, 11(6), 621-630.

Kirsner, K., Dunn, J. & Standen, P. (1989). Record-based word recognition. In M. Coltheart (Ed) Attention and Performance XII (pp 177-166): Hillsdale , NJ. Lawrence Erlbaum.

Kolers, P. A. & Roediger, H. L. (1984). Procedures of mind. Journal of Verbal Learning and Verbal Behaviour, 23, 425-449.

Kolers, P. A. (1975). Specificity of operations in sentence recognition. Cognitive Psychology, 7, 289-306.

Kramer, A. F. & Donchin, E. (1987). Brain potentials as indices of orthographic and phonological interaction during word matching. Journal of Experimental Psychology: Learning, Memory and Cognition, 13(1), 76-86.

Kutas, M. & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. Science, 207, 203-205.

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

Kutas, M. & Hillyard, S. (1984). Brain potentials during reading reflect semantic expectancy and semantic association. Nature, 307, 161-163.

Kutas, M., Lindamood, T. & Hillyard, S. A. (1984). Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum & J. Requin (Eds.), Preparatory States and Processes. (pp. 217-378). Englewood Cliffs, NJ.: Erlbaum.

Kutas, M. & Van Petten, C. (1988). Event-related potential studies of language. In P. K. Ackles, J. R. Jennings, & M. G. H. Coles (Eds.), Advances in Psychophysiology (pp. 138-187). Greenwich, CT.: JAI Press.

Kutas, M., Hillyard, S. A. & Gazzanniga, M. S. (1988). Processing of semantic anomaly by right and left hemispheres of commissurotomy patients. Brain, 111, 553-576.

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

Kutas, M. & Hillyard, S. A. (1989). An electrophysiological probe of incidental semantic association. Journal of Cognitive Neuroscience, 1(1), 38-49.

Laudanna, A. & Burani, C. (1985). Address mechanisms to decomposed lexical entries. Linguistics, 23, 775-792.

Laudanna, A., Badecker, W. & Caramazza, A. (1989). Priming homographic stems. Journal of Memory and Language, 28, 531-546.

Laudanna, A., Badecker, W. & Caramazza, A. (1992). Processing inflectional and derivational morphology. Journal of Memory and Language, 31, 333-348.

Laudanna, A., Burani, C. & Cermele, A. (1994) Prefixes as processing units. Language and Cognitive Processes, 9(3), 295-316.

Lee, A. T., Tzeng, O. J., Garro, L. C. & Hung, D. L. (1978). Sensory modality and the word frequency effect. Memory and Cognition, 6, 306-311.

Levy, B. A. & Kirsner, K. (1989). Reprocessing text: Indirect measures of word and message level processes. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(3), 407-417.

Light, L. & Singh, A. (1987). Implicit and explicit memory in young and older adults. Journal of Experimental Psychology: Learning, Memory and Cognition, 13, 531-541.

Light, L. L., LaVoie, D., Valencia-Laver, D., Albertson-Owens, S. A. & Mead, G. (1992). Direct and indirect measures of modality in young and older adults. Journal of Experimental Psychology: Learning, Memory and Cognition, 18(6), 1284-1297.

Light, L. L., LaVoie, D. & Kennison, R. (1995). Repetition priming of nonwords in young and older adults. Journal of Experimental Psychology: Learning, Memory and Cognition., 21(2), 327-346.

Lima, S. D. & Pollatsek, A. (1983). Lexical access via an orthographic code? The Basic Orthographic Syllable Structure (BOSS) reconsidered. Journal of Verbal Learning and Verbal Behaviour, 22, 310-332.

Logan, G. D. (1988). Toward an instance theory of automatization. Psychological Review, 95(4), 492-527.

Logan, G. D.(1990). Repetition and automaticity: Common underlying mechanisms. Cognitive Psychology, 22, 1-35.

Lukatela, G., Kostic, A. & Turvey, M. T. (1980). Representation of inflected nouns in the internal lexicon. Memory and Cognition, 8(5), 415-423.

Lukatela, G. & Turvey, M. T. (1995a). Visual lexical access is phonological. 1: Evidence from associative priming of words, homophones and pseudohomophones. Journal of Experimental Psychology: General, 123(4), 331-353.

Lukatela, G. & Turvey, M. T. (1995b). Visual lexical access is initially phonological 2: Phonological priming by homophones and pseudohomophones. Journal of Experimental Psychology: General, 123(2), 107-128.

Lyons, J. (1968). Introduction to Theoretical Linguistics. Cambridge: Cambridge University Press.

Mandler, G. (1980). Recognising: The judgement of previous occurrence. Psychological Review, 87, 252-271.

Manelis, L. & Tharp, D. A. (1977). The processing of affixed words. Memory and Cognition, 5(6), 690-695.

Mangun, G. R. & Hillyard, S. A. (1995). Mechanisms and models of selective attention. In M. D. Rugg & M. G. H. Coles (Eds.), Electrophysiology of Mind (pp. 40-85). New York: Oxford University Press.

Marcel, A. J. (1980). Surface dyslexia and beginning reading; A revised hypothesis of the pronunciation of print and its impairments. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), Deep Dyslexia (pp. 227-258). London: Routledge & Kegan Paul.

Marcel, A. J. (1983). Conscious and non-conscious perception: Experiments on visual masking and word recognition. Cognitive Psychology, 15, 197-237.

Marshall, J. C. & Newcombe, F. (1973). Patterns of paralexia: A psycholinguistic approach. Journal of Psycholinguistic Research, 2, 175-199.

Marslen-Wilson, W., Tyler, L. K., Waksler, R. & Older, L. (1994). Morphology and meaning in the mental lexicon. Psychological Review, 101(1), 3-33.

Marsolek, C. J., Kosslyn, S. M. & Squire, L. R. (1992). Form-specific visual priming un the right cerebral hemisphere. Journal of Experimental Psychology: Learning, Memory and Cognition, 18(3), 492-508.

Marsolek, C. J., Squire, L. R., Kosslyn, S. M. & Lulenski, M. E. (1994). Form-specific explicit and implicit memory in the right cerebral hemisphere. Neuropsychology, 8(4), 588-597.

Masson, M. E. J. (1986). Identification of typographically transformed words: Instance based skill acquisition. Journal of Experimental Psychology: Learning, Memory and Cognition, 12(4), 479-488.

