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Attention, Learning Disability Subtypes, and the Naming of Pictures and Words

by

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**A thesis submitted to the School of Graduate Studies and Research
in partial fulfilment of the requirements for the degree of
Doctor of Philosophy**

School of Psychology, University of Ottawa

Ottawa, Ontario, Canada

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ABSTRACT

A series of three studies was conducted to examine the effects of attention and semantic relation on the processing of pictures and words in adults, normally achieving children, and children with specific learning disabilities (LD) in reading and spelling versus arithmetic. Event-related potentials (ERPs) were recorded during a naming task for pictures and words presented individually and in superimposed picture-word pairs in which the meanings of the pictures and words were either congruent, semantically associated, or incongruent. Participants were required to direct their attention to either pictures or words in the superimposed conditions by naming the task-relevant stimulus. Physically, the superimposed picture-word pairs were the same in each condition. A negative ERP wave occurring approximately 450 ms post-stimulus (N450) was of particular interest in this work, as this wave is sensitive to linguistic and semantic processing and has been useful in differentiating LD subtypes.

For adults and normally achieving children, distinct ERP waveforms were observed for individually presented pictures and words. Although there were developmental differences in the ERPs to pictures, distinct waveforms were maintained for pictures and words presented in the superimposed pairs for both groups. This finding affirms the independent attentional processing of pictures and words. Whereas, for adults, there was evidence for automatic and controlled processing of words and pictures, respectively, there was little evidence that children processed the words automatically to the same degree. Children were also less efficient than adults at managing attentional resources.

Children with two subtypes of LD based on reading and spelling (RS) or arithmetic (A) achievement were differentiated from one another and from normally achieving controls on the picture-word naming task. Compared to controls, Group RS displayed naming deficits for pictures and words and smaller N450 waves to words. Their N450 to pictures was normal. These effects were indicative of deficient linguistic processing but intact visual-spatial processing. Group A displayed a specific picture-naming deficit and smaller N450 waves to words and pictures. When attending to pictures in the superimposed pairs, Group A failed to develop an early negative wave thought to reflect processes involved in the discrimination of task-relevant stimuli. This effect may indicate early deficiencies in visual-spatial processing, possibly at the stage of object identification. Overall, these effects provide support for a typology of LD based upon patterns of academic achievement and neurocognitive performance (Rourke, 1982, 1989).

CURRICULUM STUDORIUM

Stephanie Lynn Greenham was born in Barrie, Ontario on January 5, 1968. She completed a Bachelor of Science (Honours) degree in Psychology at Carleton University in 1990, and subsequently obtained a Master of Applied Science degree in Applied Psychology at the University of Waterloo in 1992. Since 1994, she has pursued a Doctor of Philosophy degree in Clinical Psychology at the University of Ottawa.

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Manuscripts submitted for publication

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- Heymans, S. L., Waheed, N., & LeFevre, J.** (1990, June). *Development of computational estimation skills in multiplication*. Presented at the annual meeting of the Canadian Psychological Association, Ottawa, Ontario.
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TABLE OF CONTENTS

ABSTRACT	ii
CURRICULUM STUDORIUM	iv
ACKNOWLEDGEMENTS	vii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
ORGANIZATIONAL NOTE	xvi
CHAPTER 1	1
General Introduction	1
Learning Disabilities and Attentional Processing	2
Independent Processing of Pictures and Words	4
LD Subtypes and Picture-Word Processing	6
Overview of the Present Series of Studies	7
Study 1	7
Study 2	7
Study 3	8
CHAPTER 2	9
Study 1: Effects of Attention and Semantic Relation on Event-Related Potentials in a Picture-Word Naming Task	9
Introduction	10
Method	15
Participants	15
Stimulus Materials	15
Procedure	17
EEG Recording	18
ERP Scoring	19

Results.....	20
Individually Presented Words and Pictures	20
Superimposed Words and Pictures	27
Individually presented words compared to attended words.....	28
Individually presented pictures compared to attended pictures	31
Attended words compared to attended pictures	34
Discussion.....	37
Attending Words.....	40
Attending Pictures.....	41
Summary and Conclusions	42
 CHAPTER 3	 46
 Study 2: Event-Related Potentials and Picture-Word Naming: Effects of Attention and Semantic Relation for Children and Adults	 46
Introduction.....	47
Method	52
Participants.....	52
Stimulus Materials	52
Procedure	54
EEG Recording	55
ERP Scoring.....	56
Results.....	57
List Naming	57
ERPs.....	57
Developmental effects on ERP latency and amplitude.....	58
Individually Presented Words and Pictures	60
Individually Presented Words versus Attended Words	63
Individually Presented Pictures versus Attended Pictures.....	67
Attended Words and Pictures.....	71
Discussion.....	73
Conclusions.....	80
 CHAPTER 4	 82
 Study 3: Learning Disability Subtypes and the Processing of Pictures and Words: The Effects of Attention and Semantic Relation on Event-Related Potentials	 82
Introduction.....	83
Subtypes of Learning Disabilities and Attentional Deficits	84
ERPs and Learning Disabilities	86
Learning Disability Subtypes and ERPs	88

Picture-Word Processing	90
The Present Study	92
Method	93
Participants.....	93
Stimulus Materials	94
Procedure	98
EEG Recording	99
ERP Scoring.....	100
Data Analyses	100
Results.....	101
Behavioural Task: Word- and Picture-List Naming	101
Naming Errors during ERP Tasks.....	104
ERPs to Individually Presented Words and Pictures	104
Group differences.....	104
Words versus pictures	107
Hemispheric differences	109
ERPs to Attended Words and Pictures.....	109
Group differences.....	109
Semantic effects	111
Attention effects.....	114
Hemispheric differences	114
Discussion	116
ERPs of Normally Achieving Children	117
Individually Presented Words and Pictures	118
Superimposed Words and Pictures	120
Hemispheric Differences.....	123
Conclusions.....	124
CHAPTER 5	126
General Discussion and Conclusions.....	126
Summary of Salient Findings	127
Adults.....	127
Normally Achieving Children.....	128
Learning Disability Subtypes.....	130
Future Directions	131
Conclusions.....	133
REFERENCES	134

APPENDIX.....	150
Behavioural List-Naming Tasks	150
English Word List.....	151
Dutch Word List	152
English and Dutch Picture List	153
CONTRIBUTIONS OF COLLABORATORS.....	154

LIST OF TABLES

Table 2.1	Mean N450 Amplitude for Individually Presented and Attended Words and Pictures at Anterior Electrode Sites for Adults.....	23
Table 2.2	Mean P390 Amplitude for Individually Presented Words and Pictures at Central-Parietal Electrode Sites for Adults.....	24
Table 2.3	Mean P240 Amplitude for Individually Presented and Attended Words and Pictures at Posterior Electrode Sites for Adults.....	25
Table 3.1	Mean ERP Latency and Amplitude Values for Adults and Children and Main Effects of Group	59
Table 3.2	Mean N450 Amplitude as a Function of Stimulus Type, Electrode Site, and Condition for Adults and Children	65
Table 4.1	Mean Age in years and WRAT-3 Discrepancy Scores for Normally Achieving Children and Learning Disability Subtypes.....	95
Table 4.2	List Naming: Mean Percentage of Errors and Naming Speed for Normally Achieving Children and Learning Disability Subtypes	102
Table 4.3	Naming during ERP Tasks: Mean Percentage of Errors for Normally Achieving Children and Learning Disability Subtypes	103
Table 4.4	Mean N450 Amplitude as a Function of Stimulus Type, Electrode Site, and Condition for Normally Achieving Children and Learning Disability Subtypes	106

LIST OF FIGURES

Figure 2.1	Examples of congruent, associated, and incongruent superimposed picture-word stimuli.....	16
Figure 2.2	Adults' grand average ERP waveforms to individually presented words and pictures	22
Figure 2.3	Adults' grand average ERP waveforms to individual and attended words.....	29
Figure 2.4	Adults' difference waveforms for attended words and attended pictures.....	32
Figure 2.5	Adults' grand average ERP waveforms to individual and attended pictures.....	33
Figure 2.6	Adults' grand average ERP waveforms to attended words and pictures in congruent, semantically associated, and incongruent picture-word pairs.....	36
Figure 3.1	Grand average ERP waveforms to individually presented words and pictures for adults and children.....	61
Figure 3.2	Grand average ERP waveforms to individually presented and attended words for adults and children.....	64
Figure 3.3	Grand average ERP waveforms to individually presented and attended pictures for adults and children.....	69
Figure 3.4	Grand average ERP waveforms to attended words and pictures as a function of semantic relatedness for adults and children	72
Figure 4.1	Examples of Dutch congruent, associated, and incongruent superimposed picture-word stimuli.....	96
Figure 4.2	Grand average ERP waveforms illustrating group differences in N450 amplitude to individually presented words and pictures for normally achieving, reading disabled, and arithmetic disabled children	105
Figure 4.3	Grand average ERP waveforms to individually presented words and pictures, presented separately for normally achieving, reading disabled, and arithmetic disabled children	108
Figure 4.4	Grand average ERP waveforms illustrating group differences in N450 amplitude to attended words and pictures for normally achieving, reading disabled, and arithmetic disabled children.....	110

Figure 4.5	Difference waveforms for attended words and attended pictures for normally achieving, reading disabled, and arithmetic disabled children.....	113
Figure 4.6	Grand average ERP waveforms to attended words and pictures as a function of semantic relatedness presented separately for normally achieving, reading disabled, and arithmetic disabled children.....	115

ORGANIZATIONAL NOTE

This thesis consists of five chapters. Chapter 1 presents a brief review of the relevant literature and outlines the goals for the three studies that follow. Chapters 2, 3, and 4 present the results from these studies. They are presented in journal article format, with each chapter containing separate Introduction, Method, Results, and Discussion sections. The studies contained in Chapters 2 and 3 have been submitted for publication and are currently under review. Chapter 2 was submitted to Biological Psychology. Chapter 3 was submitted to Developmental Neuropsychology. Chapter 4 is in preparation for submission. Inevitably, there is a degree of overlap across these three chapters, particularly in the methodology sections. However, each article addresses related but unique questions, and the introduction and discussion sections reflect these differences. Chapter 5 presents a general discussion and a summary of the salient effects from each study. References are provided for the entire thesis, rather than for each individual chapter, to avoid redundancy.

CHAPTER 1

General Introduction

The goal of this thesis was to explore the nature of deficiencies in selective attention for children who present with specific learning disabilities (LD). Of particular interest was the hypothesis that children with outstanding difficulties in reading and spelling along with deficient verbal-linguistic processing would exhibit deficits in selective attention specific to linguistic stimuli. Children with outstanding difficulties in arithmetic as well as poor visual-spatial processing were hypothesized to exhibit deficits in selective attention specific to visual-spatial, pictorial stimuli. To this end, a picture-word naming task was employed using event-related potential (ERP) recording techniques. Words and pictures were superimposed and the children's attention was directed toward either words or pictures in two separate tasks. By presenting superimposed picture-word pairs, the physical characteristics of the stimuli were identical in each task and only the focus of attention was manipulated. This procedure provided a means with which to assess the independent processing of pictures and words due to attentional processing, not physical stimulus characteristics.

Learning Disabilities and Attentional Processing

The nature of attentional deficits in the development of LD has been widely investigated. It is generally accepted that attention is a multidimensional construct, comprised of a number of components including (but not limited to) selective, sustained, divided, and shifting attention (Cooley & Morris, 1990; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991). There is good evidence that performance measures of sustained attention, attentional capacity, and level of arousal do not differentiate between children with and without LD (Pennington, Groisser, & Welsh, 1993; Richards, Samuels, Turnure, & Ysseldyke, 1990; Samuels & Edwall, 1981;

Warnke & Remschmidt, 1992; Whyte, 1994). There also seems to be a consensus that on tasks of auditory and visual selective attention, children with LD and poor readers have greater difficulty focusing their attention to task-relevant information in the presence of distracting information than do normally achieving children (Copeland & Reiner, 1984; Kelly, Best, & Kirk, 1989; Lazarus, Ludwig, & Aberson, 1984; Lovdahl, Brown, McIntyre, & North, 1986; Richards et al., 1990; Samuels & Edwall, 1981) or children with attention deficit disorders (Tarnowski, Prinz, & Nay, 1986). Similarly, there is some evidence using ERP methods for deficits in visual selective attention for individuals with LD (Harter, 1991; Harter, Anllo-Vento, & Wood, 1989; Harter, Anllo-Vento, Wood, & Schroeder, 1988; Naylor, Wood, & Harter, 1995). However, null effects are also reported (Bolster, Marshall, Bow, Chalmers, & Stubel, 1986; Lovrich & Stamm, 1983).

It is well established that LD can be differentiated into homogeneous subtypes based on reliable patterns of skills and deficits (Geary, 1993; Hooper & Willis, 1989; Rourke, 1985, 1991). However, these patterns of skills and deficits that are specific to LD subtypes may be masked in previous work on attention by the use of undifferentiated samples of children with LD. Two subtypes of LD defined on the basis of patterns of academic achievement were of particular interest for this thesis because of the specific deficits in verbal-linguistic and visual-spatial processing that are ascribed to these groups (Ozols & Rourke, 1988; Rourke, 1993; Rourke and Finlayson, 1978). Included in these patterns of specific processing deficits are proposed deficiencies in selective attention for auditory-verbal versus visual-spatial information (Rourke, 1982, 1989). Thus, children who present with LD in reading (word recognition) and spelling relative to arithmetic (Subtype R-S) are proposed to have difficulty attending to verbal or linguistic information, particularly when it is presented in the auditory modality. Children who

present with LD in mechanical arithmetic but who have well-developed reading and spelling skills (Subtype A) are thought to have difficulty attending to visual-spatial information, especially when it is novel or complex in nature (Rourke, 1989). These subtype-specific attentional deficits were explored in this thesis by employing a superimposed picture-word naming task with children who met criteria for Subtypes R-S and A.

Independent Processing of Pictures and Words

The independent processing of pictures and words is a well established phenomenon in both the behavioural and ERP literature that provides a means with which to assess subtype-specific attentional deficits in children with LD. For example, performance measures of naming and categorization indicate that pictures are named slower but are categorized faster than words (Glaser & Döngelhoff, 1984; Potter & Faulconer, 1975; Seifert, 1997). On tasks of picture-word interference, the presence of superimposed words whose meaning is unrelated to the pictures increases the time required to name, but not categorize, the pictures. Conversely, the presence of superimposed incongruent pictures increases the time required to categorize, but not name, the words (Glaser & Döngelhoff, 1984; Lupker & Katz, 1981, 1982; Rosinski, Golinkoff, & Kukish, 1975; Smith & Magee, 1980). These effects, which are observed for both adults and normally achieving children, are thought to reflect two independent, but interconnected, representational subsystems for nonverbal and linguistic information (Glaser, 1992; Johnson, Paivio, & Clark, 1996). These effects have also been taken as evidence that words are processed automatically whereas pictures are subject to controlled attentional processing (Shiffrin & Schneider, 1977).

Evidence for the independent processing of pictures and words is also provided using ERP methods. The N400 wave, a negative ERP component that occurs approximately 400 ms

post-stimulus, appears to be the “default response” to most words (Kutas & Van Petten, 1994). The N400 wave is also sensitive to semantic processing in that larger N400 amplitude is typically observed to stimuli that are incongruent with the expected context (Kutas & Hillyard, 1980). In adults, distinct ERP waveforms are observed for pictures and words, such that pictures elicit ERPs that are more positive in amplitude over posterior regions of the scalp than ERPs to words, which are characterized by N400 (Campbell, Karam, & Noldy-Cullum, 1987; Kok & Rooyakkers, 1986; Nigam, Hoffman, & Simons, 1992; Noldy, Stelmack, & Campbell, 1990). Furthermore, the ERP waveforms to pictures are modulated under attend versus ignore task demands, whereas the ERPs to words are not (Noldy et al., 1990). These findings converge with the performance data to indicate that, for adults, picture-processing is subject to attentional control and that the processing of words is automatic and not influenced by attentional focus (Shiffrin & Schneider, 1977).

The ERP waves elicited by pictures in normally achieving children are different than those observed for adults. Children exhibit prominent negative ERP waves over anterior scalp regions in the latency range of N400 to a variety of visually presented stimuli (Courchesne, 1983; Taylor, 1988), with pictures typically eliciting larger negative waves than words (Berman, Friedman, & Cramer, 1990; Robertson, Mahensan, & Campbell, 1990). Despite differences between children and adults, this effect in children has been attributed to differences between pictures and words in the automaticity of access to lexical or conceptual representations, and provides some evidence for the independent processing of pictures and words.

LD Subtypes and Picture-Word Processing

The independent nature of picture and word processing lends itself readily to the assessment of processing deficits for LD subtypes, and attempts to explore subtype-specific deficits using ERP methods have met with some success. On reading-related tasks of recognition memory and semantic priming using word and picture stimuli, children with LD in reading and spelling (Group RS) were reported to have deficiencies in the processes involved in semantic evaluation, as reflected by smaller amplitude N450 waves to words than were observed for non-LD controls (Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988). Group RS exhibited normal priming of target words by pictures that shared denotative meaning, an effect indicative of intact visual-spatial processing (Stelmack & Miles, 1990). However, Group RS was not sensitive to priming by pictures or spoken words whose meanings were associated with the target words, suggesting deficiencies in the interaction of verbal and nonverbal associative systems (Miles & Stelmack, 1994). Conversely, children with LD in arithmetic (Group A) showed normal priming of target words by associated spoken words, suggesting intact linguistic processing. These children were not sensitive to priming by associated pictures, however, an effect indicative of deficient visual-spatial processing (Miles & Stelmack, 1994).

The use of ERP recordings during the processing of superimposed pictures and words is a novel approach to the study of linguistic and visual-spatial processing in LD subtypes. Indeed, the application of ERP methods to the processing of pictures and words in this superimposed paradigm has not been reported in the literature to date. It was therefore necessary to examine these issues in non-LD samples prior to exploring them for LD subtypes. To this end, a series of three studies was undertaken.

Overview of the Present Studies

The methodology for all three studies reported in this thesis was identical. ERPs were recorded during a naming task in which pictures and words were presented individually and in superimposed pairs. The superimposed pictures and words varied in semantic relatedness, such that the meanings were either congruent (e.g., baby-BABY), semantically associated (e.g., ambulance-ACCIDENT), or incongruent (e.g., cup-MIRROR). Participants were required to direct their attention to either pictures or words in two separate tasks in which the superimposed picture-word pairs were physically the same. Analysis of the ERPs examined whether words and pictures elicited distinct waveforms, and if so, whether these distinct waveforms were maintained for words and pictures presented in superimposed picture-word pairs. Effects of semantic relation (i.e., the degree to which the meaning of the superimposed pictures and words matched) on the amplitude of the N400 wave were also examined for evidence that participants were able or unable to ignore the irrelevant superimposed stimuli.

Study 1. The goal of the first study in this series was to establish the independent attentional processing of superimposed pictures and words in adults who had no history of learning difficulties and for whom reading was a highly developed skill. As previously noted, distinct ERP waveforms to words and pictures have been reported previously for adults (e.g., Noldy et al., 1990), but not in a task in which the physical characteristics of the stimuli were the same across conditions. This issue was addressed in the first study.

Study 2. In the second study, the goal was to establish the independent processing of words and pictures in a sample of normally achieving, school-age children. The primary focus of this study was a developmental comparison of the ERP waves to words and pictures presented

individually and in superimposed picture-word pairs to examine the effects of normal development on word and picture processing. These results would then form a point of reference from which to discuss the results obtained in the same task for children with LD.

Study 3. The third and final study in this series investigated word and picture processing in this task with Dutch-speaking children who presented with specific LD in either reading and spelling (Group RS) or arithmetic (Group A). A normally achieving, Dutch-speaking control group also participated. One objective of this study was to explore whether the superimposed picture-word naming task would differentiate the LD subtypes from one another and from control children. In particular, subtype-specific deficits in selective attention to words and pictures and as well as differences in semantic processing were examined.

CHAPTER 2

Study 1

**Effects of Attention and Semantic Relation on
Event-Related Potentials in a Picture-Word Naming Task**

Introduction

There is a consensus that words and pictures are processed independently even when they have a common denotative meaning (Glaser, 1992; Paivio, 1978, 1986, 1991). This independence is manifest in effects observed during naming, categorization, memory, and semantic interference tasks using both behavioural and electrophysiological indices. There is a good deal of evidence indicating that the processing of pictures involves controlled attentional resources, whereas words are processed automatically and are not influenced by attentional focus (Shiffrin & Schneider, 1977). In this research, event-related potential (ERP) methods were employed to determine whether the independent processing of words and pictures is manifest during an attentional task when words and pictures were presented simultaneously.

In the context of cognitive information processing models, one view maintains that the familiarity of words facilitates automatic processing, whereas the physical distinctiveness of pictures requires controlled, effortful processing (LaBerge & Samuels, 1974; Shiffrin & Schneider, 1977). Alternatively, words are thought to have privileged access to lexical information whereas pictures are thought to have privileged access to semantic memory (Glaser, 1992; Glaser & Glaser, 1989; Seifert, 1997). These differences in processing demands engender faster naming times for words (Fraisse, 1969; Potter & Faulconer, 1975; Seifert, 1997; Sperber, McCauley, Ragain, & Weil, 1979; Theios & Amrhein, 1989) and faster categorization times for pictures (Guenther, Klatzky, & Putnam, 1980; Potter & Faulconer, 1975; Seifert, 1997). Incongruent distractor words interfere with picture-naming but not with picture-categorizing; opposite effects are reported for incongruent distractor pictures (Glaser & Dünghoff, 1984;

Rosinski, Golinkoff, & Kukish, 1975; Smith & Magee, 1980). Furthermore, pictures have superiority over words on tasks of free recall and recognition memory (Maisto & Queen, 1992; Nicolas, 1995; Paivio & Csapo, 1973; Reifer, Hu, & Batchelder, 1994; Standing, Conezio, & Haber, 1970; Stenberg, Radeborg, & Hedman, 1995; Weldon & Coyote, 1996).