Masson, M. E. J. & Freedman, L. (1990). Fluent identification of repeated words. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(3), 355-373.

Matthews, P. H. (1974). Morphology: An Introduction to the Theory of Word Structure. London: Cambridge University Press.

McCarthy, G. & Wood, C. C. (1985). Scalp distribution of event-related potentials: An ambiguity associated with analysis of variance methods. Electroencephalography and Clinical Neurophysiology, 62, 203-208.

McCarthy, G. & Nobre, A. C. (1993). Modulation of semantic processing by spatial selective attention. Electroencephalography and Clinical Neurophysiology, 88, 210-219.

McCarthy, G., Nobre, A. C., Bentin, S. & Spencer, D.D. (1995) Language-related field potentials in the anterior-medial temporal lobe. 1. Intra-cranial distribution and neural generators. Journal of Neuroscience, 15(2), 1080-1089.

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. Psychological Review, 88(5), 375-407.

McKoon, G. & Ratcliff, R. (1979). Priming in episodic and semantic memory. Journal of Verbal Learning and Verbal Behaviour, 18, 463-480.

McKoon, G., Ratcliff, R. & Dell, G. S. (1986). A critical evaluation of the semantic-episodic distinction. Journal of Experimental Psychology: Learning, Memory and Cognition, 12(2), 295-306.

McRae, K., Jared, D. & Seidenberg, M. S. (1990). On the roles of frequency and lexical access in word naming. Journal of Memory and Language, 29, 43-65.

Merikle, P. M. (1982). Unconscious perception revisited. Perception and Psychophysics, 31(3), 298-301.

Merikle, P. M. & Reingold, E. M. (1990). Recognition and lexical decision without detection - unconscious perception. Journal of Experimental Psychology: Human Perception and Performance, 16(3), 574-583.

Meyer, D. E. & Schvaneveldt, R. W. (1971). Facilitation in recognising pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology, 90(2), 227-234.

Meyer, D. E., Schvaneveldt, R. W. & Ruddy, M. G. (1974). Functions of graphemic and phonemic codes in visual word recognition. Memory and Cognition, 2, 309-321.

Miceli, G. & Carammaza, A. (1988). Dissociation of inflectional and derivational morphology. Brain and Language, 35, 24-65.

Miceli, G., Silveri, M. C., Romani, C. & Carammaza, A. (1989). Variation in the pattern of omissions and substitutions of grammatical morphemes in the spontaneous speech of so-called agrammatic patients. Brain and Language, 36, 447-492.

Monsell, S. (1985). Repetition and the lexicon. In A. W. Ellis (Eds.), Progress in the Psychology of Language. (pp. 147-195). London: Lawrence ERlbaum Associates.

Monsell, S. (1990). Frequency effects in lexical decision tasks: Reply to Balota and Chumbley. Journal of Experimental Psychology: General, 119(3), 335-379.

Monsell, S., Doyle, M. C. & Haggard, P. N. (1989). The effects of frequency on word recognition: Where are they? Journal of Experimental Psychology: General, 118, 43-71.

Morris, C. D., Bransford, J. D. & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. Journal of Verbal Learning and Verbal Behaviour, 16, 519-533.

Morton, J. & Patterson, K. (1980). A new attempt at an interpretation, or, an attempt at a new interpretation. In M. Coltheart, K. Patterson, & J.C. Marshall (Eds.), Deep Dyslexia London: Routledge & Kegan Paul.

Morton, J. (1969). The interaction of information in word recognition. Psychological Review, 16, 165-178.

Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen model. In P. A. Kolers, M. E. Wrolstad, & H. Bouma (Eds.), Processing of Visible Language (pp. 259-268). New York: Plenum Press.

Moscovitch, M. (1982). Multiple dissociations of function in amnesia. In L. S. Cermak (Eds.), Human memory and Amnesia. (pp. 337-370). Hillsdale, NJ: Lawrence Erlbaum.

Muente, T. F., Heinze, H. J. & Mangun, G. R. (1993). Dissociation of brain activity related to syntactic and semantic aspects of language. Journal of Cognitive Neuroscience, 5(3), 335-344.

Murrell, G. A. & Morton, J. (1974). Word recognition and morphemic structure. Journal of Experimental Psychology, 102(963-968).

Musen, G. & Squire, L. R. (1991). Normal acquisition of novel verbal information in amnesia. Journal of Experimental Psychology: Learning, Memory and Cognition, 17, 1095-1104.

Naatanen, R. (1982). Processing negativity: an evoked-potential reflection of selective attention. Psychological Bulletin, 92, 605-640

Nagy, M. & Rugg, M. D. (1989). Modulation of event-related potentials by word repetition: The effects of inter-item lag. Psychophysiology, 26, 431-436.

Nagy, W., Anderson, R., Schommer, M., Scott, J. A. & Stallman, A. C. (1989). Morphological families in the internal lexicon. Reading Research Quarterly, 24, 262-282.

Napps, S. E. & Fowler, C. A. (1987). Formal relationships among words and the organisation of the mental lexicon. Journal of Psycholinguistic Research, 16, 257-272.

Napps, S. E. (1989). Morphemic relationships in the lexicon: Are they distinct from semantic and formal relationships? Memory and Cognition, 17(6), 729-739.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), Basic Processes in Reading: Visual Word Recognition. (pp. 264-336). Hillsdale, NJ.: Lawrence Erlbaum Associates.

Neely, J. H. & Durgonuglu, A. Y. (1985). Dissociative episodic and semantic priming effects in episodic recognition and lexical decision tasks. Journal of Memory and Language, 24, 466-489.

Neely, J. H., Keefe, D. E. & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(6), 1003-1019.

Neumann, O. (1984). Automatic processing: A review of recent findings and a plea for an old theory. In W. Prinz & A. F. Sanders (Eds.), Cognition and Motor Processes. (pp. 255-293). Berlin: Springer.

Nigam, A., Hoffman, J. E. & Simons, R. F. (1992). N400 to semantically anomalous pictures and words. Journal of Cognitive Neuroscience, 4(1), 15-22.

Nobre, A. C. & McCarthy, G. (1994). Language related ERPs: Scalp distributions and modulation by word type and semantic priming. Journal of Cognitive Neuroscience, 6(3), 233-255.

Norris, D. (1984). The effects of frequency, repetition and stimulus quality in visual word recognition. Quarterly Journal of Experimental Psychology, 36A, 507-529.

Nunez, P. L. (1981). Electric Fields of the Brain. New York: Oxford University Press.

Nunez, P. L. (1990). Localisation of brain activity with electroencephalography. In S. Sato (Eds.), Advances in Neurology, Vol. 54. Magnetoencephalography. (pp. 39-65). New York: Raven Press.

Ostergaard, A. L. (1994). Dissociations between word priming effects in normal subjects and patients with memory disorders: Multiple memory systems or retrieval? Quarterly Journal of Experimental Psychology, 47A(2), 331-364.

Otten, L. J., Rugg, M. D. & Doyle, M. C. (1993). Modulation of event-related potentials by word repetition: The role of visual selective attention. Psychophysiology, 30, 559-571.

Paap, K. R., Newsome, S. L., McDonald, J. E. & Schvaneveldt, R. W. (1982). An activation-verification model of letter and word recognition: The word superiority effect. Psychological Review, 89(5), 573-594.

Paller, K. A., Kutas, M. & McIsaac, H. K. (1995). Monitoring conscious recollection via the electrical activity of the brain. Psychological Science, 6(2), 107-111.

Patterson, K. (1980). Derivational errors. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), Deep Dyslexia (pp 286-306). London: Routledge & Kegan Paul.

Patterson, K. E. & Morton, J. (1985). From orthography to phonology: An attempt at an old interpretation. In K. Patterson, J. C. Marshall & M. Coltheart, (Eds.), Surface Dyslexia (pp 335- 360). London: Lawrence Erlbaum.

Perez-Abalo, M. C., Rodriguez, R., Bobes, M. A., Gutierrez, J. & Valdes-Sosa, M. (1994). Brain potentials and the availability of semantic and phonological codes over time. NeuroReport, 5, 2173-2177.

Perfetti, C. A., Bell, L. C. & Delaney, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking. Journal of Memory and Language, 27, 59-70.

Perfetti, C. A. & Bell, L. (1991). Phonemic activation in the first 40 ms of word identification: Evidence from backword masking and priming. Journal of Memory and Language, 30, 473-485.

Perfetti, C. A. & Zhang, S. (1991). Phonemic processes in the reading of Chinese words. Journal of Experimental Psychology: Learning, Memory and Cognition, 1, 633-643.

Petersen, S. E., Fox, P. T., Snyder, A. Z. & Raichle, M. E. (1990). Activation of extrastriate and frontal cortical areas by visual words and word-like stimuli. Science, 249, 1041-1044.

Picton, T. W., Lins, O. G. & Scherg, M. (1994). The recording and analysis of event-related potentials. In F. Boller & J. Grafman (Eds.), Handbook of Neuropsychology. Vol. 9. (pp 429-497). Amsterdam: : Elsevier Science.

Plaut, D. C. & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. Cognitive Neuropsychology, 10(5), 377-500.

Polich, J. & Donchin, E. (1988). P300 and the word frequency effect. Electroencephalography and Clinical Neurophysiology, 70, 33-45.

Polich, J. (1985). Semantic categorisation and event-related potentials. Brain and Language, 26, 304-321.

Polich, J., McCarthy, X., Wang, X. & Donchin, E. (1983) When words collide: Orthographic and phonological interference during word processing. Biological Psychology, 16, 155-180.

Posner, M. I. & Keele, S. W. (1968). On the genesis of abstract ideas. Journal of Experimental Psychology, 77, 353-363.

Posner, M. I. & Snyder, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P.M.A. Rabbitt & S. Dornic (Eds) Attention and Performance V. New York: Academic Press.

Praamstra, P. & Stegeman, D. F. (1993). Phonological effects on the auditory N400 event-related brain potential. Cognitive Brain Research, 1, 73-86.

Praamstra, P., Meyer, A. S. & Levelt, W. J. M. (1994). Neurophysiological manifestations of phonological processing: Latency variation of a negative ERP component timelocked to phonological mismatch. Journal of Cognitive Neuroscience, 6(3), 204-219.

Price, C. J., Wise, R. J. S., Watson, J. D., G., Patterson, K., Howard, D. & Frackowiak, R. S. J. (1994). Brain activity during reading: The effects of exposure duration and task. Brain, 117, 1255-1269.

Prinzmetal, W., Hoffman, H. & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. Journal of Experimental Psychology: Human Perception and Performance, 17(4), 902-923.

Pritchard, W. (1981). Psychophysiology of the P300. Psychological Bulletin, 89(3), 506-540.

Rajaram, S. (1993). Remembering and Knowing: Two means of access to the personal past. Memory and Cognition, 21(1), 89-102.

Rajaram, S. & Neely, J. H. (1992). Dissociative masked repetition priming and word frequency effects in lexical decision and episodic recognition tasks. Journal of Memory and Language, 31, 152-182.

Rajaram, S. & Roediger, H. L. (1993). Direct comparison of four implicit memory tests. Journal of Experimental Psychology: Learning, Memory and Cognition, 19, 765-776.

Rapp, B. (1992). The nature of sublexical orthographic organisation: The bigram trough hypothesis examined. Journal of Memory and Language, 31(33-53).

Ratcliff, R. (1978). A theory of memory retrieval. Psychological Review, 85, 59-108.

Ratcliff, R., Hockley, W. & McKoon, G. (1985). Components of activation: Repetition and the priming effects in lexical decision and recognition. Journal of Experimental Psychology: General, 114(4), 433-450.

Richardson-Klavehn, A. & Bjork, R. A. (1988). Measures of memory. Annual Review of Psychology, 39, 475-543.

Ritter, W., Ford, J., Gaillard, A. J., Harter, R., Kutas, M., Naatanen, R., Polich, J., Renault, B. & Rohrbaugh, J. (1984). Cognition and ERPs: the relation of post-stimulus negative potentials and cognition. Annals of the New York Academy of Sciences, 425, 24-38.

Roediger, H. L. (1990). Implicit Memory: Retention without remembering. American Psychologist, 45(9), 1043-1056.