Investigations of picture-word processing using ERP methods also demonstrate clearly that words and pictures are processed independently and that they elicit distinct waveforms on tasks of reading (Nigam, Hoffman, & Simons, 1992), category matching (Kok & Rooyakkers, 1986), and recognition memory (Berman, Friedman, & Cramer, 1990; Noldy, Stelmack, & Campbell, 1990). Specifically, the amplitude of ERP waves to pictures tends to be more positive (or less negative) than for words (Campbell, Karam, & Noldy-Cullum, 1987; Kok & Rooyakkers, 1986; Nigam et al., 1992; Noldy et al., 1990; Noldy-Cullum & Stelmack, 1987). In an incidental learning task, in which participants were instructed to attend or ignore words and pictures, Noldy et al. (1990) observed larger P300 amplitude to pictures than words, an effect that was associated with the better memorability of pictures. In contrast, words elicited larger N450 amplitude than pictures, an effect that is consistent with the linguistic sensitivity that is associated with this wave (Kutas & Hillyard, 1980; Kutas & van Petten, 1988). Noldy et al. also observed that the ERPs to pictures were characterized by larger amplitude positive waves under attend than ignore conditions. No such differences between attend and ignore conditions were observed for words. These effects are consistent with the view that picture-processing involves controlled attentional resources, but that the processing of words is automatic, and not influenced by focus of attention (Shiffrin & Schneider, 1977).

The larger positive amplitude of ERP waveforms to pictures than words can be attributed to differences in the allocation of attentional resources (Kok, 1997; Polich, 1993). However, the greater spatial complexity and distinctiveness of pictures compared to words may contribute to this effect (e.g., Johnson, 1986). It is well established that the greater memorability of pictures than words, for example, can be attributed to the spatial distinctiveness of pictures (Nelson, Reed, & McEvoy, 1977; Nelson, Reed, & Walling, 1976; Weldon & Coyote, 1996). Furthermore, it has been argued that many of the processing differences between words and pictures reported in the literature may be explained in terms of physical differences in size and discriminability between lexical and pictorial stimuli (Theios & Amrhein, 1989). In this study, we attempted to assess the effects of attention on the processing of words and pictures by maintaining a constant stimulus display during a picture-word naming task. This was achieved by presenting a superimposed word and picture in a single array, and by instructing participants to attend to one form while ignoring the other. Thus, any differences in the ERP waveforms to the picture-word pairs can be attributed to the independent focus of attention on words or pictures and not to differences in the physical stimulus array.

Superimposed picture-word naming tasks provide a useful paradigm for examining the interaction of word and picture processing with ERP methods. There is an extensive literature documenting the sensitivity of ERPs to semantic incongruity using either word or picture stimuli. In particular, the N400 wave is associated with the processing of semantic information that is incongruent with semantic expectancy (Ganis, Kutas, & Sereno, 1996; Gunter, Jackson, Kutas, Mulder, & Buijink, 1994; Kutas & van Petten, 1988; McPherson & Holcomb, 1999; Neville, Kutas, Chesney, & Schmidt, 1986; Rugg, 1985; Stuss, Picton, & Cerri, 1986; Stuss, Sarazin,

Leech, & Picton, 1983). Notably, words at the end of sentences that are incongruent with the meaning of the preceding words elicit a large negative wave occurring at approximately 400 ms (Kutas & Hillyard, 1980). Similarly, in a picture-matching paradigm, the amplitude of a negative wave at 400 ms increases as the degree of semantic relationship between two pictures decreases (Friedman, Putnam, Ritter, Hamberger, & Berman, 1992; Friedman, Sutton, Putnam, Brown, & Erlenmeyer-Kimling, 1988). At the present time, it is not clear whether words and pictures presented simultaneously will manifest effects of semantic incongruity on ERP waves, or whether the independent processing of words and pictures will be maintained in distinct waveforms.

There is substantial evidence for semantic incongruity effects on reaction time measures using picture-word naming tasks. Specifically, picture-naming takes longer when incongruent words are superimposed on pictures, than when congruent words are superimposed (Glaser & Döngelhoff, 1984; Golinkoff & Rosinski, 1976; Rayner & Springer, 1986; Rosinski, 1977; Rosinski et al., 1975; Starreveld & La Heij, 1995), or when pictures are presented individually (Ehri, 1976; Ehri & Wilce, 1979; Lupker, 1979; Rayner & Springer, 1986; Smith & Magee, 1980). Distractor words from the same semantic category as the picture (i.e., the word “leg” on a picture of a hand) produce more interference than distractor words from a different semantic category (e.g., the word “truck”; Glaser & Döngelhoff, 1984; Goodman, Haith, Guttentag, & Rao, 1985; La Heij, 1988; La Heij, Dirx, & Kramer, 1990; Lupker, 1979; Rayner & Springer, 1986; Reiner & Morrison, 1983; Rosinski, 1977; Starreveld & La Heij, 1995). Furthermore, distractor words produce greater interference during picture-naming than do distractor pictures during word-naming (Glaser & Döngelhoff, 1984; Rosinski et al., 1975; Smith & Magee, 1980).

The interference effects of distractor words on picture-naming, along with the asymmetrical pattern of interference by distractor pictures on word-naming, provide strong evidence that the processing of pictures requires controlled attentional processing whereas the processing of words is automatic (Shiffrin & Schneider, 1977).

In this study, ERP components that are sensitive to the effects of physical stimulus parameters, attention, and semantic expectancy were employed to examine the processing of words and pictures during a naming task. Superimposed words and pictures that varied in semantic relatedness were presented. In one condition, hereafter referred to as attended words, participants were instructed to attend to the words and name them while ignoring the pictures. The opposite instructions (i.e., attend and name pictures and ignore words) were given in a second condition, hereafter referred to as attended pictures. Participants were not informed beforehand that the superimposed stimuli varied in semantic relatedness. Words and pictures that were presented individually were named in a control condition.

Following previously reported findings, ERPs to individually presented words were anticipated to be characterized by larger negative waves than ERPs to individually presented pictures (e.g., Noldy et al., 1990). If attentional processing of words and pictures is independent of the spatial complexity of the superimposed stimuli, then ERPs to attended words and pictures in superimposed stimulus pairs would be expected to be similar to the ERPs to individually presented words and pictures. On the view that picture-processing requires controlled attentional resources, effects of semantic relation were not anticipated in the ERPs to attended words. That is, the level of semantic relatedness between distractor pictures and attended words was not expected to differentially influence N400 amplitude in the ERPs to attended words because the

picture meanings would not be processed. On the other hand, if words are processed automatically, and therefore, are not ignored, effects of semantic relation would be anticipated in the ERPs to attended pictures. Specifically, larger amplitude N400 waves would be expected for incongruent and associated distractor words as compared to congruent distractor words.

Method

Participants

Ten adults (5 men, 5 women) from the university community, aged 21 to 42 years ($M = 29.7$ yrs, $SD = 7.8$ yrs), volunteered to participate in this study. All were right-handed (defined by self-reported writing hand), fluent in English, and had normal or corrected-to-normal vision.

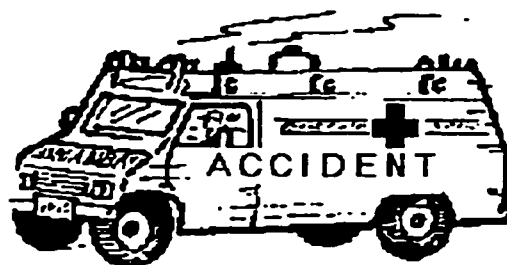
Stimulus Materials

The pictures used in this study were black-and-white line drawings of concrete objects taken from Pictures, Please!, a manual used in speech therapy (Abbate & LaChappelle, 1984). The pictures were scanned for presentation on a computer monitor. The 360 superimposed picture-word stimuli were formed by pairing each picture with a word that was either congruent (i.e., same denotative meaning), semantically associated, or incongruent (i.e., not related) with the picture meaning (see Figure 2.1). The congruent name of each picture was initially determined using a sample of 120 undergraduate students. They were asked to provide the first name that “came to mind” when the pictures were presented on a classroom screen. For each picture used in this study, there was at least 80% agreement on this name.

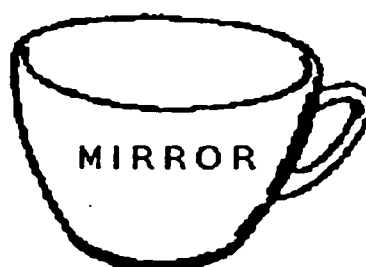
The superimposed stimuli were randomly divided into two separate lists of 180 trials with equal numbers ($n = 60$) of congruent, associated, and incongruent picture-word pairs to form the attend-word and attend-picture conditions. The attended words and pictures were matched



(A) Congruent



(B) Associated



(C) Incongruent

Figure 2.1 Examples of congruent, associated, and incongruent superimposed picture-word stimuli.

approximately for length and frequency of the base-words (Francis & Kucera, 1982). The mean base-word length of the attended pictures was longer than for attended words (6.0 vs. 5.4), $F(1, 179) = 10.3$, $p < .01$. However, this was due primarily to slightly more 10- and 11-letter base-words in the attend-picture list. Base-word length did not vary as a function of semantic relatedness in either list. The mean base-word frequency was higher for the attended words as compared to the attended pictures (59.0 vs. 16.3), $F(1, 179) = 12.3$, $p < .001$, primarily because of a small number of high frequency base-words in the attend-word list. Median base-word frequency for attended words and pictures was similar (13 vs. 6, respectively). Out of the 360 superimposed picture-word trials, 20 (5.6%) pictures and 18 (5.0%) words appeared twice. For repetitions occurring within a single attend condition, the mean interval between presentations was 65 and 66 trials (for words and pictures, respectively). For repetitions occurring between the two attend conditions, the mean interval was 299 trials (for both words and pictures). Word and picture repetitions occurred randomly across the semantic relatedness categories, $\chi^2_{\text{words}}(2) = 3.0$, $p < .25$; $\chi^2_{\text{pictures}}(2) = 1.9$, $p < .50$.

For the control condition, 60 words and 60 pictures were chosen randomly from the pool of 360 to be presented individually (i.e., not superimposed). There were no differences between control words and pictures in base-word length (5.4 vs. 5.5; $p < .80$) or frequency (24.5 vs. 29.0; $p < .62$).

Procedure

Testing took place in a sound-attenuated room. The stimuli were presented on a video monitor placed approximately 0.75 m in front of the participants. On average, pictures subtended a visual angle of 5° horizontally and 3° vertically, whereas words subtended a visual angle of 4°

horizontally and 1° vertically.¹ The words were typed in uppercase letters. In each condition, the stimuli were presented for a duration of 1400 ms. The inter-stimulus interval (offset to onset) was 3500 ms.

Participants completed a 10-item practice session, followed by the three experimental conditions. In the attend-word condition, 180 picture-word pairs were presented in a random order and the participants were instructed to attend to and name the words and ignore the pictures. In the attend-picture condition, the remaining 180 picture-word pairs were presented in a random order. Instructions required that participants attend to and name the pictures and ignore the words. Words and pictures in the control condition were presented individually in a random order and participants named each one. In all three conditions, words and pictures were named aloud after stimulus offset to avoid muscle artifact during the electroencephalogram (EEG) recordings. The attend-word and attend-picture conditions were counterbalanced and were always separated by the control condition. Prior to completing the experimental tasks, each participant gave informed consent and completed a short survey concerning current health status.

EEG Recording

The EEG was recorded using 10 mm Beckman Ag/AgCl electrodes affixed to the scalp at F_3 , F_4 , C_z , P_3 , P_4 , and O_z according to the International 10-20 system (Jasper, 1958). Each electrode was referred to a noncephalic, balanced sternovertebral site (Stephenson & Gibb, 1951). The vertical electrooculogram (EOG) was recorded from electrodes placed on the supra-

¹ There is good evidence that ERP differences between words and pictures of objects are observed even when the stimuli are equated for visual dimensions such as line thickness and total area (Ganis et al., 1996; Nigam et al., 1992; Schendan, Ganis, & Kutas, 1998). Thus, it is unlikely that any observed differences in the ERP waveforms between individually presented words and pictures will be attributable to physical stimulus differences, such as a 2° difference in size.

and infra-orbital ridges of the left eye. The horizontal EOG was recorded from electrodes placed on the outer canthus of each eye. A ground electrode was affixed to the forehead. To minimize skin potential artifacts (Picton & Hillyard, 1972), the skin was cleaned with alcohol and abraded with either a sterile needle or an abrasive scrub at each of the scalp, reference, EOG, and ground sites. Inter-electrode impedance was below 2 k Ω at scalp sites and below 10 k Ω at EOG sites.

EEG and EOG signals were amplified using Nihon Kohden EU/5D polygraph amplifiers. For each channel, the time constant was set at 2 s and the high filter at 30 Hz. The EEG was recorded continuously at a 128 Hz sampling rate for each condition. The continuous EEG was subjected to an EOG correction routine prior to signal averaging (Woestenburg, Verbaten, & Slangen, 1983). The algorithm employs correction using a regression analysis in both the time and frequency domains in an attempt to avoid overcompensation. The continuous data were subsequently reconstructed off-line to form discrete trials or sweeps. A sweep began 100 ms prior to stimulus onset and continued for the following 1000 ms. Single trials were rejected from the averaging routine when the EOG or EEG signal was saturated. An average of 2.1% of trials were rejected due to saturation or “clipping” of the amplifiers. The data were further subjected to digital filtering (without windowing) with the high filter set at 15 Hz (-3 dB setting). Trials were sorted according to condition and relatedness category to form a total of eight sets of averaged waveforms per participant (congruent, associated, and incongruent attended words and attended pictures, and individually presented words and pictures).

ERP Scoring

Grand average waveforms were used to identify latency ranges for five prominent positive and negative waves. A computer scoring routine was used to measure maximum peak

amplitude of each wave within each latency range. The latency and amplitude values were subsequently confirmed visually using manual scoring routines. P100 and N160 waves were most prominent at O_z, and amplitudes and latencies were measured at this site. P100 was identified as the maximal positive wave occurring between 50 and 150 ms, whereas N160 was identified as the maximal negative wave occurring between 100 and 200 ms. P240 was identified as the maximal positive wave occurring between 200 and 300 ms, and was most prominent at P₃, P₄, and O_z, where amplitudes and latencies were measured. N450 was identified as the maximal negative wave occurring between 350 and 550 ms. It was most prominent at F₃, F₄, and C_z, where amplitudes and latencies were measured. P390 was identified as the maximal positive wave occurring between 300 and 700 ms, and was most prominent at C_z, P₃, and P₄, where amplitudes and latencies were measured.

Results

Repeated-measures analyses of variance (ANOVAs) were conducted separately for each ERP wave using programs from STATISTICA for Windows (StatSoft, 1995). Specific questions were addressed by way of planned comparisons that isolated the effects of interest. The .05 level of confidence was applied to all statistical tests. Where necessary, multivariate significance tests, computed with Rao's R, were adopted for effects having more than one degree of freedom to protect against violations of sphericity.

Individually Presented Words and Pictures

The first question addressed in this study was whether distinct ERP waveforms would be obtained for words and pictures that were presented individually. Visual inspection of the grand average waveforms (see Figure 2.2) indicated that the ERPs to individual words and pictures

were indeed different. Overall, ERPs to words were more negative than to pictures. At anterior scalp sites, ERPs to words were characterized by a prominent frontal-central negative wave, beginning at about 300 ms and lasting until approximately 600 ms. It was most prominent at approximately 450 ms post-stimulus (N450). In contrast, ERPs to pictures were characterized by a long-lasting positive wave, beginning again at about 300 ms, that was most prominent over central-parietal sites at about 390 ms (P390). Also, ERPs to pictures displayed waves occurring approximately 240 ms post-stimulus (P240), which were positive at parietal-occipital sites and reversed polarity at frontal sites. Finally, waveforms to pictures showed a prominent occipital wave, which was positive at about 100 ms (P100) and negative at about 160 ms (N160).

Planned comparisons of the ERP waves to individually presented words and pictures were examined with Stimulus Type (words, pictures) by Electrode Site repeated-measures ANOVAs. There were no significant main effects or interactions involving Electrode Site for the following comparisons. Thus, only main effects of Stimulus Type are reported.

With respect to the anterior N450 wave, a significant main effect of Stimulus Type was observed across frontal-central sites for N450 amplitude, $F(1, 9) = 5.76$, $MSE = 25.40$, $p < .05$, with a similar trend apparent for N450 latency ($p < .10$). Compared to individually presented pictures, individual words displayed larger N450 amplitude (-3.4 vs. $-0.2 \mu V$), and somewhat shorter N450 latency (463 vs. 498 ms). Mean N450 amplitude values for all conditions and electrode sites are presented in Table 2.1.

Significant main effects of Stimulus Type were also observed across posterior sites for the amplitude of the P390, $F(1, 9) = 7.93$, $MSE = 20.44$, $p < .05$, and P240 waves, $F(1, 9) = 5.44$, $MSE = 10.71$, $p < .05$. Mean amplitude values for these waves for all conditions and

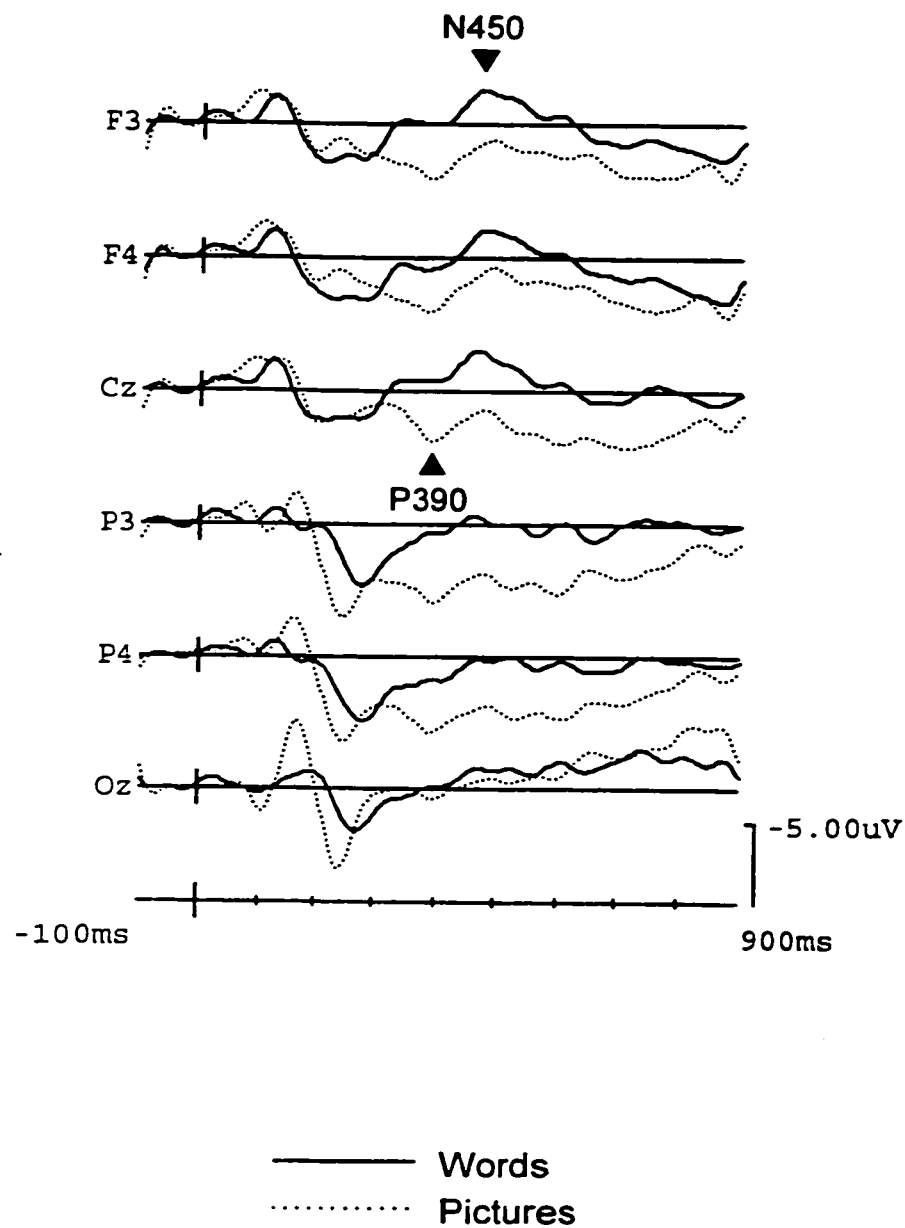


Figure 2.2 Adults' grand average ERP waveforms to individually presented words and pictures, illustrating larger amplitude negative waves at anterior electrode sites for individual words and larger amplitude positive waves at posterior electrode sites for individual pictures.

Table 2.1 Mean N450 Amplitude (μV) (SD in Parentheses) for Individually Presented and Attended Words and Pictures at Anterior Electrode Sites for Adults

Electrode	Condition			
	Individual	Congruent	Associated	Incongruent
Words				
F ₃	-3.3 (3.6)	-3.5 (4.2)	-4.5 (5.5)	-4.4 (5.1)
F ₄	-2.9 (3.6)	-3.5 (4.2)	-5.2 (6.0)	-4.3 (5.1)
C ₇	-3.9 (3.4)	-3.9 (5.0)	-4.8 (5.7)	-5.6 (5.3)
Mean	-3.4 ^a	-3.6	-4.9	-4.8
Pictures				
F ₃	-0.1 (5.4)	-2.5 (5.6)	-3.0 (6.3)	-3.1 (6.8)
F ₄	-0.4 (5.0)	-2.1 (4.9)	-2.6 (6.2)	-3.9 (5.5)
C ₂	-0.2 (5.2)	-3.8 (5.2)	-4.4 (6.1)	-5.1 (6.1)
Mean	-0.2 ^{a,b}	-2.8 ^c	-3.3	-4.0 ^{b,c}

Note. Means having the same superscript are significantly different, $p < .05$; ^c $p < .10$.