Roediger, R. L. & Blaxton, T. A. (1987). Retrieval modes produce dissociations in memory for surface information. In D. S. Gorfein & R. R. Hoffman (Eds.), Memory and Learning: The Ebbinghaus Centennial Conference (pp. 349-379). New Jersey: Hillsdale.

Roediger, H. L., Weldon, M. S. & Challis, B. H. (1989). Explaining dissociations between implicit and explicit measures of retention: A processing account. In H. L. Roediger & F. I. M. Craik (Eds.), Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving. (pp -14). Hillsdale, NJ.: Lawrence Erlbaum.

Roediger, H. L., Weldon, M. S., Stadler, M. L. & Riegler, G. L. (1992). Direct comparison of two implicit memory tests: Word fragment and word stem completion. Journal of Experimental Psychology: Learning, Memory and Cognition, 18(6), 1251-1269.

Roediger, H. L. & McDermott, K. B. (1993). Implicit memory in normal human subjects. In F. Boller & J. Grafman (Eds.), Handbook of Neuropsychology Vol. 8. (pp 63-131). Amsterdam: Elsevier Science Publishers.

Roediger, H. L. & Srinivas, K. (1993). Specificity of operations in perceptual priming. In P. Graf & M. E. J. Masson (Eds.), Implicit Memory: New Directions in Cognition, Development and Neuropsychology. (pp. 17-48). Hillsdale, NJ.: Lawrence Erlbaum.

Rosch, E. (1978). Principles of categorisation. In E. Rosch & B. B. Lloyd (Eds.), Cognition and Categorisation (pp. 28-49). Hillsdale, NJ.: Lawrence Erlbaum.

Rosler, F., Putz, P., Friederici, A. & Hahne, A. (1993). Event-related potentials while encountering semantic and syntactic constraint violations. Journal of Cognitive Neuroscience, 5(3), 345-362.

Rubin, G. S., Becker, C. A. & Freeman, R. H. (1979). Morphological structure and its effect on visual word recognition. Journal of Verbal Learning and Verbal Behaviour, 18, 757-767.

Rubinstein, H., Garfield, L. & Millikan, J. A. (1970). Homographic entries in the internal lexicon. Journal of Verbal Learning and Verbal Behaviour, 9, 487-494.

Rubinstein, H., Lewis, S. S. & Rubinstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. Journal of Verbal Learning and Verbal Behaviour, 10, 645-657.

Rueckl, J. G. & Olds, E. M. (1993). When pseudowords acquire meaning: Effect of semantic associations on pseudoword repetition priming. Journal of Experimental Psychology: Learning, Memory and Cognition, 19(3), 515-527.

Rueckl, J. G. (1990). Similarity effects in word and pseudoword repetition priming. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(3), 374-391.

Rugg, M. D. (1984). Event-related potentials and the phonological processing of words and non-words. Neuropsychologia, 22(4), 435-443.

Rugg, M. D. (1985a). The effects of handedness on event-related potentials in a rhyme-matching task. Neuropsychologia, 23(6), 765-775.

Rugg, M. D. (1985b). The effects of semantic priming and word repetition on event-related potentials. Psychophysiology, 22, 642-647.

Rugg, M. D. (1987). Dissociation of semantic priming, word and non-word repetition effects by event-related potentials. Quarterly Journal of Experimental Psychology, 39A. 123-148.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. Memory and Cognition, 18(4), 367-379.

Rugg, M.D., Kok, A., Barrett, G. & Fischler, I. (1986). ERPs associated with language and hemispheric specialization. A review. In Cerebral Psychophysiology: Studies in Event-Related Potentials (Electroencephalography and Clinical Neurophysiology Supplement 38) (pp. 273-300). B.V.: Elsevier Science.

Rugg, M. D. & Barrett, S. E. (1987). Event-related potentials and the interaction between orthographic and phonological information in a rhyme-judgment task. Brain and Language, 32(2), 336-361.

Rugg, M. D. & Nagy, M. E. (1987). Lexical contribution to non-word repetition effects: Evidence from event-related potentials. Memory and Cognition, 15(6), 473-481.

Rugg, M. D., Furda, J. & Lorist, M. (1988). The effects of task on the modulation of event-related potentials by word repetition. Psychophysiology, 25, 55-63.

Rugg, M. D., Brovedani, P. & Doyle, M. C. (1992). Modulation of event-related potentials (ERPs) by word repetition in a task with inconsistent mapping between repetition and response. Electroencephalography and Clinical Neurophysiology, 84, 521-531.

Rugg, M. D., Doyle, M. C. & Melan, C. (1993). An event-related potential study of the effects of within- and across- modality word repetition. Language and Cognitive Processes, 8(4), 357-378.

Rugg, M. D. & Doyle, M. C. (1994). Event-related potentials and stimulus repetition in direct and indirect tests of memory. In H. Heinze, Munte, T. & Mangun, G.R. (Eds.), Cognitive Electrophysiology Cambridge, MA: Birkhauser Boston.

Rugg, M. D., Doyle, M. C. & Holdstock, J. S. (1994). Modulaton of event-related brain potentials by word repetition: Effects of local context. Psychophysiology, 31, 447-459.

Rugg, M. D. & Coles, M. G. H. (1995). The ERP and cognitive psychology: Conceptual issues. In M. D. Rugg & M. G. H. Coles (Eds.), Electrophysiology of Mind - Event Related Potentials and Cognition Oxford: Oxford University Press.

Rugg, M. D., Cox, C. J. C., Doyle, M. C. & Wells, T. (1995). Event-related potentials and the recollection of low and high frequency words. Neuropsychologia, 33(4), 471-484.

Rugg, M. D., Doyle, M. C. & Wells, T. (1995). Word and non-word repetition within- and across-modality: An event-related potential study. Journal of Cognitive Neuroscience, 7(2), 209-227.

Salasoo, A., Shiffrin, R. M. & Feustel, T. C. (1985). Building permanent memory codes: Codification and repetition effects in word identification. Journal of Experimental Psychology: General, 114(1), 50-77.

Sandra, D. (1994) The morphology of the mental lexicon: Internal word structure viewed from a psycholinguistic perspective. Language and Cognitive Processes, 9(3), 227-269

Scarborough, D. L., Cortese, C. & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. Journal of Experimental Psychology: Human Perception and Performance, 3(1), 1-17.

Scarborough, D. L., Gerard, L. & Cortese, C. (1979). Accessing lexical memory: The transfer of word repetition effects across task and modality. Memory and Cognition, 7, 3-12.

Schacter, D. L. (1987). Implicit memory: History and current status. Journal of Experimental Psychology: Learning, Memory and Cognition, 13(3), 501-518.

Schacter, D. L. (1990). Perceptual representation systems and implicit memory: Towards a resolution of the multiple memory systems debate. Annals of the New York Academy of Science, 608, 543-571.

Schacter, D. L. (1992). Understanding implicit memory: A cognitive neuroscience approach. American Psychologist, 47(4), 559-569.

Schacter, D. L. & Graf, P. (1986). Effects of elaborative processing on implicit and explicit memory for new associations. Journal of Experimental Psychology: Learning, Memory and Cognition, 12(2), 432-444.

Schacter, D. L., Rapcsak, S. Z., Rubens, A. B., Tharab, M. & Laguna, J. M. (1990). Priming effects in a letter-by-letter reader depends upon access to the word form system. Neuropsychologia, 28(10), 1079-1094.

Schacter, D. L., Cooper, L. A., Delaney, S. M., Peterson, M. A. & Tharan, M. (1991). Implicit memory for possible and impossible objects: Constraints on the construction of structural descriptions. Journal of Experimental Psychology: Learning, Memory and Cognition, 17(1), 3-19.

Schacter, D. L., Chui, C.-Y. P. & Ochsner, K. N. (1993). Implicit Memory: A selective Review. Annual Review of Neuroscience, 16, 159-182.

Schriefers, H., Friederici, A. & Graetz, P. (1992). Inflectional and derivational morphology in the mental lexicon: Symmetries and asymmetries in repetition priming. Quarterly Journal of Experimental Psychology, 44A(2), 373-390.

Schriefers, H., Zwitserlood, P. & Roelofs, A. (1991). The identification of morphologically complex spoken words: Continuous processing or decomposition. Journal of Memory and Language, 30, 26-47.

Segui, J. & Zubizaretta, M. L. (1985). Mental representation of morphologically complex words and lexical access. Linguistics, 23, 759-774.

Segui, J. & Grainger, J. (1990). Priming word recognition with orthographic neighbours: Effects of relative prime-target frequency. Journal of Experimental Psychology: Human Perception and Performance, 16(1), 65-76.

Seidenberg, M., Walters, M. S., Barnes, M. A. & Tanenhaus, M. K. (1984). When does the irregular spelling or pronunciation of a word influence word recognition. Journal of Verbal Learning and Verbal Behaviour, 23, 383-404.

Seidenberg, M. S. & McClelland, J. L. (1989). A distributed developmental model of word recognition and naming. Psychological Review, 96, 523-568.

Sereno, J. (1991). Graphemic, associative, and syntactic priming effects at a brief stimulus onset asynchrony in lexical decision and naming. Journal of Experimental Psychology: Learning, Memory and Cognition, 17(3), 459-477.

Shimamura, A. P. (1985). Problems with the finding of stochastic independence as evidence for multiple memory systems. Bulletin of the Psychonomic Society, 23(506-508).

Shimamura, A. P. & Squire, L. R. (1984). Paired-associate learning and priming effects in amnesia: A neuropsychological study. Journal of Experimental Psychology: General, 113(556-570).

Shimamura, A. P. & Squire, L. R. (1989). Impaired priming of new associations in amnesia. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(721-728).

Shulman, H. G., Hornak, R. & Sanders, E. (1978). The effects of graphemic, phonetic and semantic relationships on access to lexical structures. Memory and Cognition, 6, 115-123.

Sloman, S. A., Hayman, C. A. G., Ohta, N., Law, J. & Tulving, E. (1988). Forgetting in primed fragment completion. Journal of Experimental Psychology: Learning, Memory and Cognition, 14, 223-39.

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

Smith, M. E. & Halgren, E. (1987). Event-related potentials during lexical decision: Effects of repetition, word frequency, pronouncability, and concreteness. In R. Johnson, J. W. Rohrbaugh, & R. Parasuraman (Eds.), Current Trends in Event-Related Potential Research (pp. 129-139). Amsterdam: Elsevier.

Smith, M. E. & Oscar-Berman, M. (1990). Repetition priming of words and pseudowords in divided attention and amnesia. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(6), 1033-1042.

Soloman, R. L. & Postman, L. (1952). Frequency of usage as a determinant of recognition thresholds for words. Journal of Experimental Psychology, 43, 195-201.

Squire, L. R. (1992). Memory and the hippocampus: A synthesis from findings in rats, monkeys and humans. Psychological Review, 99, 195-231.

Squire, L. R., Shimamura, A. P. & Graf, P. (1987). Strength and duration of priming effects in normal subjects and in amnesic patients. Neuropsychologia., 25, 195-210.

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

Srinivas, K. & Roediger, H. L. (1990). Classifying implicit memory tests: Category association and anagram solution. Journal of Memory and Language, 29, 389-412.

Stanners, R., Jastrzembski, J. & Westbrook, A. (1975). Fequency and visual quality in a word-nonword classification task. Journal of Verbal Learning and Verbal Behaviour, 1975(14), 259-264.

Stanners, R. F., Neiser, J. J., Hernon, W. P. & Hall, R. (1979a). Memory representation for morphologically related words. Journal of Verbal Learning and Verbal Behaviour, 18, 399-412.

Stanners, R. F., Neiser, J. J. & Painton, S. (1979b). Memory representation for prefixed words. Journal of Verbal Learning and Verbal Behaviour, 18, 733-743.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donder's method. In W. G. Koster (Ed.), Attention and Performance II. (pp. 276-315). Amsterdam: North-Holland.

Swick, D. & Knight, R. T. (in press). Contributions of the right inferior temporal-occipital cortex to visual word and non-word priming. NeuroReport.

Taft, M. (1979a). Lexical access vis an orthographic code: The Basic Orthographic Syllable Structure (BOSS). Journal of Verbal Learning and Verbal Behaviour, 18, 21-39.

Taft, M. (1979b). Recognition of affixed words and the word frequency effect. Memory and Cognition, 7(4), 263-272.