Table 2.2 Mean P390 Amplitude (μV) (SD in Parentheses) for Individually Presented Words and Pictures at Central-Parietal Electrode Sites for Adults

Electrode	Condition	
	Words	Pictures
C _z	2.2 (3.0)	5.5 (4.9)
P ₃	2.8 (2.8)	6.4 (3.2)
P ₄	3.2 (2.7)	6.2 (3.4)
Mean	2.7	6.0 ^a

Note. ^a P390 amplitude is larger for pictures than for words, $p < .05$.

Table 2.3 Mean P240 Amplitude (μV) (SD in Parentheses) for Individually Presented and Attended Words and Pictures at Posterior Electrode Sites for Adults

Electrode	Condition			
	Individual	Congruent	Associated	Incongruent
Words				
P ₃	4.0 (3.8)	4.4 (3.9)	4.2 (3.7)	4.4 (4.1)
P ₄	4.3 (3.7)	3.7 (3.1)	4.1 (3.9)	4.0 (3.3)
O _z ^b	3.2 (3.2)	5.9 (4.9)	5.4 (4.2)	5.4 (4.4)
Mean	3.8 ^a			
Pictures				
P ₃	6.3 (4.0)	3.5 (2.8)	4.0 (4.0)	3.5 (4.2)
P ₄	5.7 (3.6)	3.2 (3.2)	4.4 (3.7)	3.1 (4.4)
O _z	5.4 (4.7)	4.5 (4.7)	3.8 (4.1)	3.1 (3.4)
Mean	5.8 ^a			

^a P240 amplitude is larger for individually presented pictures than words, $p < .05$.

^b P240 amplitude is larger for attended words (collapsed) than individual words at O_z, $p < .05$.

electrode sites are presented in Tables 2.2 and 2.3, respectively. Individually presented pictures elicited larger amplitude P390 and P240 waves than did individually presented words. For words, the P390 wave appeared to be modulated by the more prominent N450 wave (see Figure 2.2). There was a main effect of Stimulus Type on P240 latency, with significantly shorter latency for individually presented pictures than words (234 vs. 254 ms) across all posterior electrode sites, $F(1, 9) = 19.78$, $MSE = 320.55$, $p < .005$. There were no effects on P390 latency.

Because the P100 and N160 waves were measured only at O_z , one-way planned comparisons of the amplitude and latency values were computed with Stimulus Type (words, pictures) as a repeated measures factor. Individually presented words and pictures did not differ in P100 amplitude or latency or N160 latency ($F_s < 1$). The difference between individually presented words and pictures for N160 amplitude that can be observed at O_z (see Figure 2.2) approached significance ($p < .13$). This tendency for N160 amplitude to be larger for individual pictures was reasonably large (effect size of .80), and approximately twice as many participants would be required to demonstrate this effect reliably.

In sum, distinct ERP waveforms were obtained for individually presented words and pictures.² Except for the early occipital waves (i.e., P100 and N160), significant differences were

² ERP repetition effects have been reliably demonstrated for words and line drawings of objects in lexical decision and matching tasks, and are manifest as a widely distributed, sustained, positive-going shift in the waveform to repeated stimuli that is observed between approximately 300 and 600 ms post-stimulus (e.g., Friedman, 1990; Nagy & Rugg, 1989; Rugg, Furda, & Lorist, 1988). In the present naming experiment there was some repetition. Depending on the order of presentation (attend-word first or attend-picture first), either 27% or 63% of the control pictures and either 20% or 28% of the control words were presented in the preceding condition. However, a comparison of the waveforms to repeated and unrepeated individual words and pictures revealed essentially identical waves, with both repeated and unrepeated pictures eliciting larger parietal positivities than repeated and unrepeated words, which elicited larger frontal-central negativities. Moreover, the differences in mean peak amplitude between individual words and pictures were similar in magnitude to effects reported previously in our lab (Campbell et al., 1987; Noldy et al., 1990) and by others (Stuss, Leech, Sarazin, & Picton, 1984). Thus,

observed between individually presented words and pictures, such that words elicited larger anterior negative waves than pictures, which elicited larger posterior positive waves than words. These findings are in accord with previous reports (e.g., Noldy et al., 1990).

Superimposed Words and Pictures

The next question addressed in this study was whether the distinct waveforms observed for individual words and pictures would be maintained when words and pictures were presented simultaneously and focus of attention was manipulated. This effect would indicate that the ERP waveforms were influenced by attentional effort independent of the complex physical stimulus array. It was also of interest to determine whether the waveforms would be differentially influenced by the semantic meaning of words and pictures. conditions that would allow for inferences about automatic and controlled processing. In an attempt to answer these questions, four points were addressed: (1) Do the ERPs to attended words differ from the ERPs to individually presented words? (2) Do the ERPs to attended pictures differ from the ERPs to individually presented pictures? (3) Do the ERPs to attended words differ from the ERPs to attended pictures? and (4) Are there effects of semantic relation on the ERPs to attended words and pictures?

The first two points were addressed separately for word and picture stimuli with planned comparisons of the amplitude and latency of each ERP wave using Condition (individual, attended - collapsed across the three relatedness categories) by Electrode Site repeated-measures ANOVAs. The third point was addressed for attended stimuli only with planned comparisons

repeated stimuli in the control condition did not alter the basic finding of distinct ERP waveforms for individual words and pictures.

using Stimulus Type (words, pictures) by Relatedness (congruent, associated, incongruent) by Electrode Site repeated-measures ANOVAs.

Effects of semantic relation for attended words and pictures, as indexed by differences in the amplitude of the N450 wave at C_z , were investigated using planned comparisons for word and picture stimuli separately, with Condition (individual, congruent, associated, incongruent) and Electrode Site as repeated measures factors. Significant main effects of Condition were followed by a priori comparisons that were of particular interest following effects reported in the behavioural literature: (a) individually presented versus incongruent stimuli (e.g., Ehri, 1976; Ehri & Wilce, 1979); (b) incongruent versus congruent stimuli (e.g., Golinkoff & Rosinski, 1976; Rosinski, 1977); and (c) incongruent versus associated stimuli (e.g., Lupker, 1979). These comparisons were made using multiple t tests for dependent samples.

Individually presented words compared to attended words. Grand-average waveforms for individually presented and attended words are shown in Figure 2.3. The waveforms illustrate that attended words exhibited early frontal-central negative waves at approximately 280 ms post-stimulus (N280), whereas individually presented words elicited positive waves at this peak latency. In contrast, both individual and attended words elicited anterior N450 waves that did not differ significantly in amplitude or latency. With respect to the P240 wave, there was a significant Condition by Electrode Site interaction, Rao $R(2, 8) = 5.97$, $p < .05$. Attended words (collapsed across relatedness categories) exhibited larger P240 amplitude than did individually presented words (5.6 vs. 3.2 μV), but only at O_z , $F(1, 9) = 6.51$, $MSE = 6.15$, $p < .05$. There were no effects on P240 latency. There were also no significant differences between individual and attended words in P100 latency and amplitude or N160 latency ($F_s < 1$). There was a trend

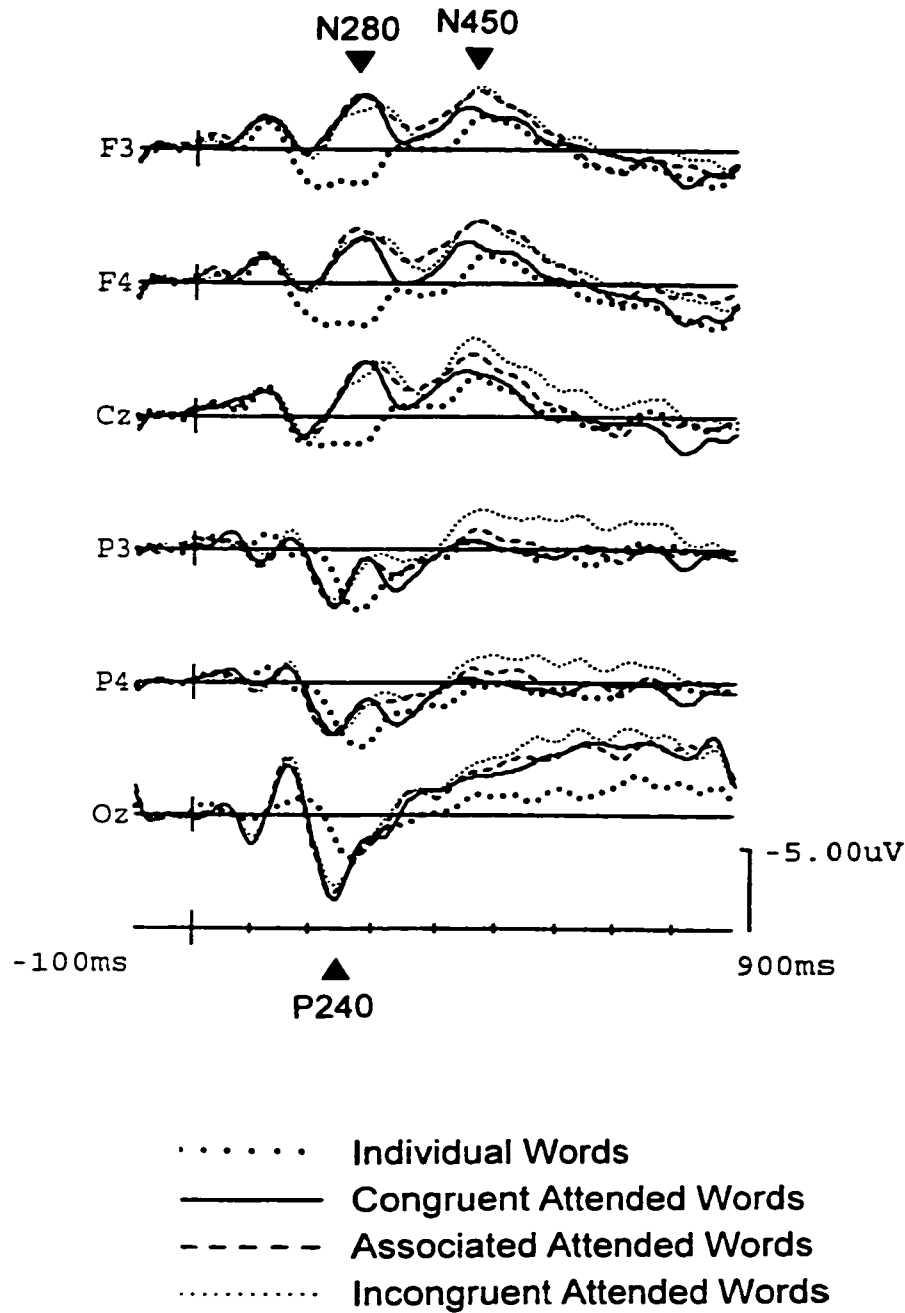


Figure 2.3 Adults' grand average ERP waveforms to individual and attended words, illustrating anterior N280 waves and larger amplitude N160 and P240 waves at the occipital electrode site for attended words compared to individual words. At longer peak latencies, no differences were observed between individual and attended words for N450 amplitude, nor were there differences in N450 amplitude between congruent, associated, and incongruent stimuli.

($p < .12$) for attended words to elicit larger N160 amplitude at the occipital site than did individual words (-4.4 vs. $-3.2 \mu V$; see Figure 2.3).

With respect to effects of semantic relation, there were no significant differences in N450 amplitude between individually presented words and attended words superimposed by congruent, associated, or incongruent pictures ($F < 1$ for main effect of Condition). That is, the presence of incongruent or associated distractor pictures did not result in significantly larger amplitude N450 waves for attended words compared to individually presented words, despite the sensitivity of this wave to violations of semantic expectancy.³ These results indicate that the level of semantic relatedness between attended words and superimposed distractor pictures did not have a differential influence during later stages of processing the attended words.

In sum, at early peak latencies, the ERPs to attended words differed from ERPs to individually presented words, in that attended words elicited larger amplitude P240 waves at the occipital site as well as a prominent frontal-central N280 wave. There was also a trend toward larger N160 waves at O_z for attended words. Thus, despite instructions to ignore superimposed pictures in this task, there was evidence of early processing of pictures in the ERP waveforms to attended words. However, at later peak latencies, the ERP waveform to individually presented words was maintained. Specifically, there was no significant difference in N450 amplitude between individually presented and attended words. Furthermore, there were no effects of semantic relation on N450 amplitude. These effects were also evident in the difference

³ Although Figure 2.3 shows that words superimposed by incongruent and associated pictures appear to have larger N450 amplitude than congruent or individually presented words, these effect sizes were small and ranged from approximately .20 to .35. More than 100 participants would be required to demonstrate effects of this size reliably with adequate power.

waveforms for attended words minus individually presented words (presented in Figure 2.4a), which illustrate the influence of the superimposed distractor pictures at early peak latencies.

Individually presented pictures compared to attended pictures. Grand-average waveforms for individual and attended pictures are shown in Figure 2.5. Overall, the ERP waveforms to attended pictures were more negative than ERPs to individually presented pictures. As shown in Figure 2.5, attended pictures displayed a frontal-central N280 wave (as did attended words) that was larger in amplitude than a negative-going wave at approximately 240 ms that was observed for individual pictures. Attended pictures (collapsed across relatedness categories) also elicited larger amplitude N450 waves than individually presented pictures (-3.4 vs. -0.2 μV); the Condition by Electrode Site interaction was significant, Rao $R(2, 8) = 15.67$, $p < .005$. Analysis of simple effects revealed that although this difference in N450 amplitude was significant at all anterior electrode sites, it was greatest at C_z . N450 latency did not differ for individually presented and attended pictures. At posterior scalp sites, attended pictures did not show the central-parietal P390 wave that was observed for pictures presented individually, thus planned comparisons were not possible. However, an attenuated P240 wave was observed for attended pictures (main effect of Condition), $F(1, 9) = 9.33$, $MSE = 10.71$, $p < .05$. There were no significant differences between attended and individual pictures for P240 latency, or for the amplitude or latency of the occipital P100 and N160 waves ($F_s < 1$).

In contrast to the findings for attended words, effects of semantic relation were observed in the ERPs to attended pictures (see the bottom panel of Table 2.1 and Figure 2.5). A significant Condition by Electrode Site interaction was obtained for N450 amplitude, Rao $R(6, 4) = 23.61$, $p < .005$. A priori comparisons showed that attended pictures that were superimposed by

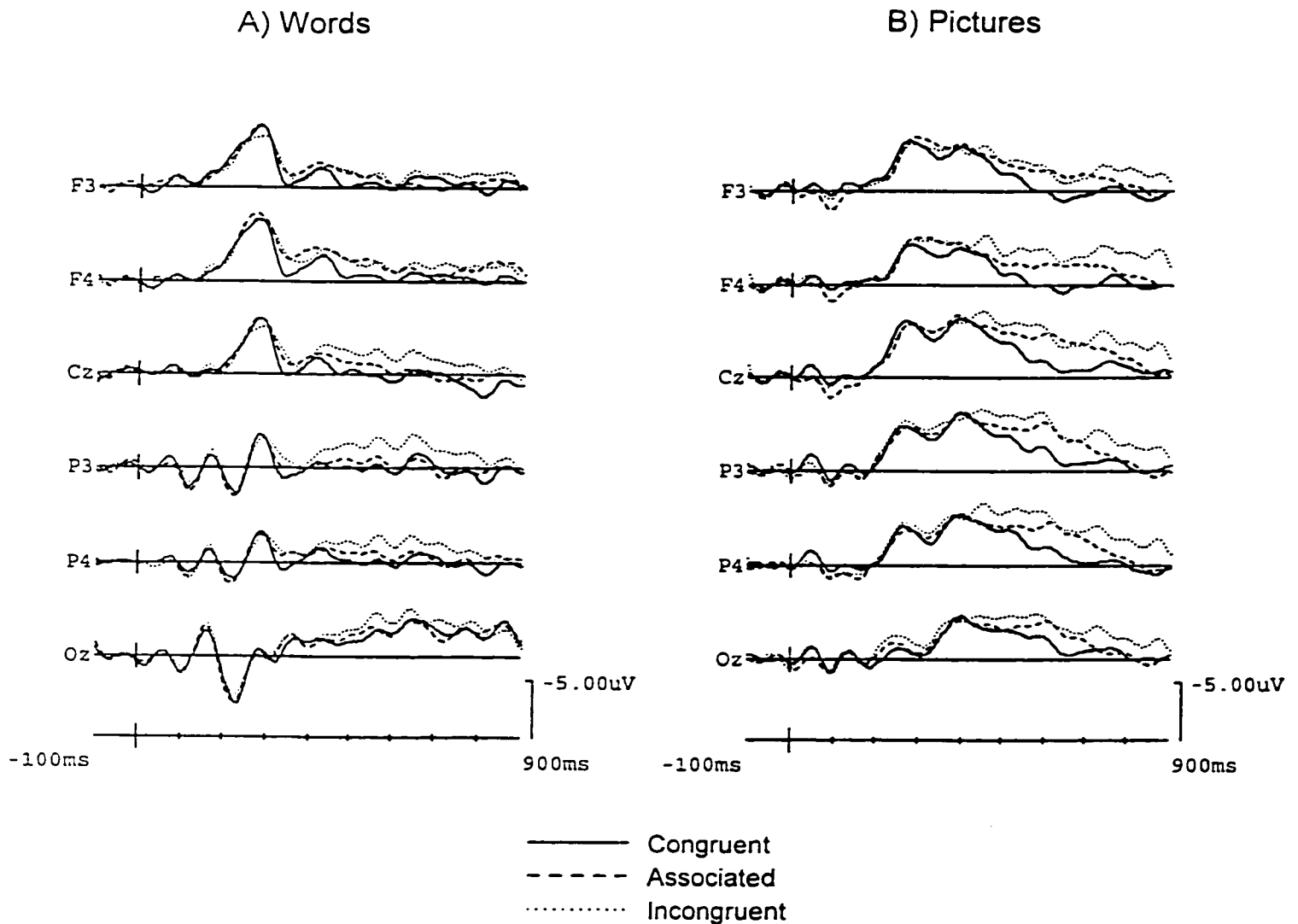


Figure 2.4 Adults' difference waveforms for attended words (Panel A) and attended pictures (Panel B), with the waveforms to individually presented words and pictures subtracted from the waveforms to congruent, associated, and incongruent stimuli. These waveforms illustrate the influence of the superimposed distractor pictures (A) and words (B). Note that the distractor words had a considerably greater influence on the later portion of the waveforms to attended pictures than the distractor pictures had on the waveforms to attended words.

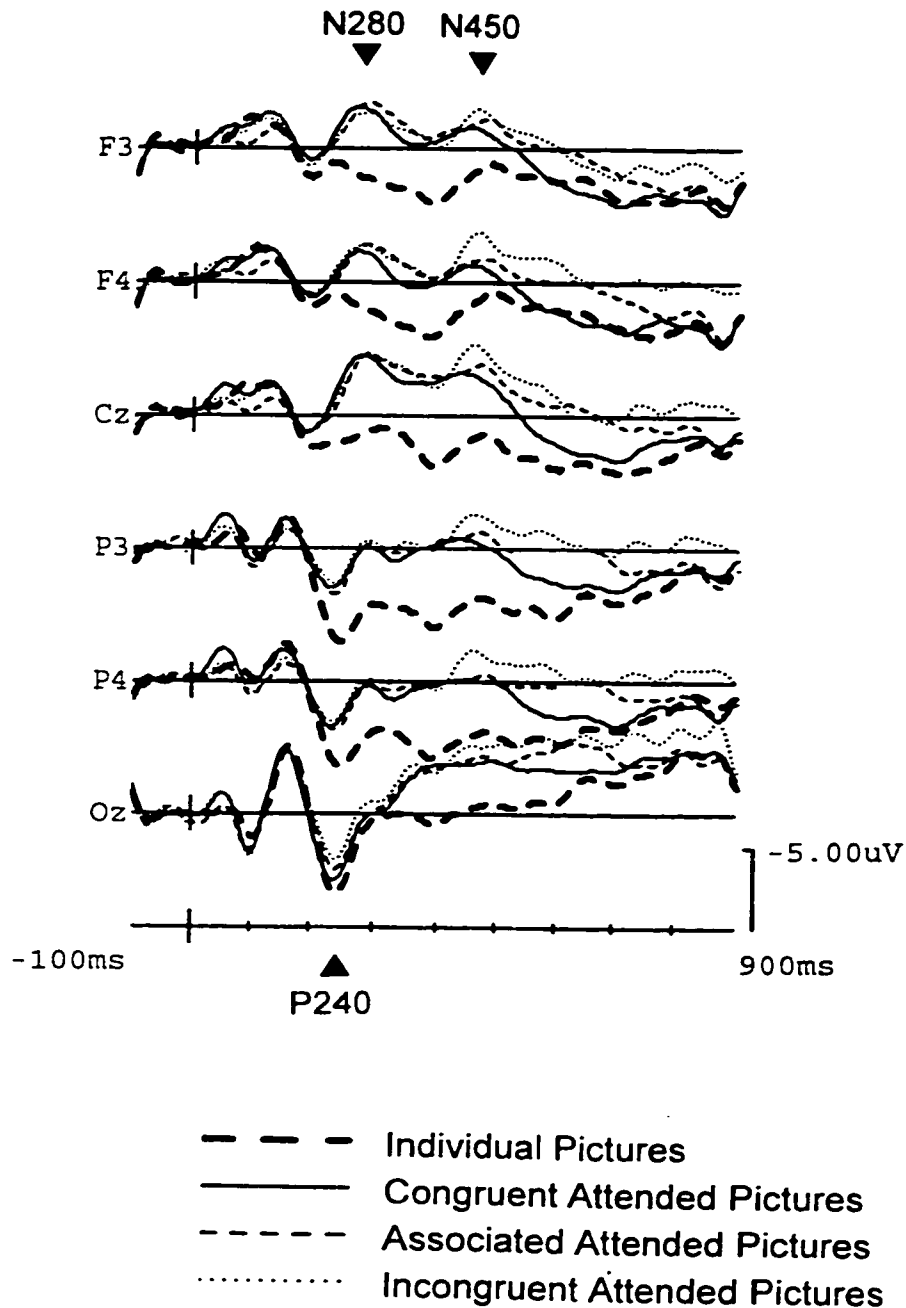


Figure 2.5 Adults' grand average ERP waveforms to individual and attended pictures, illustrating no differences at the occipital electrode site but smaller amplitude P240 waves at parietal sites for attended pictures compared to individual pictures. No P390 wave was observed for attended pictures at central or parietal electrode sites. At anterior sites, attended pictures elicited N280 waves and larger amplitude N450 waves compared to individual pictures. Larger amplitude N450 waves were observed for attended pictures superimposed by incongruent words compared to individual pictures and pictures superimposed by congruent words, but not semantically associated words.

incongruent words elicited significantly larger amplitude N450 waves at C_z than either individually presented pictures, $t(9) = 5.91$, $p < .001$ (one-tailed), or attended pictures in the congruent condition, $t(9) = 1.84$, $p < .05$ (one-tailed). No significant differences in N450 amplitude were observed between incongruent and associated picture-word pairs.