Taft, M. (1981). Prefix stripping revisited. Journal of Verbal Learning and Verbal Behaviour, 20, 289-297.

Taft, M. (1985). The decoding of words in lexical access: A review of the morphographic approach. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), Reading Research: Advances in Theory and Practice Vol. 5. New York: Academic Press.

Taft, M. (1992). The body of the boss: Subsyllabic units in the lexical processing of polysyllabic words. Journal of Experimental Psychology: Human Perception and Performance, 18(4), 1004-1014.

Taft, M. (1994) Interactive-activation as a framework for understanding morphological processing. Language and Cognitive Processes, 9(3), 271-294

Taft, M. & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. Journal of Verbal Learning and Verbal Behaviour, 14, 638-647.

Taft, M. & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. Journal of Verbal Learning and Verbal Behaviour, 15, 607-620.

Taraban, R. & McClelland, J. L. (1987). Conspiracy effects in word pronunciation. Journal of Memory and Language, 26, 608-631.

Taylor, W. L. (1953). 'Cloze' procedure: A new tool for measuring readability. Journalism Quarterly, 30, 415.

Thomas, S. M. (1992) Visual processing of pictorial and facial images in human and monkey. Unpublished doctoral dissertation, University of St. Andrews, St. Andrews, UK.

Toth, J. P., Reingold, E. M. & Jacoby, L. L. (1994). Toward a redefinition of implicit memory: Process dissociations following elaborative processing and self-generation. Journal of Experimental Psychology: Learning, Memory and Cognition, 20(2), 290-303.

Treiman, R. & Chafetz, J. (1987). Are there onset- and rime-like units in printed words? In M. Coltheart (Eds.), Attention and Performance XII. (pp. 281-298). London: Lawrence Erlbaum.

Tulving, E. (1983). Elements of Episodic Memory. New York: Oxford University Press.

Tulving, E. (1985). How many memory systems are there? American Psychologist, 40(4), 385-398.

Tulving, E., Schacter, D. L. & Stark, H. A. (1982). Priming effects in word fragment completion are independent of recognition memory. Journal of Experimental Psychology: Learning, Memory and Cognition, 8(4), 336-342.

Tulving, E. & Schacter, D. L. (1990). Priming and human memory systems. Science, 24, 301-306.

Tweedy, J. R., Lapinski, R. H. & Schvaneveldt, R. W. (1977). Semantic context effects on word recognition: Influences of varying the proportion of items presented in an appropriate context. Memory and Cognition, 5(1), 84-89.

Tyler, L. K. & Cobb, H. (1987). Processing bound grammatical morphemes in context: The case of an aphasic patient. Language and Cognitive Processes, 2, 245-262.

Tyler, L. K., Behrens, S., Cobb, H. & Marslen-Wilson, W. (1990). Processing distinctions between stems and affixes: Evidence from a non-fluent aphasic patient. Cognition, 36, 129-153.

Van der Molen, M. W., Bashore, T. R., Halliday, R. & Callaway, E. (1991). Chronopsychophysiology: mental chronometry augmented by psychophysiological time markers. In J. R. Jennings & M. G. H. Coles (Eds.), Handbook of Cognitive Psychophysiology: Central and Autonomic Nervous System Approaches. (pp. 9-178). Chichester: Wiley.

Van Orden, G. C. (1987). A rows is a rose: Spelling, sound and reading. Memory and Cognition, 15, 181-198.

Van Petten, C. & Kutas, M. (1990). Interactions between sentence context and word frequency. Memory and Cognition, 18, 380-393.

Van Petten, C., Kutas, M., Kluender, R., Mitchiner, M. & McIsaac, H. (1991). Fractionating the word repetition effect with event-related potentials. Journal of Cognitive Neuroscience, 3(2), 131-150.

Van Petten, C. (1993). A comparison of lexical and sentence level context effects in event-related potentials. Language and Cognitive Processes, 8(4), 485-532.

Vanderwart, M. (1984). Priming by pictures in lexical decision. Journal of Verbal Learning and Verbal Behaviour, 23, 67-83.

Vanier, M. & Caplan, D. (1985). CT scan correlates of surface dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), Surface Dyslexia (pp. 511-525). London: Lawrence Erlbaum.

Verfaille, M., Cermak, L. S., Letourneau, L. & Zuffante, P. (1991). Repetition effects in the lexical decision task: The role of episodic memory in the performance of alcoholic Korsakoff patients. Neuropsychologia, 29(7), 641-657.

Verleger, R. (1988). Event-related potentials and cognition: A critique of the context updating hypothesis and an alternative interpretation of the P3. Behavioural and Brain Sciences, 11, 343-427.

Warrington, E. K. & Weiskrantz, L. (1968). New method of testing long-term retention with special reference to amnesic patients. Nature, 228, 972-974.

Warrington, E. K. & Weiskrantz, L. (1970). Amnesic syndrome: Consolidation or retrieval? Nature, 228, 629-630.

Warrington, E. K. & Weiskrantz, L. (1974). The effect of prior learning on subsequent retention in amnesic patients. Neuropsychologia., 12, 419-428.

Weldon, M. S. (1991). Mechanisms underlying priming on a perceptual test. Journal of Experimental Psychology: Learning, Memory and Cognition 17, 3(3), 526-541.

Weldon, M. S. (1993). The time course of perceptual and conceptual contributions to word fragment completion priming. Journal of Experimental Psychology: Learning, Memory and Cognition, 19(5), 1010-1023.

Weldon, M. S. & Roediger, H. S. (1987). Altering retrieval demands reverses the picture superiority effect. Memory and Cognition, 15, 269-280.

Weldon, M. S. & Jackson-Barrett, J. L. (1993). Why do pictures produce priming on the word fragment completion test? A study of encoding and retrieval factors. Memory and Cognition, 21(4), 519-528.

Weldon, M. S., Roediger, H. L., Beitel, D. A. & Johnston, T. R. (1995). Perceptual and conceptual processes in implicit and explicit tests with picture fragment and word fragment cues. Journal of Memory and Language, 34, 268-285.

Whitlow, J. W. & Cebollero, A. (1989). The nature of word frequency effects on perceptual identification. Journal of Experimental Psychology: Learning, Memory and Cognition, 15(4), 643-656.

Whittlesea, B. W. A. & Cantwell, A. L. (1987). Enduring influence of the purpose of experiences: Encoding retrieval interactions in word and pseudoword perception. Memory and Cognition, 15(6), 465-472.

Whittlesea, B. W. A. & Jacoby, L. L. (1990). Interaction of prime repetition with visual degradation: Is priming a retreival phenomenon? Journal of Memory and Language, 29, 546-565.

Wilding, E. L., Doyle, M. C. & Rugg, M. D. (1995). Recognition memory with and without retrieval of context: An event related potential study. Neuropsychologia, 33(6), 743-767.

Wilding, J. (1986). Joint effects of semantic priming and repetition in a lexical decision task: Implications for a model of lexical access. Quarterly Journal of Experimental Psychology, 38A, 213-228.

Winer, B. J. (1971). Statistical Principles in Experimental Design. New York: McGraw-Hill.

Winnick, W. A. & Daniel, S. A. (1970). Two kinds of response priming in tachistoscopic word recognition. Journal of Experimental Psychology, 84(1), 74-81.

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

Woltz, D. J. (1990). Repetition of semantic comparisons: Temporary and persistent priming effects. Journal of Experimental Psychology: Learning, Memory and Cognition, 16(3), 392-403.

Yonelinas, A. P. & Jacoby, L. L. (1995). Dissociating automatic and controlled processes in a memory-search task: Beyond implicit memory. Psychological Research, 57, 156-165.

Young, M. & Rugg, M. D. (1992). Word frequency and multiple repetition as determinants of the modulation of event-related potentials in a semantic classification task. Psychophysiology, 29, 664-676.

Appendices

Appendix 1: Derivationally related word pairs used in Experiments 1A, 1B and 2.

Group 1		Group 2		Group 3	
acid	acidity	absent	absentee	abuse	abusive
aim	aimless	arab	arabic	angel	angelic
boost	booster	arouse	arousal	arid	aridity
bride	bridal	bigot	bigotry	asia	asiatic
bulk	bulky	bishop	bishopric	axiom	axiomatic
choir	choral	damp	dampen	beg	beggar
cool	coolant	dense	densest	bind	binder
cream	creamy	erase	eraser	brave	braver
cup	cupful	eye	eyeful	brute	brutal
dose	dosage	faint	faintest	coast	coastal
entry	entrant	fibre	fibrous	coy	coyness
fatal	fatality	flaw	flawless	ghost	ghostly
froth	frothy	foot	footage	gland	glandular
gene	genetic	globe	global	hero	heroism
haul	haulage	grief	grievous	idyll	idyllic
hot	hotter	harsh	harsher	joy	joyous
leak	leakage	hate	hateful	link	linkage
loose	loosen	lever	leverage	lyric	lyrical
master	masterly	mason	masonic	mercy	merciful
meek	meekest	myth	mythic	noise	noisily
melody	melodic	nice	nicely	orator	oratory
mock	mockery	noble	nobler	orbit	orbital
parent	parental	nude	nudist	pious	piously
pope	papal	pack	package	pity	piteous
rigid	rigidly	pain	painless	pomp	pompous
rude	rudely	peril	perilous	prime	primal
season	seasonal	poor	poorest	rain	rainy
self	selfish	prior	priority	riot	riotous
shade	shady	pure	purism	rival	rivalry
soft	soften	safe	safest	ruin	ruinous
soul	soulful	silk	silken	spoil	spoilage
steam	steamily	sleep	sleepy	storm	stormy
tact	tactful	snug	snugly	style	stylish
topic	topical	sore	sorest	tacit	tacitly
trawl	trawler	stop	stoppage	thin	thinly
tune	tuneful	sunk	sunken	tight	tighter
valid	validity	tide	tidal	weak	weakest
velvet	velvety	vain	vanity	wet	wetter
village	villager	venom	venomous	wide	widen
wild	wildest	waste	wastage	wrong	wrongly

Appendix 2: Formally similar words used in Experiments 1A, 1B and 2.

Group 1		Group 2		Group 3	
amaze	amazon	adult	adultery	accord	accordion
ball	ballast	beak	beaker	acre	acrid
barge	bargain	blaze	blazer	bang	bangle
bow	bowel	bus	bush	blood	bloom
brand	brandish	casual	casualty	comply	compliment
budge	budgetary	chap	chaplain	copy	copious
bug	bugle	cheek	cheese	cord	cordon
cane	canyon	cow	coward	curt	curtain
dear	dearth	crate	crater	die	diesel
event	eventual	draw	drawl	dive	divert
flag	flagrant	fall	fallacy	drag	dragon
flora	florid	fat	fatigue	dung	dungeon
gaunt	gauntlet	fee	feeble	flank	flange
grave	gravel	fur	furious	germ	germane
grove	grovel	gala	galaxy	glow	glower
habit	habitat	grim	grimace	heat	heather
halt	halter	hare	harem	hide	hideous
ham	hammer	hurt	hurtle	insult	insulin
hang	hangar	lunar	lunatic	iron	irony
hatch	hatchet	mist	mistress	jew	jewel
lace	lacerate	monk	monkey	lap	lapel
lad	ladle	morse	morsel	lure	lurid
leg	legion	nurse	nursery	mass	massage
lot	lotion	pall	pallid	mess	messiah
lung	lunge	pass	passive	page	pagan
organ	organise	pear	pearl	par	parish
pot	potent	pen	pendant	path	pathetic
raise	raisin	pick	pickle	pert	pertain
raven	ravenous	pig	pigment	pill	pillow
rust	rustle	plea	pleat	ramp	rampage
scar	scarf	poise	poison	revere	reversal
sent	sentry	post	postulate	roman	romance
skill	skillet	sad	sadist	snore	snorkle
slum	slumber	scan	scandal	sole	solemn
swam	swamp	solve	solvent	spine	spinach
tail	tailor	son	sonata	stall	stallion
tent	tentacle	steep	steeple	surge	surgeon
trip	tripod	torso	torsion	test	testify
twin	twinge	trait	traitor	tin	tinder
villa	villain	vine	vinegar	tyre	tyrant

Appendix 3: Formally similar words used in Experiment 3.