In sum, ERP waveforms to attended pictures that were presented in superimposed picture-word pairs differed from ERPs to individual pictures. These differences are also illustrated in the difference waveforms for attended pictures (minus individually presented pictures) which are presented in Figure 2.4b. Overall, attended pictures elicited larger amplitude negative waves than pictures presented individually, except at the occipital site where early waves (i.e., P100, N160, and P240 waves) did not differ between conditions. Anterior ERP waves to attended pictures resembled the waves to attended words, at both early and later portions of the waveform, including the presence of a frontal-central N280 wave that was not observed when pictures were presented individually. Furthermore, effects of semantic relation were observed such that N450 amplitude was larger for attended pictures superimposed by incongruent words as compared to congruent words or individually presented pictures.

Attended words compared to attended pictures. Examination of the grand averages to attended words and pictures as a function of semantic relatedness indicated that distinct ERP waveforms for words and pictures were largely maintained despite their simultaneous presentation. Moreover, the difference waveforms (Figure 2.4) indicate clearly that the superimposed distractor words had a greater influence on the ERPs to attended pictures than did distractor pictures on the ERPs to attended words, particularly at later peak latencies. Figure 2.6 illustrates that ERP waves to attended words were more negative than to attended pictures at

frontal electrode sites. There was a significant Stimulus Type (words, pictures) by Relatedness (congruent, associated, incongruent) by Electrode Site (F_3 , F_4) interaction, Rao $R(2, 8) = 8.85$, $p < .01$. Simple effects analyses showed that differences in N450 amplitude between attended words and pictures reached significance only for associated picture-word pairs, $F(1, 9) = 13.75$, $MSE = 3.24$, $p < .005$. There were no significant stimulus type differences for congruent or incongruent stimuli pairs; however, the differences were in the expected direction,⁴ and the main effect of Stimulus Type approached significance ($p < .13$).

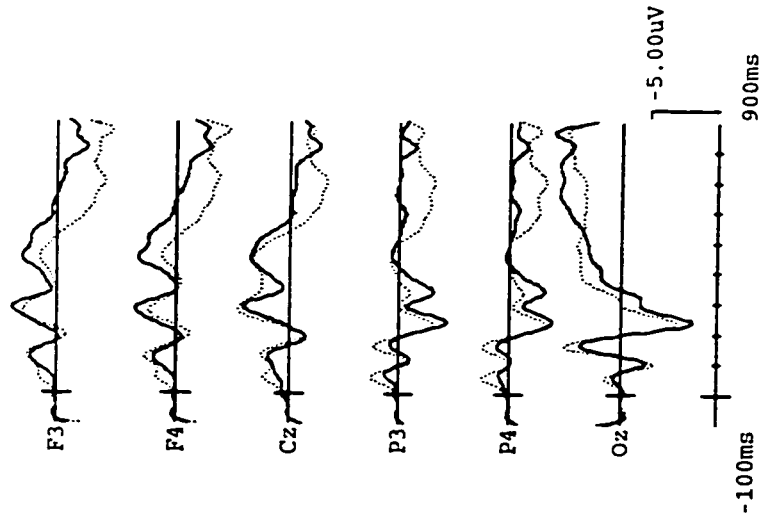
Across posterior electrode sites, attended words displayed larger amplitude P240 waves than attended pictures, but this effect interacted with Electrode Site, Rao $R(2, 8) = 4.30$, $p < .05$, such that the difference (collapsed across relatedness categories) was significant only at O_z , $F(1, 9) = 11.37$, $MSE = 3.84$, $p < .01$. There was a marginal Stimulus Type by Electrode interaction for P240 latency ($p < .06$), such that latency was shorter for attended pictures (collapsed across relatedness categories) as compared to attended words at P_3 , $F(1, 9) = 6.74$, $MSE = 257.86$, $p < .05$. No stimulus type differences were observed for the amplitude or latency of the P100 or N160 waves ($F_s < 1.77$).

In sum, although ERP waves to attended words and pictures in superimposed picture-word pairs differed from ERP waves to individually presented words and pictures, distinct frontal waves were observed for attended words and pictures that were paired with an associative distractor stimulus. A similar trend was observed for congruent and incongruent picture-word pairs. Somewhat shorter latency P240 waves to pictures than words were also maintained for

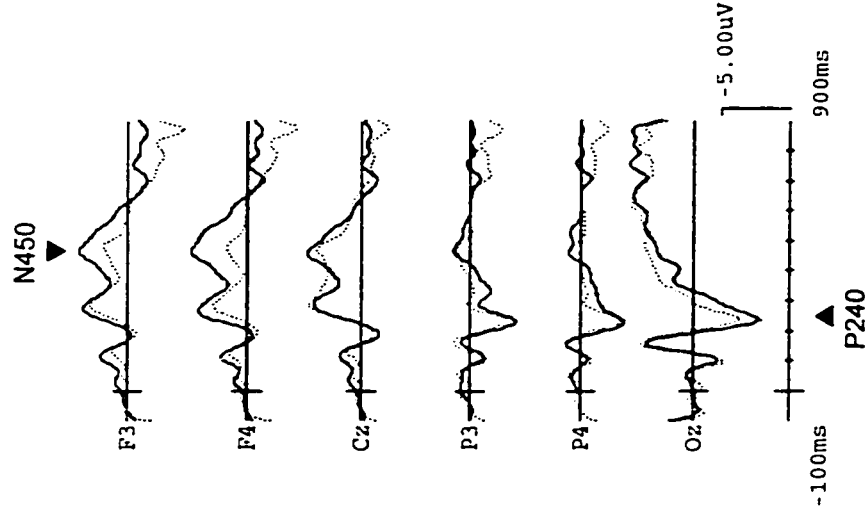
⁴ Although the design may have had insufficient power to detect significant differences for such small effects (.20 - .30), a sample of over 125 would be required to demonstrate these effects reliably.

Figure 2.6 Adults' grand average ERP waveforms to attended words and pictures in congruent, semantically associated, and incongruent picture-word pairs (Panels A, B, and C, respectively), illustrating that attended words exhibited larger amplitude anterior N450 waves and larger amplitude occipital P240 waves than did attended pictures.

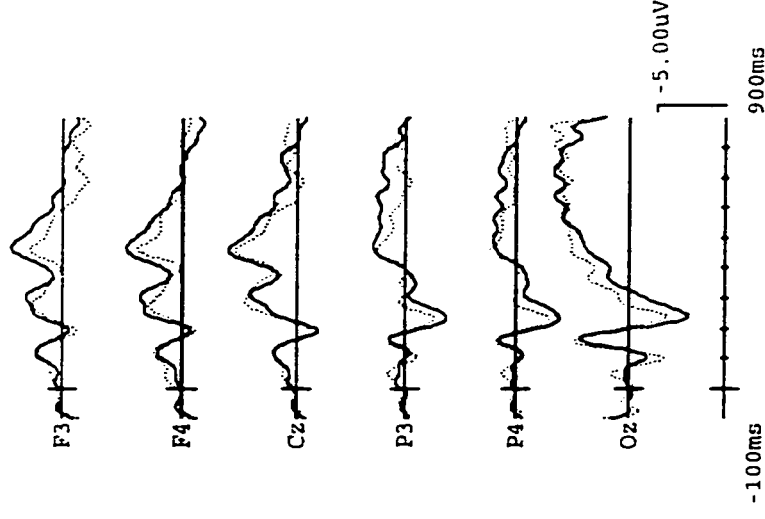
A) Congruent



B) Associated



C) Incongruent



— Words
 Pictures

superimposed images, however larger amplitude P240 waves were observed occipitally for attended words instead of attended pictures.

Discussion

In this study, distinct ERP waveforms were obtained for individually presented words and pictures. Overall, words exhibited larger amplitude N450 waves than did pictures over anterior scalp sites. In contrast, pictures exhibited larger positive waves over posterior scalp sites than did words. Parietal P240 waves had larger amplitude and shorter latency for pictures than words. Similarly, P390 amplitude was larger for pictures than words at central-parietal sites. These findings affirm previous observations in the ERP literature (Campbell et al., 1987; Kok & Roozakkers, 1986; Nigam et al., 1992; Noldy-Cullum & Stelmack, 1987; Noldy et al., 1990), and are consistent with the large behavioural literature demonstrating the independent processing of words and pictures (e.g., Potter & Faulconer, 1975; Smith & Magee, 1980).

When attending to words or pictures that were presented in superimposed images, differences were observed in the ERP waveforms to attended words and pictures as compared to the ERPs to individually presented words and pictures. Prominent anterior negative waves occurring at approximately 280 ms were evident in the ERPs to words and pictures in the attend conditions, but not to individually presented stimuli. For attended words, it is unlikely that this N280 wave represents the influence of the spatial complexity of the distractor pictures, because the N280 wave was not elicited by individually presented pictures. If the N280 wave was determined by the complexity of pictures, one would expect to see comparable N280 waves to pictures in both individual and attend conditions. Furthermore, one cannot argue that the

enhanced N280 wave to attended pictures reflects the influence of the spatial features of the distractor words if words are processed automatically (Shiffrin & Schneider, 1977).

A number of N2 components in the latency range of the N280 wave have been studied (see Pritchard, Shappell, & Brandt, 1991 for a review) that can account for the emergence of anterior N280 waves to words and pictures attended in superimposed stimulus pairs. N2 waves thought to reflect the discrimination and identification of relevant stimulus dimensions are sensitive to attentional task-requirements (Hillyard, Mangun, Woldorff, & Luck, 1995; Mangun & Hillyard, 1987). This family of negative components is associated with stimulus classification (Gaillard & Verduin, 1984; Heinze, Luck, Mangun, & Hillyard, 1990; Luck, Heinze, Mangun, & Hillyard, 1990; Luck & Hillyard, 1994a; Pritchard et al., 1991; Ritter, Vaughan, & Simson, 1983) as well as further processing of relevant stimuli (Rugg, Milner, Lines, & Phalp, 1987), particularly with respect to stimulus features other than spatial location (Hillyard & Münte, 1984; Mangun & Hillyard, 1987).

Although often observed at posterior scalp sites, several N2 waves have been reported at frontal-central sites that correspond with the N280 wave observed in this study. Both Rugg and colleagues (1987) and Mangun and Hillyard (1987) observed anterior N2 waves at longer latencies (i.e., 200 to 400 ms) that were larger to attended compared to unattended stimuli. These components were associated with continued discriminative processing of task-relevant stimuli. In this study, only words and pictures attended in superimposed stimulus pairs elicited the N280 wave. Neither words nor pictures presented individually elicited such a negative component. According to this view, further processing was required to discriminate the task-relevant stimulus

(word or picture) from the spatially complex superimposed array, resulting in the emergence of an N280 (N2) wave.

Recently, Luck and Hillyard (1994b; Luck, 1995) reported a negative ERP wave in the latency range of 200 to 300 ms (i.e., N2pc) that was observed during the detection of target stimuli that were embedded amongst nontarget distractor stimuli. The N2pc wave is thought to reflect an attentional filtering process, whereby a target is selected for subsequent identification while information from unattended distractors is suppressed. Functionally, the N2pc wave resembles what would be expected in this study based on the task demands in the attend conditions. Namely, target words and pictures must be detected and later identified while the distracting stimuli are ignored. Thus, the N280 wave maps onto the N2pc wave from a functional point of view. However, in this study, N280 effects were observed only at frontal-central sites, whereas the N2pc has only been observed at posterior sites and is thought to reflect a filtering mechanism in the occipital cortex (Luck & Hillyard, 1994b).

A salient finding in this study was that distinct ERP waveforms were observed for attended words and pictures even though the stimulus array was the same. Specifically, frontal N450 waves elicited by attended words were larger than those elicited by attended pictures. This effect was observed across all levels of semantic relatedness but was statistically significant only for picture-word pairs that shared an associative meaning. Shorter latency P240 waves were maintained for attended pictures compared to attended words at the left parietal site. Interestingly, P240 amplitude at the occipital site was larger for attended words than attended pictures. This effect was opposite to that found for individually presented stimuli (i.e., larger P240 amplitude to pictures than words). Given that the stimulus array was the same in the two

conditions, the larger amplitude P240 wave observed for attended words can be attributed to the greater resources required to process the words against the distracting picture background.

The results observed in the superimposed conditions illustrate that distinct ERPs to words and pictures were maintained when only attentional focus was manipulated. Thus, the independent processing of words and pictures that is manifest in recognition memory, naming, and categorization is also manifest in attention. Moreover, there are notable differences between individual and attended stimuli that address the role of attention in the processing of words and pictures.

Attending Words

Compared to individually presented words, words that were attended in superimposed picture-word pairs exhibited larger amplitudes for the early peak latency waves but no differences in amplitude for the longer peak latency waves. Specifically, attended words showed larger amplitude P240 waves, and a trend for larger N160 waves, at the occipital site than individually presented words. In fact, at this scalp site, waveforms to attended words closely resembled the waveforms to pictures (both individual and attended). Attended words also showed larger anterior negativities in the latency range of 200 to 300 ms (i.e., N280 wave) that were not observed for individual words. In contrast, no differences were observed in the latency or amplitude of anterior N450 waves for individual versus attended words. Moreover, there was no evidence that N450 amplitude varied as a function of the semantic relationship between attended words and distractor pictures.

Thus, in comparison to the individually presented words, attending to words in the presence of superimposed distractor pictures had an effect on early latency ERP waves.

However, no differences were observed for longer peak latency waves. Because there were no differences between congruent, associated, or incongruent picture-word pairs, the differences between the individual and attended words cannot be attributed to differences in the semantic processing of the distractor pictures. This effect is consistent with the view that picture-processing requires controlled attentional resources. These findings are also consistent with the view that the semantic meaning of pictures can be inhibited after initial encoding (Babbitt, 1982; Driver & Tipper, 1989; McCauley, Parmelee, Sperber, & Carr, 1980; Tipper & Driver, 1988; Yee, 1991).

Attending Pictures

Whereas ERP waves to attended words exhibited larger amplitude than individual words at posterior sites for the early peaks (i.e., P240) but no differences at anterior sites for the later peaks (i.e., N450), the comparison of ERP waveforms between individual and attended pictures exhibited the opposite pattern. Specifically, no differences were observed between individual and attended pictures over the occipital scalp for the early peaks P100, N160, or P240. However, attended pictures exhibited attenuated P240 waves at posterior sites compared to individually presented pictures. Furthermore, the long lasting positive wave between 250 and 400 ms (P390) elicited by individual pictures was not evident in the waveforms to attended pictures. Rather, as with the attended words, an anterior N280 wave was observed in this latency range.

Notably, the ERP waves to attended pictures exhibited larger amplitude than individual pictures at anterior sites for the later peaks (i.e., N450). In this respect, the ERP waveforms to attended pictures more closely resembled ERPs to words (both individual and attended) than they resembled the waveforms to individual pictures. This finding suggests that the processing of

attended pictures was influenced by the distractor words, despite instructions to ignore words. That is, the distractor words were processed automatically. Evidence for this view is seen in the effects of semantic relation on the amplitude of the N450 wave. Specifically, N450 amplitude was larger for attended pictures when the distractor words were incongruent than when they were congruent or when pictures were presented in isolation. No differences in N450 amplitude were observed between the incongruent and associated conditions, consistent with reports in the behavioural literature that associated and incongruent distractors produce similar amounts of semantic interference (Lupker, 1979).

Summary and Conclusions

In this study, as in previous research, distinct ERPs were obtained during a naming task for individually presented words and pictures. The interactive effects of attention and semantic relation on ERP waves were subsequently examined during a naming task in which the physical stimulus array was the same across conditions. Distinct waveforms were observed for words and pictures attended in superimposed picture-word pairs, an effect that can be attributed to the independent deployment of attentional resources. Thus, the independent processing of words and pictures that is manifest in naming, categorization, and recognition memory is also manifest in attention.

At early portions of the ERP waveform, anterior N280 waves were observed only for words and pictures in the superimposed conditions, not for words and pictures presented individually. The fact that there were no differences between attended words and attended pictures indicates that this negative component must reflect a process common to both conditions. Such a process would be required when identifying one stimulus while ignoring a

distracting stimulus, but not when identifying a stimulus that is presented in isolation. Thus, the N280 wave observed in the current study can be attributed to the process of extracting task-relevant information from a spatially complex stimulus. This process likely occurs prior to identification of semantic information, however, as N280 waves were not sensitive to the semantic relationship between the superimposed words and pictures.

At later portions of the ERP waveform, attended words exhibited larger anterior N450 waves compared to attended pictures. This effect was the same as that observed for individually presented words and pictures, namely that words exhibited larger negative waves than pictures. However, the distinct ERP waveforms observed for attended words and pictures cannot be attributed to differences in the physical characteristics of the stimuli between conditions, as superimposed picture-word stimuli were presented in both tasks. Rather, the distinct waveforms for attended words and pictures manifest the effects of attention, independent of the physical stimulus array.

The endogenous nature of ERP waves, that is characteristics of the waveform that are largely influenced by intrinsic activity of the individual, have been illustrated in several paradigms, including attending to stimuli in one ear and ignoring the other, attending to rare or omitted stimuli, and responding to signal stimuli (Duncan-Johnson & Donchin, 1977; Hillyard, Hink, Schwent, & Picton, 1973; Sutton, Braren, Zubin, & John, 1965; Sutton, Tueting, Zubin, & John, 1967). It is interesting to note, however, that these demonstrations all involve a stimulus change to elicit the effect, whereas in this study, the stimulus remains constant. The changes in the ERP waveform that are contingent on the shift of attention to name the word or to name the

picture are determined solely by the intrinsic activity of the individual and in the absence of stimulus change.

The pattern of results regarding the effects of semantic relation can be understood in terms of the distinction between automatic and controlled processing of words and pictures (LaBerge & Samuels, 1974; Shiffrin & Schneider, 1977). The presence of distractor pictures had no significant effect on N450 amplitude or latency to attended words compared to individually presented words. Moreover, there were no effects of semantic relation on the amplitude of the N450 wave for attended words. Thus, the processing of pictures is said to be controlled because the meaning of the distractor pictures was not processed when attending words. In contrast, the presence of distractor words influenced the ERP waveforms to pictures, resulting in prominent anterior N450 waves to attended pictures instead of the posterior positive waves observed for individual pictures. Furthermore, the meaning of the distractor words differentially influenced the amplitude of N450 waves to attended pictures, such that larger negativities were observed in the incongruent condition. Taken together, these results indicate that despite instructions to ignore words, they were automatically processed at a semantic level.

In conclusion, these findings using ERP recording techniques complement the behavioural literature by providing a discrete manifestation of the independent processing of words and pictures, rather than the indirect inferences that are made on the basis of behavioural measures, such as reaction time. In addition, this work integrates ERPs to superimposed picture-word stimuli with the previous ERP literature to individual words and pictures. More important, however, this work demonstrates the independent effects of attention on ERP waveforms to superimposed words and pictures. Furthermore, the independent effects of semantic relation for

attended words and pictures support the distinction between automatic processing for words and controlled processing for pictures. The differences observed in the ERPs to superimposed stimuli when attending either words or pictures cannot be attributed to differences in spatial complexity. That distinct ERP waveforms were obtained when the same physical array was presented underscores the distinct attentional processing that this task demanded, and illustrates clearly the endogenous nature of these late ERP components.

CHAPTER 3

Study 2

Event-Related Potentials and Picture-Word Naming:

Effects of Attention and Semantic Relation for Children and Adults

Introduction

Adults are remarkably adept at focusing their attention to task-relevant stimuli in the presence of distracting information. This effect has been demonstrated in the auditory and visual modalities using both behavioural (Cherry, 1953; Neisser & Becklen, 1975) and electrophysiological indices (Hillyard, Hink, Schwent, & Picton, 1973; Luck & Hillyard, 1994b; Näätänen, Gaillard, & Mäntysalo, 1978). Recent research with adults in our laboratory (Greenham, Stelmack, & Campbell, 1999) demonstrated that the distinct event-related potentials (ERPs) that were obtained for individually presented words and pictures were maintained when words and pictures were presented in superimposed picture-word pairs where only the focus of attention was manipulated. In this study, adults were asked to attend to and name the words in one condition, and to attend to and name the pictures in another condition. Physically, the picture-word stimuli were identical in both conditions. Attending to the task-relevant stimulus (word or picture) in the superimposed array resulted in distinct waveforms for words and pictures. This effect indicated the independent processing of words and pictures due to endogenous attentional processes rather than exogenous stimulus characteristics.

In addition, the superimposed picture-word pairs were either congruent in meaning, semantically associated, or incongruent. An effect of semantic relation was observed when attending to superimposed pictures, but not when attending to superimposed words. That is, the extent to which the picture-word pairs were semantically related had a differential effect on the amplitude of an anterior negative ERP wave (N450). These semantic effects were consistent with the view that the distractor words were processed automatically, whereas processing of the

distractor pictures was under attentional control (Noldy, Stelmack, & Campbell, 1990; Shiffrin & Schneider, 1977). In the current research, we compared the ERP results obtained previously for adults with those obtained for a group of school-age children to investigate whether these effects of attentional demand and semantic relation were evident for children in their ERPs to superimposed words and pictures.

Adults exhibit distinct ERPs to words and pictures across a variety of naming, categorization, and recognition memory tasks, with pictures typically eliciting larger amplitude positive (or less negative) waves than words (Campbell, Karam, & Noldy-Cullum, 1987; Greenham et al., 1999; Kok & Rooyakkers, 1986; Nigam, Hoffman, & Simons, 1992; Noldy et al., 1990). These effects converge with considerable behavioural evidence, largely based on response time data, that words and pictures are processed independently (e.g., Glaser, 1992; Potter & Faulconer, 1975; Seifert, 1995; Smith & Magee, 1980). Furthermore, for adults, these distinct ERPs to words and pictures are subject to independent attentional processing (Greenham et al., 1999). However, at the present time, it is not clear whether children will manifest similar effects of attention on word and picture processing.

An increased negative ERP wave at about 400 ms (N400) is observed when semantic information is processed that is incongruent with semantic expectancy (Connolly, Byrne, & Dywan, 1995; Ganis, Kutas, & Sereno, 1996; Gunter, Jackson, Kutas, Mulder, & Buijink, 1994; Kutas & Iragui, 1998; Kutas & van Petten, 1988; McPherson & Holcomb, 1999; Neville, Kutas, Chesney, & Schmidt, 1986; Rugg, 1985; Stuss, Picton, & Cerri, 1986; Stuss, Sarazin, Leech, & Picton, 1983). For example, words at the end of sentences that are incongruent with the meaning of the preceding words elicit a large N400 wave (Kutas & Hillyard, 1980). Similarly, N400

amplitude increases as the degree of semantic relationship between two pictures decreases in a picture-matching task (Friedman, Putnam, Ritter, Hamberger, & Berman, 1992; Friedman, Sutton, Putnam, Brown, & Erlenmeyer-Kimling, 1988). In the paradigm in which words and pictures were superimposed, the presence of incongruent distractor pictures had no differential effect on N450 amplitude to attended words (Greenham et al., 1999). In contrast, incongruent distractor words elicited larger N450 waves to attended pictures compared to pictures presented individually or with congruent distractor words. That is, a semantic incongruity effect was observed for the distractor words despite instructions to ignore them. Whether similar effects of semantic relation will be observed in this paradigm for children has not been investigated using ERPs.

Compared to adults, children are more susceptible to interference by irrelevant information on tasks of selective attention (Cooley & Morris, 1990; Lane & Pearson, 1982; Plude, Enns, & Brodeur, 1994). For example, this effect is manifest in greater interference for children than adults on Stroop colour-word (Comalli, Wapner, & Werner, 1962; MacLeod, 1991) and picture-word interference tasks (Ehri, 1976; Guttentag & Haith, 1978; Rosinski, 1977; Rosinski, Golinkoff, & Kukish, 1975). The poorer performance of children on tasks of selective attention is often attributed to a decreased ability to ignore or inhibit distracting information (Harnishfeger, 1995; Tipper, Bourque, Anderson, & Brehaut, 1989). The ability to attend selectively to task-relevant stimuli continues to develop into adolescence and becomes more efficient with age (Kaye & Ruskin, 1990; Tipper & McLaren, 1990). Age-related improvements in selective attention are understood in terms of increasing strategic control over attentional processes into adulthood, including both the active facilitation of information that is task-relevant

and the active inhibition of information that is task-irrelevant (Enns, 1990; Harnishfeger, 1995; Plude et al., 1994). Such improvements may be linked to maturation of the frontal lobes (Bjorklund & Harnishfeger, 1995; Dempster, 1992), which reach maturity during adolescence (Kolb & Whishaw, 1996; Stuss, 1992), and which are thought to be involved in selective attention and inhibitory control (Foster, Eskes, & Stuss, 1994).

Differences in ERP waves that are observed between children and adults to words, pictures, and other visual stimuli may reflect differences in the development of attentional processes. Compared to adults, who exhibit distinct waveforms to words and pictures, children exhibit prominent anterior negative ERP waves to a variety of stimuli across a number of experimental tasks (Berman & Friedman, 1993; Berman, Friedman, & Cramer, 1990; Courchesne, 1977, 1978; Friedman et al., 1988; Kok & Rooijakkers, 1985; Licht, Bakker, Kok, & Bouma, 1992; Neville, 1977; Robertson, Mahesan, & Campbell, 1990; Symmes & Eisengart, 1971; Taylor, 1988; van der Stelt, Kok, Smulders, Snel, & Gunning, 1998). For example, Kok and Rooijakkers (1985) observed prominent temporal N500 waves for 5 and 6 year old children that were similar in word reading and picture recognition tasks. In contrast, adults exhibited parietal P340 waves rather than N500 waves. Using lexical-decision and object-decision tasks, Robertson et al. (1990) reported larger fronto-central N400 waves for 8 to 11 year old children compared to adolescents and adults. In children, N400 waves were larger for objects (pictures) than words. Similarly, Berman et al. (1990; Berman & Friedman, 1993) reported frontal N350 waves for 7 to 10 year old children in a recognition memory task for words and pictures, which were larger in amplitude as compared to adolescents and adults. Furthermore, N350 amplitude was larger for pictures than words, but only for the children. No such differences were observed

for the older participants. The functional significance of these negative waves is poorly understood, although they have been observed consistently in children.

In the present study, words and pictures were presented both individually (control condition) and in superimposed pairs (attended words and pictures). From the previous ERP research cited, it was expected that the children would exhibit large anterior negative waves to both individual words and pictures, and that pictures would elicit larger amplitude negative waves than words (Berman et al., 1990; Robertson et al., 1990). In contrast, adults have exhibited distinct waves to individual words and pictures, such that pictures were more positive over posterior electrode sites and less negative over anterior electrode sites than words. When adults attended to words or pictures presented in superimposed stimulus arrays, distinct waveforms were maintained for each stimulus type. That is, attended words continued to elicit larger anterior negative waves than attended pictures, even though the stimulus arrays were physically identical. Further, for adults, it appeared that the semantic meaning of the distractor words was processed automatically, whereas there was no evidence for semantic processing of the distractor pictures. Although there is considerable evidence that children are less able than adults to attend selectively (Plude et al., 1994), it has also been demonstrated in the behavioural literature that children process the semantic meaning of distractor words automatically during picture-word interference tasks and that this interference effect is stable into adulthood (Rosinski, 1977; Rosinski et al., 1975). Thus, it is unclear at this time whether the children will manifest effects of attention and semantic relation on the ERP waves.

Method

Participants

Ten adults (5 men, 5 women) from the university community, aged 21 to 42 years ($M = 29.7$ yrs, $SD = 7.8$ yrs), and nine children⁵ (5 male, 4 female), aged 9 to 13 years ($M = 10.9$ yrs, $SD = 1.4$ yrs) volunteered to participate in this study. All of the children met the following criteria: (a) at least average intelligence ($IQ > 90$; $M_{FSIQ} = 111.6$, $SD = 16.7$) as determined by estimating Full Scale IQ (Sattler, 1992) from performance on the Information, Vocabulary, Similarities, and Block Design subtests of the Wechsler Intelligence Scale for Children - Third Edition (WISC-III; Wechsler, 1991); (b) at least average academic achievement (standard scores ≥ 89) as determined by performance on the Reading ($M_R = 111$, $SD = 9.5$), Spelling ($M_S = 107$, $SD = 11.0$), and Arithmetic ($M_A = 106$, $SD = 10.5$) subtests of the Wide Range Achievement Test - 3 (Wilkinson, 1993); (c) no history of psychiatric or neurological disorder, including head injury or loss of consciousness; (d) no visual or auditory deficits; and (e) no current medication use. For one male child, the WISC-III Full Scale IQ was estimated from only the Similarities and Block Design subtests because he was not available when the remaining subtests were administered. All adults and children were right-handed, fluent in English, and had normal or corrected-to-normal vision.

Stimulus Materials

The pictures used in this study were black-and-white line drawings of concrete objects taken from Pictures, Please!, a manual used in speech therapy (Abbate & LaChappelle, 1984).

⁵ The initial sample of children was comprised of five males and five females, aged 9 to 13 years ($M = 10.8$, $SD = 1.3$). The data from one female child was excluded from all grand average waveforms and statistical analyses because of a disproportionate number (47%) of rejected trials.

The pictures were scanned for presentation on a computer monitor. The 360 superimposed picture-word stimuli were formed by pairing each picture with a word that was either congruent (i.e., same denotative meaning), semantically associated, or incongruent (i.e., not related) with the picture meaning (see Figure 2.1). The congruent name of each picture was initially determined using a sample of 120 undergraduate students. They were asked to provide the first name that “came to mind” when the pictures were presented on a classroom screen. For each picture used in this study, there was at least 80% agreement on this name.

The superimposed stimuli were randomly divided into two separate lists of 180 trials each with equal numbers ($n = 60$) of congruent, associated, and incongruent picture-word pairs to form the attend-word and attend-picture conditions. The attended words and pictures were matched approximately for length and frequency of the base-words. Out of the 360 superimposed picture-word trials, 20 (5.6%) pictures and 18 (5.0%) words appeared twice. For repetitions occurring within a single attend condition, the mean interval between presentations was 65 and 66 trials (for words and pictures, respectively). For repetitions occurring between the two attend conditions, the mean interval was 299 trials (for both words and pictures). Word and picture repetitions occurred randomly across the semantic relatedness categories.

For the control condition, 60 words and 60 pictures were chosen randomly from the pool of 360 to be presented individually (i.e., not superimposed). There were no differences between control words and pictures in base-word length (5.4 vs. 5.5) or frequency (24.5 vs. 29.0). A proportion of the control words (20% or 28% depending on the order of conditions) and pictures (27% or 63%) were repetitions from the previous attend condition. The mean interval between presentations was 189 and 145 trials (for control words and pictures, respectively).

Procedure

The ERP recordings took place in a sound-attenuated room. The stimuli were presented on a video monitor placed approximately 0.75 m in front of the participants. On average, pictures subtended a visual angle of 5° horizontally and 3° vertically, whereas words subtended a visual angle of 4° horizontally and 1° vertically. The words were typed in uppercase letters. In each condition, the stimuli were presented for a duration of 1400 ms. The inter-stimulus interval (offset to onset) was 3500 ms.

Participants completed a 10-item practice session, followed by the three experimental conditions. In the attend-word condition, 180 picture-word pairs were presented in a random order and the participants were instructed to attend to and name the words and ignore the pictures. In the attend-picture condition, the remaining 180 picture-word pairs were presented in a random order. Instructions required that participants attend to and name the pictures and ignore the words. Words and pictures in the control condition were presented individually in a random order and participants named each one. In all three conditions, words and pictures were named aloud after stimulus offset to avoid muscle artifact during the electroencephalogram (EEG) recordings. Participants were also instructed to avoid blinking or moving the head as much as possible while the stimuli were displayed on the monitor. The order of presentation of the attend-word and attend-picture conditions was counterbalanced, and these two conditions were always separated by the control condition.

Prior to completing the experimental tasks, adults as well as parents of the children gave informed consent and completed a short survey concerning either their or their child's current health status. Children also gave their verbal consent and completed the WISC-III Similarities

and Block Design subtests and the WRAT-3. Several months following the EEG recordings, all but one of the children completed the WISC-III Information and Vocabulary subtests, as well as a speeded naming task in which they were asked to name lists of 48 words and 48 pictures (printed in columns on single sheets of paper) as quickly and accurately as possible (see Appendix). Errors and list naming time (in seconds) were recorded. Adults did not complete the list naming task.

EEG Recording

The EEG was recorded using 10 mm Beckman Ag/AgCl electrodes affixed to the scalp at F_3 , F_4 , C_z , P_3 , P_4 , and O_z according to the International 10-20 system (Jasper, 1958). Each electrode was referred to a noncephalic, balanced sternovertebral site (Stephenson & Gibb, 1951). The vertical electrooculogram (EOG) was recorded from electrodes placed on the supra- and infra-orbital ridges of the left eye. The horizontal EOG was recorded from electrodes placed on the outer canthus of each eye. A ground electrode was affixed to the forehead. To minimize skin potential artifacts, the skin was cleaned with alcohol and abraded with either a sterile needle or an abrasive scrub at each of the scalp, reference, EOG, and ground sites. Inter-electrode impedance was below 2 k Ω at scalp sites and below 10 k Ω at EOG sites.

EEG and EOG signals were amplified using Nihon Kohden EU/5D polygraph amplifiers. For each channel, the time constant was set at 2 s and the high filter at 30 Hz. The EEG was recorded continuously at a 256 Hz sampling rate for each condition. The continuous EEG was subjected to an EOG correction routine prior to signal averaging (Woestenburg, Verbaten, & Slangen, 1983). The algorithm employs correction using a regression analysis in both the time and frequency domains in an attempt to avoid overcompensation. The continuous data were

subsequently reconstructed off-line to form discrete trials or sweeps. A sweep began 100 ms prior to stimulus onset and continued for the following 1000 ms. Single trials were rejected from the averaging routine when the EOG or EEG signal was saturated. On average, the number of rejected trials was very low, and there were significantly fewer rejected trials per condition for adults (2.1%) than children (8.7%), $F(1, 17) = 6.39$, $p < .05$. The data were further subjected to digital filtering (without windowing) with the high filter set at 15 Hz (-3 dB setting). Trials were sorted according to condition and relatedness category to form a total of eight sets of averaged waveforms per participant (congruent, associated, and incongruent attended words and attended pictures, and individually presented words and pictures).

ERP Scoring

Grand average waveforms were used to identify latency ranges for five prominent positive and negative waves that were evident for adults, and four waves that were evident for children. A computer scoring routine was used to measure maximum peak amplitude of each wave within each latency range. The latency and amplitude values were subsequently confirmed visually using manual scoring routines. For adults, P100 and N160 waves were most prominent at O_z , and amplitudes and latencies were measured at this site. P100 was identified as the maximal positive wave occurring between 50 and 150 ms, whereas N160 was identified as the maximal negative wave occurring between 100 and 200 ms. For children, the corresponding waves at O_z were P140 (100 to 200 ms) and N210 (175 to 300 ms). P240 was identified as the maximal positive wave occurring between 200 and 300 ms in the adults' ERP waveforms, and it was most prominent at P_3 , P_4 , and O_z , where amplitudes and latencies were measured. For children, the corresponding wave was P320 (250 to 375 ms). N450 was identified as the maximal

negative wave occurring between 350 and 550 ms (325 to 650 ms for children). Peak amplitude occurred at approximately 450 ms for both adults and children and this wave was most prominent at F_3 , F_4 , and C_z , where amplitudes and latencies were measured. For adults, P390 was identified as the maximal positive wave occurring between 300 and 700 ms, and was most prominent at C_z , P_3 , and P_4 , where amplitudes and latencies were measured. This component was not evident in the children's ERP waveforms.

Results

List Naming

The children made very few errors on the list naming task both for words ($M = 1.0$, $SD = 0.9$) and pictures ($M = 0.4$, $SD = 0.7$), and the error data were not analyzed further. The reaction time data were analyzed using a t test for dependent samples. Children took significantly longer to name the list of pictures ($M = 49.0$ s, $SD = 5.6$) than to read the list of words ($M = 28.3$ s, $SD = 6.8$), $t(7) = 8.97$, $p < .0001$, consistent with previous observations that naming times are longer for pictures than for lexical stimuli (Denckla & Rudel, 1974; Fraisse, 1969).

ERPs

Analyses of variance (ANOVAs) were conducted separately for each ERP wave using programs from STATISTICA for Windows (StatSoft, 1995). Specific questions were addressed by way of planned comparisons that isolated the effects of interest. The .05 level of confidence was applied to all statistical tests. Multivariate significance tests computed with Rao's R were adopted for repeated measures effects having more than one degree of freedom to protect against violations of sphericity.

The effect of the order of presentation of the attend-word and attend-picture conditions on the latency and amplitude of the ERP waves was unremarkable. A significant Group by Order interaction was observed only for P240/P320, $F(1, 15) = 8.27$, $MSE = 181.33$, $p < .05$. For children, P320 amplitude was larger (collapsed across stimuli, conditions, and electrode sites) when the attend-picture condition was presented second than when it was presented first. No order effects were observed for P240 amplitude for the adults. Order of presentation did not interact for any of the other ERP waves, therefore, it was not included as a factor in subsequent analyses.

Developmental effects on ERP latency and amplitude. Overall, children exhibited much larger amplitude and longer latency ERP waves than did adults. Table 3.1 provides the means and main effects of group for each ERP wave based upon separate ANOVAs with group as a between-subjects factor and repeated measures for stimulus type, condition, and electrode site. In contrast to the general trend, however, children had shorter latency N450 waves (collapsed across word and picture stimuli as well as individual and attend conditions) than did adults. Further, although it appears that N160/N210 amplitude was larger for adults than children according to the mean amplitude values (see Table 3.1), there were slight differences in the morphology of the waves at the occipital site. Children's ERPs exhibited an overall positive shift, and the absolute peak-to-peak amplitude of the children's P140-N210 wave was clearly larger than the corresponding amplitude of the P100-N160 wave for adults.

Table 3.1 Mean ERP Latency and Amplitude Values for Adults and Children and Main Effects of Group

ERP Wave	Latency			Amplitude		
	Adults	Children	<u>F</u>	Adults	Children	<u>F</u>
P100/P140	107	142	24.94 **	2.3	17.7	90.02 ***
N160/N210	164	216	43.00 ***	-4.6	3.6	20.28 **
P240/P320	240	303	38.96 ***	4.3	11.4	20.73 **
N450	478	437	6.48 *	-3.4	-14.3	24.25 **

Note. Significant main effects of Group are indicated with $df = (1, 17)$. Values are collapsed across word and picture stimuli, individually presented and attend conditions, and electrode site.

* $p < .05$ ** $p < .001$ *** $p < .00001$

Individually Presented Words and Pictures

To examine whether individually presented words and pictures elicited distinct waveforms for children as they did for adults, two-way mixed ANOVAs with group as a between-subjects factor and repeated measures on stimulus type were conducted separately for each ERP wave. Specific a priori comparisons were made for adults and children separately. The effects were evaluated at the electrode site where they were largest. When the appropriate electrode site was different for adults and children (e.g., P240/P320), separate one-way repeated measures ANOVAs of stimulus type were conducted. Figure 3.1 illustrates the grand average ERP waveforms to individually presented words and pictures for adults and children.

For adults, long latency ERPs (after 300 ms) to individually presented words were more negative than to individually presented pictures, particularly over anterior electrode sites. At C_z , larger amplitude N450 waves were observed to words than to pictures (-3.9 vs. $-0.2 \mu V$), $F(1, 17) = 6.27$, $MSE = 10.75$, $p < .05$. In contrast, over parietal sites ERPs to individually presented pictures were more positive than to individually presented words. At P_3 , larger amplitude P390 and P240 waves were observed to pictures than to words (P390: 6.4 vs. $2.8 \mu V$, $F(1, 9) = 8.09$, $MSE = 7.75$, $p < .05$; P240: 6.3 vs. $4.0 \mu V$, $F(1, 9) = 7.80$, $MSE = 3.54$, $p < .05$). For adults, individually presented pictures also appeared to elicit larger amplitude N160 waves at O_z compared to words (see Figure 3.1); however, this comparison did not reach statistical significance ($F < 1$). Finally, shorter P240 latency was observed at P_3 for individually presented pictures as compared to words (235 vs. 255 ms), $F(1, 9) = 14.02$, $MSE = 147.14$, $p < .005$. No other amplitude or latency differences were significant ($F_s < 1.34$).

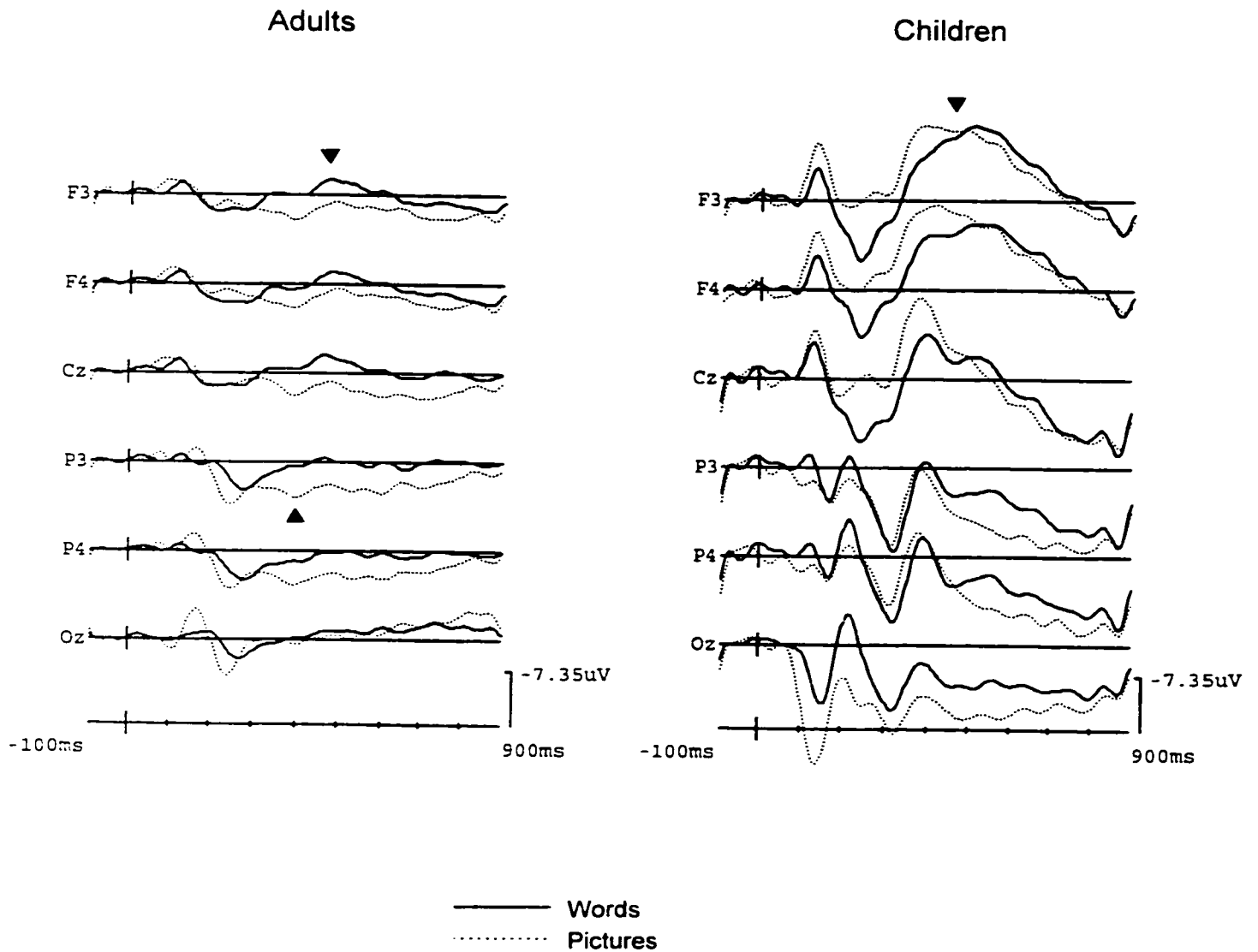


Figure 3.1 Grand average ERP waveforms to individually presented words and pictures for adults and children. For adults, note the larger amplitude negative waves at anterior electrode sites for words and the larger amplitude positive waves at posterior electrode sites for pictures. For children, note the prominent frontal-central negative waves for both words and pictures.