Group 1		Group 2	
accord	accordion	acre	acrid
adult	adultery	ball	ballast
amaze	amazon	bang	bangle
barge	bargain	beak	beaker
blood	bloom	blaze	blazer
brand	brandish	cane	canyon
budge	budgetary	cheek	cheese
casual	casualty	comply	compliment
chap	chaplain	dear	dearth
copy	copious	draw	drawl
cord	cordon	dung	dungeon
crate	crater	flag	flagrant
curt	curtain	flank	flange
dive	divert	flora	florid
drag	dragon	gaunt	gauntlet
east	easter	germ	germane
event	eventual	grave	gravel
fall	fallacy	grim	grimace
gala	galaxy	habit	habitat
glow	glower	halt	halter
grove	grovel	hang	hangar
hare	harem	heat	heather
hatch	hatchet	insult	insulin
hide	hideous	lace	lacerate
hurt	hurtle	lure	lurid
iron	irony	mass	massage
lunar	lunatic	mess	messiah
lung	lunge	organ	organise
mist	mistress	path	pathetic
monk	monkey	pear	pearl
morse	morsel	pert	pertain
nurse	nursery	pick	pickle
page	pagan	post	postulate
pall	pallid	raise	raisin
pass	passive	raven	ravenous
pill	pillow	revere	reversal
plea	pleat	scar	scarf
poise	poison	sent	sentry
ramp	rampage	skill	skillet
roman	romance	slum	slumber
rust	rustle	snore	snorkle
scan	scandal	spine	spinach
sole	solemn	stall	stallion
solve	solvent	steep	steeple
swam	swamp	surge	surgeon
tail	tailor	test	testify
tent	tentacle	trait	traitor
torso	torsion	trip	tripod
villa	villain	twin	twinge
vine	vinegar	tyre	tyrant

Appendix 4: Formally similar non-words used in Experiment 4

Group 1		Group 2	
ataze	atazon	amult	amultery
brove	brovel	bis	bish
bup	buple	camuan	camuanty
burge	burgetary	chab	chablain
cade	cadyon	cheeb	cheene
cail	cailor	col	colard
doan	doanth	crade	crader
ement	ementual	dost	dostress
fent	fentry	foll	follacy
flig	fligrant	foo	fooble
flona	flonid	fraw	frawl
fow	fowel	fum	fumious
frand	frandish	fust	fustulate
gace	gacerate	gare	garem
gaint	gaintlet	golo	goloxy
gam	gammer	grom	gromace
grake	grakel	heak	heaker
habin	habinat	hunar	hunatic
hant	hanter	hurk	hurkle
harge	hargain	lat	latigue
hetch	hetchet	lonk	lonkey
lig	ligion	molve	molvent
lod	lodle	monse	monsel
lut	lution	nolse	nolsery
mang	mangar	pawt	pawtid
orban	orbanise	pilk	pilkle
pon	ponent	poar	poarl
prip	pripod	poile	poilon
rall	rallast	pon	pondant
roben	robenous	prea	preat
roise	roisin	saf	safist
rost	rostle	scen	scendal
shar	shart	slaze	slazer
snam	snamp	sneep	sneeple
snill	snillet	sof	sofata
stum	stumber	thait	thaitor
telt	teltacle	tig	tigment
twid	twidge	torpo	torpion
vinna	vinnain	vone	vonegar
vung	vunge	wass	wassive

Appendix 5 : Formally similar words used in Experiment 5

PH+ Words				PH- Words			
Group 1		Group 2		Group 1		Group 2	
barge	bargain	accord	accordion	amaze	amazon	acre	acrid
beak	beaker	bang	bangle	ball	ballast	bow	bowel
blaze	blazer	brand	brandish	blood	bloom	cap	caper
cheek	cheese	bride	bribe	bug	bugle	cover	covert
comply	compliment	burn	burly	bus	bush	crane	crank
cord	cordon	casual	casualty	cane	canyon	dig	digest
crate	crater	chap	chaplain	copy	copious	dream	dread
dive	divert	cow	coward	dear	dearth	drop	drown
drag	dragon	draw	drawl	die	diesel	fall	fallacy
dung	dungeon	fee	feeble	gap	gape	fat	fatigue
grim	grimace	flank	flange	gaze	gazelle	flag	flagrant
hurt	hurtle	gasp	gasket	glad	glade	flora	florid
insult	insulin	gaunt	gauntlet	glum	glue	fur	furious
lunar	lunatic	halt	halter	grove	grovel	gala	galaxy
mass	massage	ham	hammer	hare	harem	glow	glower
mint	mink	hatch	hatchet	heat	heather	grave	gravel
monk	monkey	jew	jewel	hero	heron	hide	hideous
morse	morsel	lung	lunge	kind	kindle	lap	lapel
nurse	nursery	lure	lurid	lace	lacerate	luck	lucid
park	parcel	milk	mill	lad	ladle	pall	pallid
pass	passive	mist	mistress	lathe	lather	par	parish
pen	pendant	page	pagan	leg	legion	path	pathetic
pick	pickle	pert	pertain	male	malice	pear	pearl
pig	pigment	pill	pillow	mat	matrix	pot	potent
plea	pleat	poise	poison	mess	messiah	raven	ravenous
pram	prank	rust	rustle	plump	plume	ripe	ripple
raise	raisin	sent	sentry	post	postulate	sad	sadist
ramp	rampage	skill	skillet	ratio	ratify	shin	shine
revert	reversal	slum	slumber	rave	ravine	shrine	shrink
roman	romance	snore	snorkle	roar	roam	slice	slick
scan	scandal	solve	solvent	rob	robust	slog	slogan
scar	scarf	sting	stink	rum	rumour	span	spade
spark	sparse	sweet	sweep	slim	slime	stall	stallion
spice	spider	tent	tentacle	slope	sloppy	strange	strangle
steam	steal	tin	tinder	sole	solemn	strip	stripe
steep	steeple	trait	traitor	spare	sparse	swam	swamp
surge	surgeon	twin	twinge	spine	spinach	swim	swipe
tail	tailor	wink	winch	split	splice	swine	swindle
test	testify	wish	wisp	vine	vinegar	treat	treasure
tyre	tyrant	wood	wool	wrap	wrath	trip	tripod