In contrast to the adults' waveforms, in which long latency anterior negative waves were observed only for words, children's ERPs to both individually presented words and pictures were characterized by prominent anterior negative waves (see Figure 3.1). Furthermore, for children, N450 amplitude was larger at C_z for individually presented pictures than words (-11.5 vs. -7.8 μV). $F(1, 17) = 5.85$, $MSE = 10.75$, $p < .05$. Individually presented pictures also had shorter N450 latency compared to words (400 vs. 455 ms), $F(1, 17) = 5.94$, $MSE = 2340.01$, $p < .05$.

A qualitative examination of the early portions of the children's waveforms at anterior electrode sites shows that the ERPs to individually presented pictures exhibited a larger amplitude, long-lasting and overlapping negativity as compared to words. Such differences were not observed in the adults' ERPs (see Figure 3.1). Over the parietal electrode sites, children's ERPs were similar to adults' in that the long latency waveforms (after 400 ms) were more positive to individually presented pictures than words, although there was no evidence of a P390 wave for children. At O_z , children's waveforms were characterized by a long latency positive shift which was larger for individually presented pictures than words. Significant amplitude differences were observed for the P140 (18.5 vs. 9.0 μV , $F(1, 17) = 30.62$, $MSE = 13.11$, $p < .0001$) and N210 waves (3.1 vs. -6.1 μV , $F(1, 17) = 12.93$, $MSE = 29.21$, $p < .005$). No stimulus type differences were observed for the P320 wave at O_z for children ($F_s < 1$).

In sum, for adults, long latency ERPs to individually presented words were more negative than to pictures at anterior electrode sites, whereas pictures elicited more positive waveforms over posterior electrode sites. A different pattern emerged for children, with prominent anterior negative waves to both words and pictures. Furthermore, for adults, N450 was larger in amplitude to words, whereas for children, pictures elicited larger amplitude and shorter latency

N450 waves. Thus, the most salient difference between adults' and children's ERPs when naming individually presented words and pictures was the presence of large anterior negative waves to pictures for children.

Individually Presented Words versus Attended Words

To examine the effects of the distractor pictures on the processing of attended words, two-way mixed ANOVAs with group as a between-subjects factor and repeated measures on condition (individually presented, congruent-attended, associated-attended, incongruent-attended) were conducted separately for each ERP wave. Specific a priori comparisons were made for adults and children separately. The effects were evaluated at the electrode site where they were largest. In addition, for N450 amplitude, significant effects of condition were followed by planned comparisons to evaluate the effects of semantic relation on attended words. Mean N450 amplitude values across groups, conditions, and electrode sites are presented in Table 3.2. The grand average waveforms to individually presented words and attended words in the superimposed arrays are shown in Figure 3.2 for adults and children.

For adults, effects of the distractor pictures on the ERPs to attended words were evident only at early peak latencies in the waveforms, providing some evidence for the early processing of the "ignored" pictures (see Figure 3.2). Attended words elicited prominent N280 waves at anterior electrode sites that were not observed for individually presented words. As well, Figure 3.2 shows that attended words appeared to have larger amplitude N160 and P240 waves than individually presented words at O_z , although these differences did not reach statistical significance ($F_s < 1.35$). In contrast, at later peak latencies there were no differences in N450 amplitude at C_z between individually presented words, or words superimposed by congruent,

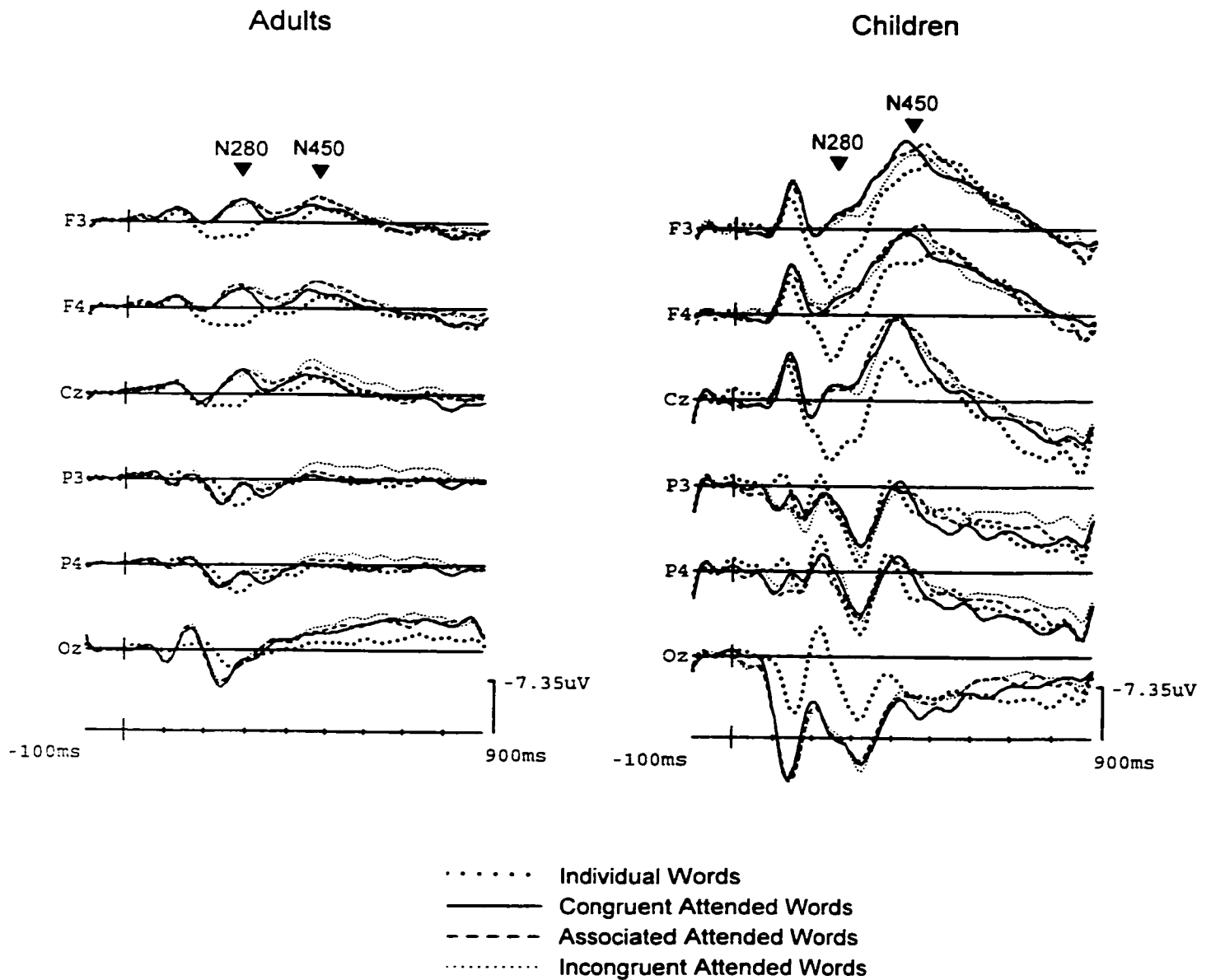


Figure 3.2 Grand average ERP waveforms to individually presented and attended words for adults and children, illustrating N280 waves over frontal-central electrode sites for attended words only for both groups. For adults, note that there are no differences between conditions for N450 amplitude. For children, larger N450 amplitude is observed for attended versus individually presented words, but there are no semantic incongruity effects.

Table 3.2 Mean N450 Amplitude (μ V) (SD in parentheses) as a Function of Stimulus Type, Electrode Site, and Condition for Adults and Children

Stimulus Type	Condition			
	Individual	Congruent	Associated	Incongruent
Adults				
Words				
F ₃	-3.3 (3.6)	-3.5 (4.2)	-4.5 (5.5)	-4.4 (5.1)
F ₄	-2.9 (3.6)	-3.5 (4.2)	-5.2 (6.0)	-4.3 (5.1)
C _z	-3.9 (3.4) _a	-3.9 (5.0)	-4.8 (5.7)	-5.6 (5.3)
Pictures				
F ₃	-0.1 (5.4)	-2.5 (5.6)	-3.0 (6.3)	-3.1 (6.8)
F ₄	-0.4 (5.0)	-2.1 (4.9)	-2.6 (6.2)	-3.9 (5.5)
C _z	-0.2 (5.2) _{a,b}	-3.8 (5.2) _c	-4.4 (6.1)	-5.1 (6.1) _{b,c}
Children				
Words				
F ₃	-12.0 (5.0)	-13.3 (7.5)	-13.3 (5.2)	-12.4 (3.2)
F ₄	-11.4 (5.4)	-12.5 (6.4)	-13.2 (7.0)	-13.3 (2.5)
C _z	-7.8 (8.1) _d	-12.5 (8.3)	-13.0 (7.9)	-12.6 (6.5)
Pictures				
F ₃	-12.7 (7.1)	-18.0 (6.1)	-18.7 (6.2)	-16.1 (7.3)
F ₄	-13.7 (6.2)	-19.1 (7.5)	-19.4 (6.8)	-16.8 (8.3)
C _z	-11.5 (8.1) _{d,e,f}	-17.2 (7.9) _e	-17.6 (8.7) _f	-15.0 (11.4)

Note. Means having the same subscript are significantly different ($p < .05$).

associated, or incongruent pictures ($F < 1$ for the main effect of condition). This finding indicated that, for adults, the superimposed distractor pictures had no significant effect on the N450 wave to attended words, nor was there evidence that adults processed the semantic meaning of the pictures.

For children, ERP waveforms to individually presented words and attended words differed at both early and late peak latencies. At early portions of the waveform, children's ERPs to individually presented and attended words differed at O_z , where ERPs to words superimposed by congruent, associated, and incongruent pictures were all characterized by a long-lasting and overlapping positivity. Significant differences in amplitude were observed at O_z for P140, N210, and P320, Rao $R(3, 15) = 30.48, 9.64, \text{ and } 4.98$, respectively, $p < .01$ in all cases. Children also exhibited anterior N280 waves for attended words, as did adults, rather than the positive waves that were observed for individually presented words at the same latency.

At longer latencies, children's ERPs to attended words were more negative at anterior sites than to individually presented words. A main effect of condition was significant for N450 amplitude at C_z , Rao $R(3, 15) = 4.75$, $p < .05$. Post hoc comparisons indicated that N450 amplitude was larger for attended words (collapsed across semantic relatedness) than for individually presented words (-12.7 vs. $-7.8 \mu V$), $F(1, 17) = 12.36$, $MSE = 13.22$, $p < .005$. There were no differences in N450 amplitude between attended words in the congruent, associated, or incongruent conditions. Thus, unlike adults who showed no differences in the N450 wave between individually presented and attended words, children displayed larger amplitude N450 waves for attended than individually presented words. However, despite this

modulation of the N450 wave for children, there were no effects of semantic relation on N450 amplitude.

In sum, adults showed evidence for early processing of the distractor pictures when attending to words in superimposed stimulus arrays, but no effects of either the pictures or their semantic relationship to the words at later portions of the waveform. This is consistent with the view that, for adults, picture-processing is subject to attentional control. When words were attended, there was little evidence that the meaning of the pictures was processed. Children, in contrast, showed evidence for effects of the distractor pictures across all portions of the waveform to attended words. In particular, these effects extended to the N450 wave, such that larger negativities were observed when children attended to words in superimposed stimulus arrays. However, again, no effects of the semantic relationship between the attended words and the distractor pictures were evident. This suggests that the children may have exerted more effort in order to attend selectively to the words, but that the semantic meaning of the pictures was not processed.

Individually Presented Pictures versus Attended Pictures

As above, two-way mixed ANOVAs with group as a between-subjects factor and repeated measures on condition (individually presented, congruent-attended, associated-attended, incongruent-attended) were conducted separately for each ERP wave to examine the effects of the distractor words on the processing of attended pictures. Specific a priori comparisons were made for adults and children separately. The effects were evaluated at the electrode site where they were largest. Significant effects of condition on N450 amplitude were followed by a priori comparisons to evaluate the effects of semantic relation on attended pictures. Figure 3.3

illustrates the grand average waveforms to individually presented pictures and attended pictures in the superimposed arrays for adults and children.

For adults, ERPs to attended pictures were more negative after 200 ms than to individually presented pictures, except at O_z where there were no differences until approximately 325 ms. Furthermore, attended pictures did not exhibit the central-parietal P390 wave that was observed for individually presented pictures. At P_3 , the main effect of condition on P240 amplitude approached significance, $p = .057$. Attended pictures superimposed by congruent, associated, and incongruent words appeared to elicit attenuated P240 waves compared to individually presented pictures, but did not appear to differ from one another.

Across anterior sites, prominent N280 waves were observed in the adults' waveforms for attended pictures (as for attended words) that were not evident in the ERPs to individually presented pictures. Furthermore, there was a main effect of condition on N450 amplitude at C_z , Rao R (3, 7) = 11.24, $p < .005$. A priori comparisons based on predictions made from the behavioural literature were conducted to examine the effects of semantic relation. For adults, these comparisons indicated that pictures superimposed by incongruent words had larger N450 amplitude at C_z than individually presented pictures, $t(9) = 5.91$, $p < .001$ (one-tailed). Pictures superimposed by incongruent words also elicited larger N450 amplitude than attended pictures in the congruent condition, $t(9) = 1.84$, $p < .05$ (one-tailed). N450 amplitude did not differ between attended pictures in the incongruent and associated conditions. These findings indicated that the processing of attended pictures was differentially influenced by the meaning of the distractor words, and provide evidence that the distractor words were processed automatically.

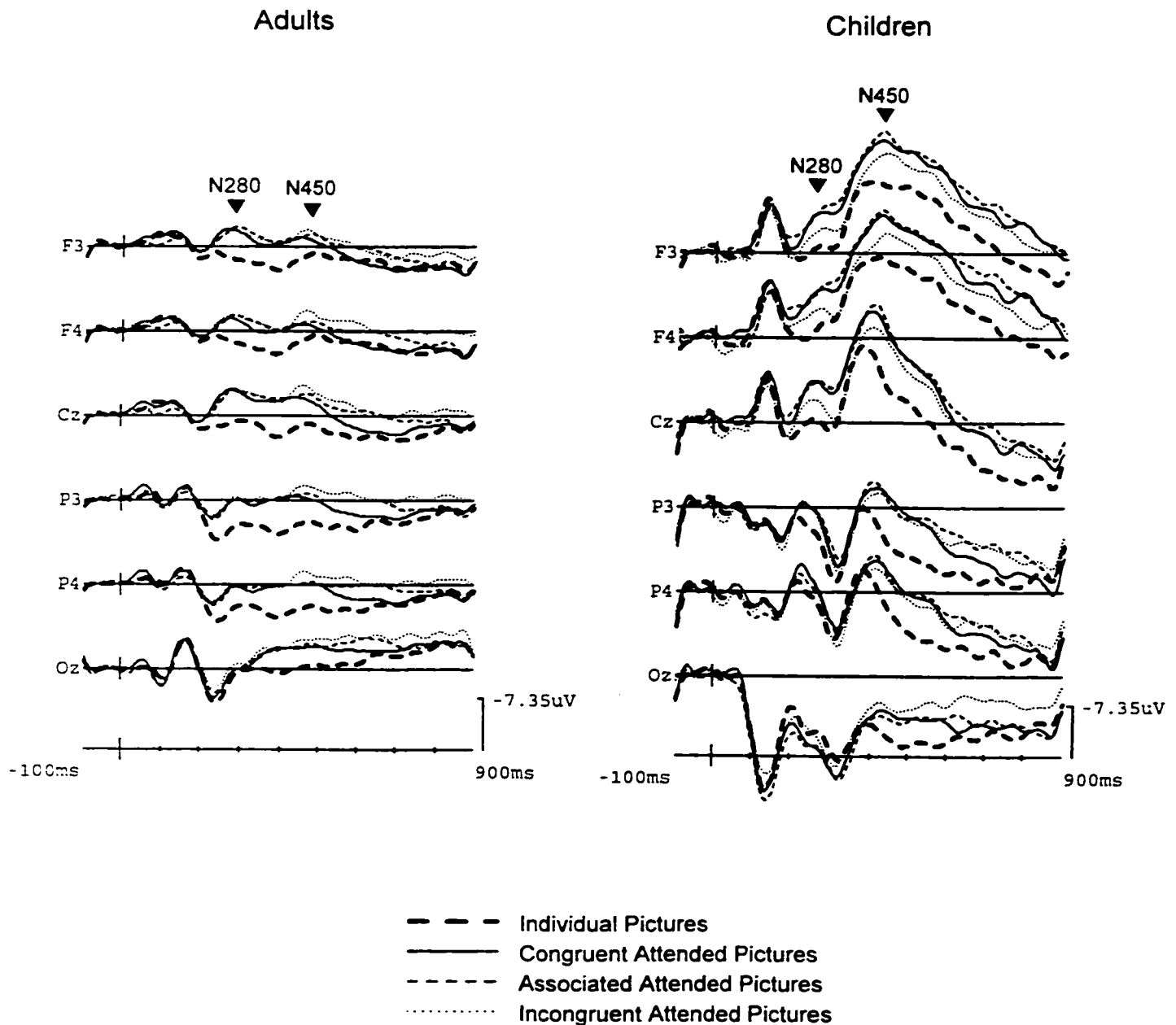


Figure 3.3 Grand average ERP waveforms to individually presented and attended pictures for adults and children, illustrating N280 waves over frontal-central electrode sites for attended pictures only for both groups. For adults, larger N450 amplitude is observed for attended versus individually presented pictures. Semantic incongruity effects are also observed, with larger N450 amplitude for attended pictures superimposed by incongruent words. For children, larger N450 amplitude is observed for attended versus individually presented pictures. However the semantic incongruity effects are in the opposite direction, such that attended pictures superimposed by congruent and associated words elicit larger N450 amplitude.

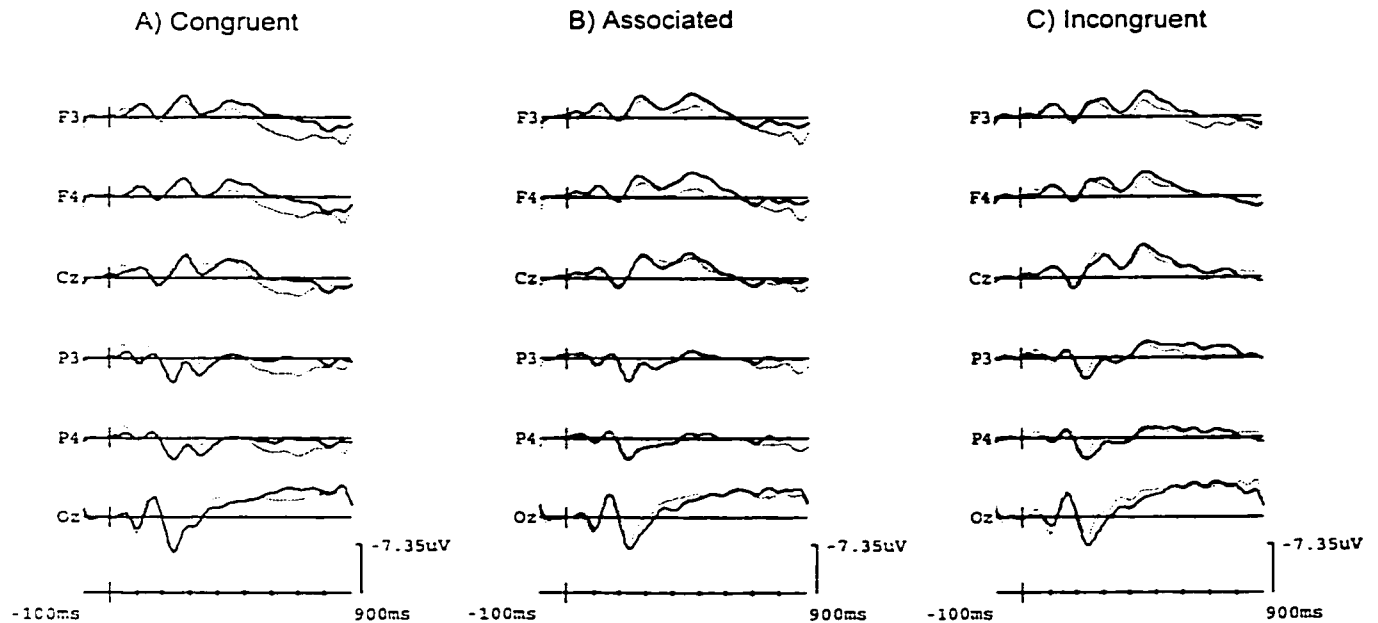
For children, attended pictures also elicited larger long-latency negative waves than individually presented pictures. At early latencies across the posterior sites, there were no differences in P140, N210, or P320 between individually presented and attended pictures (see Figure 3.3). In contrast, at anterior sites, children exhibited anterior N280 waves for attended pictures (as for attended words) that were not observed for individual pictures, similar to adults. Attended pictures also elicited larger amplitude N450 waves across anterior sites than did individual pictures. This effect was significant at C_z , where there was a main effect of condition, $Rao R(3, 6) = 6.46, p < .01$. Post-hoc comparisons indicated that N450 amplitude was significantly larger for attended pictures superimposed by congruent and associated words as compared to individually presented pictures. Pictures superimposed by incongruent words were intermediate in N450 amplitude, but did not differ significantly from the other conditions. Thus, the effects of semantic relation for children followed a different pattern from that of adults.

In sum, for both adults and children, ERPs were more negative when attending pictures in superimposed stimulus arrays than when naming pictures presented individually. In both cases, the distractor words influenced the processing of the attended pictures, and these effects were most prominent over the anterior regions. However, adults and children exhibited different effects of semantic relation on the amplitude of the N450 wave. For adults, larger N450 amplitude was observed for attended pictures superimposed by incongruent words compared to congruent words or pictures presented individually. The children did not exhibit larger N450 waves in the incongruent condition, but rather, had larger N450 amplitude for attended pictures superimposed by congruent and associated words.

Attended Words and Pictures

To examine the effects of attention on the processing of words and pictures in the superimposed stimulus arrays, three-way mixed ANOVAs were conducted for each ERP wave at O_z with group as a between-subjects factor and repeated measures on stimulus type (attended words, attended pictures) and condition (congruent, associated, incongruent). Specific planned comparisons were made for adults and children. ANOVAs with repeated measures on stimulus type, condition, and electrode site (F_3 , F_4) for N450 amplitude were conducted separately for adults and children because of the different patterns of semantic effects that were observed for each group. Grand average waveforms to attended words and pictures in the superimposed arrays as a function of semantic relatedness are presented in Figure 3.4 for adults and children.

For adults, the differences between attended words and pictures were similar to those observed for individual stimuli. As Figure 3.4 shows, ERPs to attended words (as for individual words) were more negative after 350 ms over frontal scalp areas than ERPs to attended pictures. Specifically, there was a significant three-way interaction of stimulus type, condition, and electrode site for adults, $Rao R(2, 8) = 8.85$, $p < .01$. Simple effects analysis indicated that N450 amplitude was larger over frontal sites to attended words than pictures, but only for picture-word pairs with associated meanings, $F(1, 9) = 13.75$, $MSE = 3.24$, $p < .005$. Similar trends were observed for attended words in the congruent and incongruent conditions, and the main effect of stimulus type approached significance ($p < .13$). None of the waves at O_z differed significantly between attended words and pictures. However, there was a trend for larger P240 amplitude at O_z for attended words as compared to attended pictures ($p = .058$). Thus, despite the presence of



CHILDREN

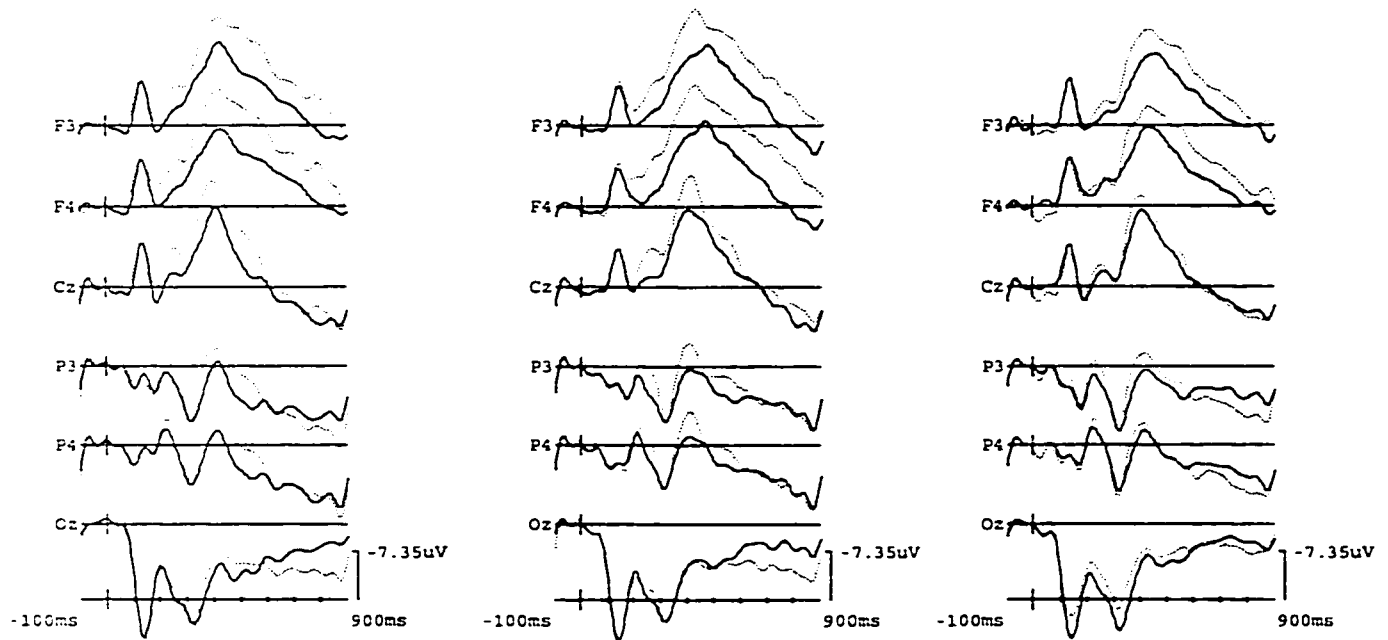


Figure 3.4 Grand average ERP waveforms to attended words (—) and pictures (.....) as a function of semantic relatedness for adults and children. Note that for adults, larger N450 waves are observed for attended words than pictures over frontal electrode sites, especially for associated stimulus pairs. For children, frontal N450 waves are larger for attended pictures than words in all conditions.

distractor stimuli. distinct ERPs were largely maintained for adults for words and pictures that were attended in superimposed stimulus arrays.

For children, the differences between attended words and pictures were also similar to those observed for individual stimuli. Attended pictures elicited larger amplitude N450 waves than did attended words across all conditions and frontal electrode sites (-18.0 vs. -13.0 μV), $F(1, 8) = 10.62$, $\text{MSE} = 63.64$, $p < .05$. The shorter N450 latencies observed for individual pictures compared to words was not evident for the attended stimuli. There was a significant stimulus type by condition interaction for P140 amplitude at O_z for children, $\text{Rao } R(2, 16) = 5.24$, $p < .05$. Analysis of simple effects indicated that P140 amplitude was larger for attended words than pictures in the incongruent condition only (19.7 vs. 16.3 μV), $F(1, 17) = 10.89$, $\text{MSE} = 4.81$, $p < .005$. Finally, as for adults, there was a trend toward larger P320 amplitude at O_z for attended words than pictures across conditions ($p < .10$). Thus, for children (like adults), the differences observed in the ERPs to individual words and pictures were also largely manifest in the ERPs to words and pictures that were attended in superimposed stimulus arrays.

Discussion

Large, long-latency anterior negative ERP waves were observed for children in both picture and word naming tasks. Furthermore, individually presented pictures elicited larger amplitude and shorter latency N450 waves than did individual words. The latter effect is consistent with previous reports that pictures elicit larger anterior negative waves than words for children (Berman et al., 1990; Robertson et al., 1990), an effect that has been attributed to differences between words and pictures in the automaticity of lexical access or access to conceptual representations. In this study, the amplitude of the N450 wave may reflect processes

involved in stimulus identification, which, for children, may be more effortful for pictures than words. Consistent with this view, the children took longer to name pictures than words in the list naming task. The children's ERPs contrast dramatically with the morphologically distinct waveforms observed for adults, where individually presented pictures elicited larger amplitude positive waves over posterior sites than did words. The present findings concur with previous work, where large anterior negativities are commonly observed for children, but not adults, across different experimental tasks and with a variety of lexical and pictorial stimuli (e.g., Courchesne, 1983; Taylor, 1995).

For both adults and children, differences were observed in the ERPs to attended words and pictures that were presented in superimposed stimulus arrays compared to individually presented words and pictures. In both attend conditions for adults and children, an N280 wave was observed over anterior electrode sites that was similar for words and pictures. This wave was not evident in the ERPs to individually presented words or pictures. Although the N280 wave was somewhat less prominent for the children, it was nonetheless similar in latency and scalp topography to the N280 observed for adults. The N280 wave was similar for both attended words and pictures, therefore, it is likely that it represents a process common to both tasks. This ERP component would seem to be indicative of the additional processing required in the attend conditions to discriminate the task-relevant stimulus (word or picture) from the spatially complex superimposed array (Greenham et al., 1999). Similar anterior negative (N2) ERP waves associated with further discriminative processing of task-relevant stimuli have been reported in the literature (e.g., Mangun & Hillyard, 1987; Rugg, Milner, Lines, & Phalp, 1987). Thus, at relatively early portions of the waveform, children appeared to initiate the process of

discriminating the complex, superimposed stimuli in a manner similar to adults, consistent with reports that the cognitive processes associated with N2-like waves are largely mature by early adolescence (Taylor, 1988, 1995).

At longer latencies, adults exhibited distinct waveforms to attended words and pictures that mirrored the pattern of results observed for individually presented words and pictures. Specifically, larger amplitude N450 waves were observed for attended words compared to attended pictures. This effect of attention was apparent across all levels of semantic relatedness, although the effect was significant only for picture-word pairs with associated meanings. For children, the opposite pattern emerged, with larger amplitude N450 waves observed to attended pictures compared to attended words. These differences did not vary as a function of semantic relation. Similar results were obtained for children for the individually presented stimuli, in that individual pictures elicited larger N450 amplitude than words. Thus, for both adults and children, the differences in the N450 wave that were observed between individually presented words and pictures were also observed for attended words and pictures. These differences in N450 cannot be attributed to physical stimulus features, however, as identical stimuli were presented in both attend conditions. To the extent that the ERP differences between individually presented words and pictures were maintained for words and pictures presented in superimposed stimulus arrays, these findings indicate that words and pictures differ in their attentional processing demands for both children and adults. Moreover, both adults and children were able to attend to words or pictures when presented in superimposed arrays and extract the task-relevant stimulus for naming. However, examination of the differences between individually presented and attended

stimuli bears on the role of attention in the processing of words and pictures, and reveals different patterns of effects for adults and children.

Compared to individually presented words, children's ERPs to attended words were clearly influenced by the presence of the distractor pictures. ERPs to attended words were more positive at early latencies over the occipital scalp due to an overall positive shift that resulted in a waveform that closely resembled the waveform to individually presented pictures. As previously mentioned, an N280 wave was observed at anterior sites for attended words but not for individually presented words. More importantly, larger amplitude N450 waves were observed for attended words compared to individually presented words. However, no effects of semantic relation on N450 amplitude were observed for children. These results contrasted with the results observed for adults, for whom N450 amplitude did not differ between attended words and individually presented words, nor as a function of semantic relation.

As was observed for attended words, children's ERPs to pictures that were attended in superimposed stimulus arrays were influenced by the presence of distractor words. The most salient differences were observed at anterior electrode sites, where ERPs to attended pictures were more negative after 200 ms as compared to individually presented pictures. As was observed for attended words, attended pictures elicited an N280 wave that was more prominent than for individually presented pictures. Furthermore, attended pictures elicited larger amplitude N450 waves than individually presented pictures that were also sensitive to effects of semantic relation. Adults exhibited a very similar pattern of results, with larger negativities to attended pictures than to individually presented pictures, as well as effects of semantic relation on the N450 wave.

However, the pattern of semantic effects for the distractor words was quite different for adults and children. For adults, attended pictures that were superimposed by incongruent words elicited larger N450 amplitude than individual pictures and pictures superimposed by congruent words. That is, N450 amplitude was sensitive to the semantic incongruity between the words and pictures. For children, pictures superimposed by incongruent words did not elicit larger amplitude N450 waves. Rather, pictures superimposed by associated and congruent words elicited larger N450 amplitude than individually presented pictures.

For adults, the pattern of semantic effects of the distractor words and pictures can be understood in terms of the distinction between automatic and controlled processing. Despite the evidence for early processing of the distractor pictures, as manifest by differences in the early portions of the waveforms to attended words, there were no effects of the distractor pictures on the N450 wave for adults. In effect, the meaning of the distractor pictures was ignored and did not influence N450 amplitude to the attended words. This observation is consistent with the view that picture processing is subject to attentional control (Noldy et al., 1990; Shiffrin & Schneider, 1977). Or, from another perspective, adults inhibited the processing of the semantic meaning of pictures (Driver & Tipper, 1989; Tipper et al., 1989; Tipper & Driver, 1988; Yee, 1991). In contrast, larger N450 waves were observed to attended pictures that were superimposed by incongruent distractor words. That is, the meaning of the distractor words intruded or was not ignored, resulting in enhanced N450 waves when the words did not match the attended pictures. This effect is consistent with the view that the distractor words were processed automatically and were not subject to attentional control.

When attending to words, children exhibited effects of the distractor pictures across early and later portions of the waveform, including the N450 wave. Although N450 amplitude was larger when attending to the superimposed words, there were no effects of semantic relation. There is good evidence that children's ERPs are sensitive to effects of semantic incongruity for both words and pictures (Byrne, Dywan, & Connolly, 1995; Friedman et al., 1992; Holcomb, Coffey, & Neville, 1992; Juottonen, Revonsuo, & Lang, 1996; Miles & Stelmack, 1994; Stelmack & Miles, 1990). However, children did not exhibit effects of semantic incongruity for distractor pictures in this paradigm. It appears that word processing was not completely automatic for these children, particularly for words that were presented in complex stimulus arrays. That is, the process of attending to and naming the words required attentional resources for successful completion, leaving fewer resources to actively ignore or inhibit the processing of the distractor pictures. In contrast, adults recognized the words automatically, leaving their attentional resources to actively inhibit the meanings of the distractor pictures. Accordingly, the adults did not display effects of semantic incongruity for attended words, consistent with evidence that adults can effectively inhibit the semantic meaning of pictures after initial encoding (e.g., Tipper & Driver, 1988; Yee, 1991).

On the view that children are less able to apply inhibitory processes, one might expect to observe large semantic incongruity effects for the meanings of the distractor pictures (i.e., increased N450). However, this was not the case. Although speculative, it may be that the children inhibited the distractor pictures before semantic meaning was fully processed, although they may have been slower or less efficient than adults (Tipper et al., 1989). This might account for the influence of the distractor picture at later portions of the waveform (N450) in the absence

of semantic incongruity effects for children compared to adults. Furthermore, the children may not have been able to simultaneously attend to the words and inhibit the pictures, whereas adults appeared to complete these processes in parallel (Robertson et al., 1990).

When children attended to pictures in superimposed stimulus arrays, effects of semantic relation were observed. Pictures superimposed by congruent and associated words elicited larger N450 waves than individually presented pictures. This effect was opposite to expectations based upon the sensitivity of the N400 wave to semantic incongruity for both words and pictures (e.g., Kutas & Hillyard, 1980; Friedman et al., 1988, 1992). The effect was also opposite to that observed for adults with this paradigm who showed larger N450 amplitude to pictures paired with incongruent words. There is good evidence that it takes longer to name pictures that are superimposed by incongruent than congruent words (Glaser & D ngelhoff, 1984; Golinkoff & Rosinski, 1976; Rayner & Springer, 1986; Rosinski, 1977; Rosinski et al., 1975; Starreveld & La Heij, 1995). These interference effects are greater for children than adults (Ehri, 1976; Guttentag & Haith, 1978; Rosinski, 1977; Rosinski et al., 1975), and are understood in terms of response selection or competition (La Heij, 1988; Lupker, 1979, 1982; Lupker & Katz, 1981, 1982). In the present study, it may be the case that the children attempted to use the distractor words to help them name the pictures, despite instructions to ignore the words. This is consistent with the finding that word naming was faster than picture naming, and therefore, the words may have been available more quickly than the names of the pictures. Perhaps the congruent and associated words facilitated the processing and subsequent naming of the attended pictures for children, resulting in larger N450 amplitude. The incongruent words may have interfered with or delayed the processing and naming of the attended pictures, resulting in less activation of the N450 wave.

In adults, the detection of semantic incongruity appears to be a function of automatic word processing, in that it occurs despite attempts to ignore or inhibit distractor words. The surprising pattern of semantic effects for children suggests that they do not process words automatically to the degree observed in adults.

Conclusions

The present study highlights a number of similarities and differences in the way adults and children processed words and pictures in a picture-word interference task. Whereas adults clearly processed the individually presented words and pictures independently, as manifest in distinct ERP waveforms, children's ERPs to words and pictures were similar in morphology. Specifically, individually presented pictures elicited prominent negative waves over the anterior scalp in children, rather than the posterior positive waves that were observed in adults. In previous work this effect has been associated with developmental differences in the automaticity of access to lexical information or conceptual representations (Robertson et al., 1990). Thus, children appeared to process the pictures differently than did adults. Nevertheless, differences were observed between individually presented words and pictures in children, and these differences were maintained for pictures that were attended in superimposed stimulus arrays. This effect suggests that, like adults, children were successful in discriminating the task-relevant stimulus (word or picture) from the spatially complex superimposed stimulus. Thus, the attentional effect that was observed for adults was also observed for children.

However, adults and children exhibited different effects of semantic relation on the ERPs. Although word processing was automatic for adults, in that incongruent distractor words enhanced N450 amplitude to attended pictures, there was no evidence for automatic semantic

processing of the incongruent distractor words for children, as indexed by enhanced amplitude of the N450 wave. This finding contrasts with reports that children are slower to name pictures superimposed by incongruent than congruent words, which has been taken as evidence that children process semantic information automatically (e.g., Rosinski, 1977; Rosinski et al., 1975). However, it may be the case that picture-word interference occurs at a later stage in processing than is reflected by the N450 wave, such as response production and competition (Lupker, 1979, 1982). The current results lend support to the view that children are less efficient in managing attentional resources, including inhibitory processes. Furthermore, the anterior topography of these effects can be considered consistent with maturation of the frontal lobes. Overall, these findings indicate that this paradigm was successful in demonstrating attentional control in the processing of pictures and words in children.

CHAPTER 4

Study 3

**Learning Disability Subtypes and the Processing of Pictures and Words:
The Effects of Attention and Semantic Relation on Event-Related Potentials**

Introduction

The nature of deficiencies in attention to visual-spatial or auditory-verbal information in the development of learning disabilities (LD) has been widely investigated. There is a consensus that measures of vigilance or sustained attention, attentional capacity, and level of arousal do not differentiate between children with LD and children without LD (Pennington, Groisser, & Welsh, 1993; Richards, Samuels, Turnure, & Ysseldyke, 1990; Samuels & Edwall, 1981; Tarnowski, Prinz, & Nay, 1986; Warnke & Remschmidt, 1992; Whyte, 1994), whereas there are some reports that measures of selective attention to visual and auditory information do identify children with LD. Poor readers and children with LD exhibit greater difficulty focusing their attention on task-relevant information than do normally achieving children (Copeland & Reiner, 1984; Kelly, Best, & Kirk, 1989; Lazarus, Ludwig, & Aberson, 1984; Lovdahl, Brown, McIntyre, & North, 1986; Richards et al., 1990; Samuels & Edwall, 1981) or children with attention deficit disorders (Tarnowski et al., 1986). However, null effects have also been reported (Bolster, Marshall, Bow, Chalmers, & Stubel, 1986; Samuels, 1987).

Event-related potentials (ERPs) are measures of electrocortical activity that are elicited by sensory stimuli and that are modulated by cognitive processes relevant to attention, decision-making, memory, and language. There has been a good deal of progress in establishing ERP components as reliable indices of selective attention and semantic processing. Attempts to explore the role of selective attention in LD with ERP methods have met with some success. Differences in the amplitude of ERP components thought to be involved in visual selective attention have been reported for children and adults with dyslexia or reading disabilities (RD) as

compared to non-LD controls (Harter, Anllo-Vento, & Wood, 1989; Harter, Anllo-Vento, Wood, & Schroeder, 1988; Naylor, Wood, & Harter, 1995; Sobotka & May, 1977). On the other hand, others do not report deficits in selective attention (e.g., Lovrich & Stamm, 1983), but rather indicate that children with LD exhibit attenuated long latency ERP components that are involved in either stimulus discrimination and decision-making or further processing of stimuli (Holcomb, Ackerman, & Dykman, 1985; Olo & Squires, 1986). Furthermore, there are reports that poor readers and children with RD exhibit deficits in some aspects of selective attention (e.g., for a particular type of information at a given location) but not others (e.g., spatial location) (see Harter, 1991, for a review).

In the present research, the role of attention in the processing of pictures and words for children with LD was explored by utilizing a visual selective attention paradigm and examining ERP components that are reliable indices of attention and semantic processing. Children were shown pictures and words that were superimposed in a single array. They were required to direct their attention to either the picture or the word by naming it. The superimposed pictures and words were composed of congruent, semantically associated, and incongruent pairs that allowed an examination of semantic effects. We were particularly interested in whether children with LD who exhibited specific patterns of academic deficits for verbal versus nonverbal material would exhibit specific differences in attentional and semantic processing of words and pictures.

Subtypes of Learning Disabilities and Attentional Deficits

The use of undifferentiated samples of children with LD may be a confounding factor in previous work on the role of attention in LD. It is now well established that children with LD can be differentiated into homogeneous subtypes based on reliable patterns of skills and deficits

(Geary, 1993; Hooper & Willis, 1989; Rourke, 1985, 1991). Thus, these patterns of skills and deficits that are specific to LD subtypes may be masked in undifferentiated samples. A reliable and externally validated (Rourke, 1985, 1991) typology of LD subtypes based on patterns of academic achievement and neurocognitive performance was described by Rourke and Finlayson (1978; also Ozols & Rourke, 1988; Rourke, 1993). Three LD subtypes were identified. Children in Subtype R-S-A are consistently deficient in reading (word recognition), spelling, and mechanical arithmetic as compared to same-age peers. Children in Subtype R-S have poor reading and spelling ability relative to their arithmetic performance, which is also below average. Children in Subtype A have at least average reading and spelling ability but deficient arithmetic skill. Children in Subtypes R-S-A and R-S perform better on measures of visual-perceptual and visual-spatial skill and have higher nonverbal IQ scores than do children in Subtype A, who are deficient in these tasks. Conversely, children in Subtype A perform better on measures of verbal and auditory-perceptual skill and have higher verbal IQ scores than do children in Subtypes R-S-A and R-S, who perform poorly on these tasks. These patterns are thought to reflect underlying cerebral hemisphere dysfunction inasmuch as the performance of children in Subtypes R-S-A and R-S is consistent with left hemisphere dysfunction, and the performance of children in Subtype A, who are thought to exhibit the syndrome of nonverbal learning disabilities (NLD; Rourke, 1989), is consistent with right hemisphere dysfunction (Geary, 1993; Rourke, 1982, 1989; Rourke & Conway, 1997; Rourke & Finlayson, 1978; Rourke & Strang, 1978).

Children in Subtypes R-S and A also exhibit different patterns of attentional deficits, according to Rourke's (1982, 1989) developmental neuropsychological model of LD. Attentional deficits are proposed as secondary deficits that arise directly, by way of cause-effect

relationships, from poor sensory-perceptual capacities. For Subtype R-S, attentional deficits are observed for auditory-verbal material, particularly when presented in the auditory modality, whereas for Subtype A, or NLD, attentional deficits are observed for visual material, with the exception of overlearned information such as printed text. Specifically, children with NLD are described as exhibiting difficulties in discriminating and recognizing visual detail and in visual-spatial-organization, which subsequently leads to deficient selective and sustained visual attention for complex, novel, nonverbal material (Rourke, 1989). These patterns of attentional deficits subsequently result in specific auditory-verbal and visual memory deficits for Subtypes R-S and A, respectively (see Rourke & Tsatsanis, 1995, for a review).

The purpose of the present research was to examine whether these differences in attentional processing for verbal versus visual-spatial material ascribed to Subtypes R-S and A would be observed in a picture-word naming task. Specifically, we hypothesized that children with LD who met criteria for Subtype R-S would exhibit deficient selective attentional processing specific to word stimuli, whereas children who met criteria for Subtype A would exhibit deficient selective attentional processing specific to picture stimuli.

ERPs and Learning Disabilities

Detection of simple sensory stimuli (e.g., visual and auditory acuity) is intact in children with broadly defined LD. This finding is endorsed in research using ERP methods. As indicated in recent comprehensive reviews of the ERP literature for children with LD (Dool, Stelmack, & Rourke, 1993; Stelmack, Rourke, & van der Vlugt, 1995; Taylor, 1995), there is no compelling evidence of differences between children with and without LD for exogenous sensory ERP components elicited by simple repetitive stimuli such as auditory tones, light flashes, or simple

letters. In contrast, a fairly consistent effect that is observed for children with LD is longer latency and smaller amplitude of a late positive ERP component (P300) as compared to non-LD controls. This effect emerges most clearly during the processing of reading related, linguistic target stimuli. The P300 wave is thought to reflect endogenous cognitive activity such as stimulus evaluation and classification (Picton, 1992; Pritchard, 1981). Thus, the longer latency and smaller amplitude of P300 for children with LD relative to controls can be interpreted as reflecting deficient or inefficient information processing, particularly for linguistic material.

The amplitude of a late negative ERP component (N400) has also been successful in discriminating children with and without LD. In adults, an enhanced N400 wave is observed during sentence processing when a terminal word deviates from the expected semantic context of the sentence (Kutas & Hillyard, 1980). The amplitude of the N400 wave is also larger to target words that are preceded by semantically unrelated words than to target words that are preceded by semantically related words (Bentin, McCarthy, & Wood, 1985). Although the N400 wave is a sensitive index of linguistic processing (Kutas & Van Petten, 1988, 1994), it is also observed to line drawings and pictures of objects (Friedman, Putnam, Ritter, Hamberger, & Berman, 1992; McPherson & Holcomb, 1999; Stuss, Picton, & Cerri, 1986).

A number of investigations utilizing auditory and visual tasks of linguistic and/or semantic processing with word and picture stimuli report that N400 amplitude differentiates between children and adults with RD and normally achieving controls. Typically, the LD groups exhibit smaller N400 amplitude or reduced N400 priming effects relative to non-LD controls (Johannes. Mangun, Kussmaul, & Münte, 1995; Lovrich, Cheng, & Velting, 1996; Lovrich, Cheng, Velting, & Kazmerski, 1997; McPherson & Ackerman, 1999; McPherson, Ackerman,

Holcomb, & Dykman, 1998; Neville, Coffey, Holcomb, & Tallal, 1993; Stelmack & Miles, 1990; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988). There is also evidence that adolescents with different subtypes of RD based upon phonological skill (i.e., phonetics and dysphonetics) exhibit differences in N400 (McPherson & Ackerman, 1999; McPherson et al., 1998; McPherson, Ackerman, Oglesby, & Dykman, 1996). The smaller N400 effects observed for LD groups have been interpreted to reflect reduced activation of semantic processes (e.g., Stelmack et al., 1988) or deficits in phonological processing (e.g., McPherson et al., 1998).

There are a few reports of larger N400 amplitude for RD groups compared to non-LD controls. For example, during a task in which spoken words were classified according to their rhyming features (Lovrich et al., 1996, 1997), impaired readers developed larger amplitude N480 waves over central-parietal sites than did normal readers. Similarly, children with language impairments and RD exhibited abnormally large N400 waves to words during a sentence reading task (Neville et al., 1993). These seemingly contradictory effects are thought to reflect the use by individuals with RD of compensatory efforts in integrating these stimuli into a context or an inappropriate reliance on contextual information.

Learning Disability Subtypes and ERPs

Although there are a number of investigations of RD subtypes in the ERP literature (e.g., Dool et al., 1993; McPherson et al., 1996, 1998), the examination of arithmetic disability subtypes (i.e., Subtype A or NLD in Rourke's typology), has been neglected. There are a few studies that have explored ERP differences between children who exhibit specific LD for reading and spelling versus arithmetic according to Rourke's typology. Mattson, Sheer, and Fletcher (1992) reported abnormal patterns of lateralized 40-Hz EEG activity during sentence repetition

and face recognition tasks that differentiated children with specific reading versus arithmetic disabilities from each other and from non-LD controls. Similarly, Brigell, Gordon, Appleby, and Harding (1996) reported less robust effects of attention on early visual ERPs during a spatial, sustained attention task for children with specific LD in either reading or arithmetic relative to non-LD controls, as well as attentional patterns that differentiated the two LD groups. Their results suggested that children with specific LD differed from controls in how they allocated attentional resources. Stelmack and colleagues (Miles & Stelmack, 1994; Stelmack & Miles, 1990; Stelmack et al., 1988) conducted a series of ERP studies of recognition memory and semantic priming using words and pictures with carefully selected groups of school-age children who met criteria for Rourke's typology. Their results, based on group differences in the amplitude of a negative wave at about 450 ms (N450), differentiated the LD subtypes. Children with reading disabilities (i.e., Subtypes R-S and R-S-A) exhibited normal N450 waves to pictures and a normal reduction of N450 to target words that were primed by pictures that shared denotative (i.e., congruent) meaning. This effect was indicative of intact visual-spatial processing. However, children with RD did not exhibit N450 priming effects for semantically associated spoken word- or picture-primers, suggesting that they had deficiencies in the interaction of auditory-verbal and visual-spatial associative systems. Conversely, children in Group A exhibited normal priming by spoken words, suggesting intact auditory-verbal processing, but no evidence of priming by semantically associated pictures, consistent with the view that visual-spatial processing is deficient for these children. Overall, the results of these studies that include homogeneous groups of children with specific LD for reading or arithmetic clearly provide external validation for Rourke's LD typology.

Picture-Word Processing

The independent processing of pictures and words is an established phenomenon in a number of paradigms, including naming, categorization, memory, and semantic interference tasks (Glaser, 1992; Noldy, Stelmack, & Campbell, 1990; Potter & Faulconer, 1975; Rosinski, Golinkoff, & Kukish, 1975; Seifert, 1997; Smith & Magee, 1980). In our previous work using ERP methods (Greenham & Stelmack, 1999; Greenham, Stelmack, & Campbell, 1999), we established that this independence is maintained when pictures and words are presented in superimposed arrays and only attentional focus is manipulated. Adults and normally achieving children aged 9 to 13 years named words and pictures that were presented individually and in superimposed picture-word pairs. In two separate conditions, attention was directed to words (while ignoring pictures) and to pictures (while ignoring words). Physically, the picture-word stimuli were identical in the attend-word and attend-picture conditions. Both adults and children demonstrated the ability to attend to words or pictures in the superimposed pairs and extract the task-relevant stimulus for naming despite the presence of distractor stimuli. That is, for both adults and children, the differences observed in the ERPs to individually presented words and pictures were also observed for words and pictures presented in superimposed pairs. For adults, attention directed to words resulted in larger amplitude N450 waves than attention directed to pictures, whereas for children, in contrast, pictures elicited larger amplitude N450 waves than words. These developmental differences in attentional processing for words and pictures were also observed in effects of semantic relation on N450 amplitude. When adults attended to and named words, there was evidence that the processing of distractor pictures was subject to attentional control (i.e., picture meanings were successfully inhibited). When attending to

pictures. however, adults appeared to process the distractor words automatically, as the word meanings (i.e., congruent, semantically associated, or incongruent with the picture) differentially influenced the amplitude of an anterior N450 wave. There was little evidence that children processed words automatically to the degree observed in adults. Further, the children appeared to be slower or less efficient than adults in managing inhibitory processes.

In the present study, we applied this picture-word naming paradigm to LD subtypes R-S and A to explore the linguistic versus visual-spatial processing differences ascribed to these groups (Rourke, 1989). In previous work with performance measures of picture-word interference, poor readers and undifferentiated groups of children with LD exhibited effects of semantic interference from superimposed distractor words on picture-naming speed that were similar to effects observed for good readers or children without LD, provided that the superimposed words were familiar (Briggs & Underwood, 1982; DeSoto & DeSoto, 1985; Golinkoff & Rosinski, 1976; Guttentag & Haith, 1978; Lovdahl et al., 1986). A similar result was reported for colour-naming speed using a Stroop-like task with pictures of objects that were strongly colour-associated, such as a head of lettuce or an ear of corn (Alwitt, 1966). These findings have been taken as evidence that children with reading difficulties automatically access semantic information from distractor words and pictures. However, children with LD show more interference than non-LD controls when any extraneous information is present (Lovdahl et al., 1986), suggesting that children with LD may be generally less able to inhibit task-irrelevant stimuli. In line with this view, children with LD and poor comprehenders are reported to have deficient inhibitory mechanisms (Gernsbacher & Faust, 1991; Lorschach, Wilson, & Reimer, 1996).

The Present Study

The use of superimposed picture-word pairs provides a method for the assessment of attentional and semantic processing of pictures and words. For adults, distinct ERP waveforms for pictures and words endorses their independent processing. Furthermore, words appear to be processed automatically whereas pictures are subject to attentional control. Although the ERP waveforms of normally achieving children differ from those observed with adults in this task, they do provide some evidence for the independent processing of pictures and words. In the present study, we attempted to determine the way in which subtype-specific deficits in linguistic and visual-spatial processing manifest themselves in the attentional and semantic processing of pictures and words. Although the use of ERP recordings during a picture-word interference task with LD subtypes is a novel approach, certain general predictions can be made for Subtypes R-S and A based on previous work. For example, children in Subtype R-S are expected to exhibit normal N450 waves when attending to pictures (Stelmack & Miles, 1990) but reduced N450 amplitude when attending to words. Associative processing deficits might also be anticipated for Subtype R-S based on previous work with semantic priming of pictures and words (Miles & Stelmack, 1994). For children in Subtype A, it seems reasonable to expect that they might experience difficulty processing the superimposed stimuli in general, given the novelty and visual-spatial complexity of the picture-word pairs (Rourke, 1989). Reductions in N450 amplitude may therefore be anticipated for Subtype A for both attended words and attended pictures. These effects may be more evident, however, when attending to pictures than to words.

Method

Participants

The participants were 26 Dutch-speaking children between the ages of 7 and 12 years. The normally achieving control group was comprised of 10 children (5 males) who were related to a member of the university faculty or staff. The children with learning disabilities were recruited from local elementary schools and from a neuropsychology clinic at Tilburg University. The following selection criteria were met by all children: (a) normal intelligence as determined either by at least average Full Scale IQ scores (> 90) on a Dutch version of the Wechsler Intelligence Scale for Children - Revised (Wechsler, 1974) or by school placement⁶; (b) no auditory or visual deficits; (c) no evidence of brain damage or psychosocial dysfunction; (d) no evidence of attentional deficits; (e) no medications; (f) right-handed (except for one left-handed control child); and (g) normal or corrected-to-normal vision.

Prior to selection for participation, all children who attended Grades 3 through 8 at two elementary schools completed a Dutch version (Bermdsen & van der Vlugt, 1995) of the Wide Range Achievement Test - Third Edition (WRAT-3; Wilkinson, 1993). Scores on the Reading, Spelling, and Arithmetic subtests were converted into discrepancy scores by comparing a child's actual grade level with the grade-equivalent score obtained on each subtest. The learning disability subtype groups were composed on the basis of the children's performance on the three WRAT-3 subtests following the criteria outlined by Rourke and Finlayson (1978). Children in

⁶ In the Netherlands, all children aged 4 to 5 years undergo a screening assessment conducted by a national school screening board. Children with low scores on this screening measure are placed in special observation classes and, if necessary, undergo a full psychoeducational assessment. In this way, children with low IQ are detected prior to entering Grade 3. By virtue of their regular class placement, the children who participated in this study were considered to be of at least average intelligence.

Group RS ($n = 8$; 5 males) obtained Reading and Spelling discrepancy scores of at least -1.5 along with average scores (± 1.0) on the Arithmetic subtest. Children in Group A ($n = 8$; 4 males) obtained Arithmetic discrepancy scores of at least -1.5 along with average scores on the Reading and Spelling subtests. One Group A child with a very poor Arithmetic score (-3.6) also exhibited deficits in reading (-1.5) and spelling (-1.3), however, this followed the overall pattern of deficient arithmetic relative to reading and spelling (Rourke & Finlayson, 1978). Normal control children (Group NC) obtained average or better scores on the Reading, Spelling, and Arithmetic subtests. The mean WRAT-3 subtest scores were significantly higher for controls compared to the RS and A groups, which differed significantly from each other according to the selection criteria ($F(4, 40) = 36.66$, $MSE = 0.27$, $p < .0001$). The groups did not differ with respect to age ($F < 1$). Mean selection scores for the three groups are presented in Table 4.1.

Stimulus Materials

With minor modifications, the stimuli were the same as those used in our previous work (Greenham et al., 1999; Greenham & Stelmack, 1999). All of the word stimuli were translated from English into Dutch and verified for appropriate meaning in relation to the pictures with which they were paired.

The 360 superimposed picture-word stimuli were formed by pairing unambiguous, black-on-white line drawings with words that were either congruent (i.e., same denotative meaning), semantically associated, or incongruent (i.e., not related) with the picture meanings (see Figure 4.1). The pictures were taken from Pictures. Please!, a manual used in speech therapy (Abbate & LaChappelle, 1984), and were scanned for presentation on a computer monitor. The superimposed stimuli were divided randomly into two separate lists of 180 trials with equal

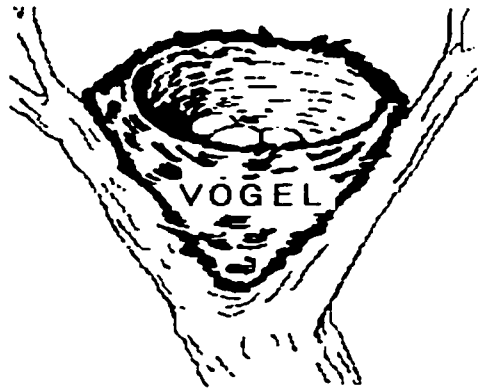
Table 4.1 Mean Age in years and WRAT-3 Discrepancy Scores (SDs) for Normally Achieving Children and Learning Disability Subtypes

Group	n	Age (years)	WRAT-3 Subtest		
			Reading	Spelling	Arithmetic
NC	10	8.8 (1.7)	0.7 (0.6)	0.7 (0.5)	1.3 (0.7)
RS	8	9.3 (1.4)	-1.9 (0.5)	-2.0 (0.3)	-0.3 (0.3)
A	8	9.0 (1.5)	-0.1 (0.4)	-0.5 (0.6)	-2.3 (0.7)

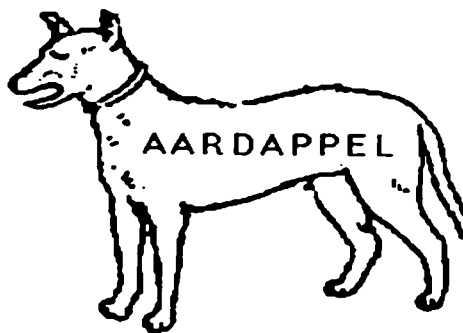
Note. NC = Normally-achieving Controls; RS = Reading-Spelling disabled; A = Arithmetic disabled



A) Congruent



B) Associated



C) Incongruent

Figure 4.1 Examples of Dutch congruent (doll-DOLL), associated (nest-BIRD), and incongruent (dog-POTATO) superimposed picture-word stimuli.

numbers ($n = 60$) of congruent, associated, and incongruent picture-word pairs to form the attend-word and attend-picture conditions. For the control condition, 60 words and 60 pictures were chosen randomly from the pool of 360 to be presented individually (i.e., not superimposed)⁷.

There were slight differences between the words and pictures in each condition (control, congruent, associated, and incongruent) with respect to the length and frequency (per million) of the base-words according to the CELEX Dutch database (Baayen, Piepenbrock, & Gulikers, 1995). Across conditions, pictures were slightly longer in mean base-word length than words (6.4 vs. 6.0). Attended words that were superimposed by associated pictures had a higher mean base-word frequency count (173 per million) than did stimuli in all other conditions (range: 17 to 44 per million). However, this was due to the presence of three very high frequency (> 600 per million) attended words in the associated condition (mean = 73 per million without these outliers).

The stimuli were presented on a computer monitor placed approximately 0.75 m in front of the children. On average, pictures subtended a visual angle of 5° horizontally and 3° vertically, whereas words subtended a visual angle of 4° horizontally and 1° vertically. The words were typed in uppercase letters. In each condition, the stimuli were presented for a duration of 1400 ms. The inter-stimulus interval (offset to onset) was 3500 ms.

⁷ A proportion of the control words and pictures appeared in the previous attend condition; however, as reported in our previous work (Greenham et al., 1999), these repetitions did not affect the overall pattern of results. Both repeated and unrepeated pictures elicited greater posterior positivities than did repeated and unrepeated words, which elicited greater anterior negativities.

Procedure

The ERP recordings were obtained in one session that lasted 1½ to 2 hours. Upon entering the lab, the children and their parents were familiarized with the equipment and the procedure. Parents gave informed consent, and the children also gave verbal consent. The electrodes were then applied.

The children completed a short practice session followed by the three experimental conditions. In the attend-word condition, 180 picture-word pairs were presented randomly and the participants were instructed to attend to and name the words and ignore the pictures. In the attend-picture condition, the remaining 180 picture-word pairs were presented randomly. Instructions required that participants attend to and name the pictures and ignore the words. Words and pictures in the control condition were presented individually in a random order and participants named each one. In all three conditions, words and pictures were named aloud after stimulus offset to avoid muscle artifact during the EEG recordings. The children's naming responses to each trial were recorded. The children were instructed to avoid blinking or moving their head as much as possible while the stimuli were displayed on the monitor. The order of presentation of the attend-word and attend-picture conditions was counterbalanced across participants, and these two conditions were always separated by the control condition.

Immediately following the EEG recordings, all children (except one child in Group A) completed a behavioural naming task in which they were asked to name lists of 48 words and 48 pictures (printed in columns on single sheets of paper) as quickly and accurately as possible (see Appendix). Naming errors and total list naming time (in seconds) were recorded. All children

received a certificate and a photograph of themselves wearing the electrodes for their participation.

EEG Recording

The EEG was recorded using 10 mm Beckman Ag/AgCl electrodes affixed to the scalp at F₃, F₄, C₂, P₃, P₄, and O₂ according to the International 10-20 system (Jasper, 1958). Each electrode was referred to a noncephalic, balanced sternovertebral site (Stephenson & Gibb, 1951). The vertical electrooculogram (EOG) was recorded from electrodes placed on the supra- and infra-orbital ridges of the left eye. The horizontal EOG was recorded from electrodes placed on the outer canthus of each eye. A ground electrode was affixed to the nose. To minimize skin potential artifacts, the skin was cleaned with alcohol and abraded with either a sterile needle or an abrasive scrub at each of the scalp, reference, EOG, and ground sites. Inter-electrode impedance was below 2 k Ω at scalp sites and below 10 k Ω at EOG sites.

EEG and EOG signals were amplified using custom-built amplifiers. For each channel, the time constant was set at 2 s and the high filter at 30 Hz. The EEG was recorded continuously at a 256 Hz sampling rate per channel for each condition. The EEG was subjected to an EOG correction routine prior to signal averaging (Woestenburg, Verbaten, & Slangen, 1983). The algorithm employs correction using a regression analysis in both the time and frequency domains in an attempt to avoid overcompensation. The data were subsequently reconstructed off-line to form discrete trials that began 100 ms prior to stimulus onset and continued for the following 1000 ms. Trials were sorted and averaged according to stimulus category to form a total of eight sets of waveforms per participant (i.e., congruent, associated, and incongruent attended words and pictures, and individually presented words and pictures). Only trials for which a correct

naming response was given were included for averaging. Overall, the number of naming errors was low ($< 7.5\%$). The mean number of correct trials included in each stimulus category waveform was 47 (range: 39 to 51), and this did not vary as a function of group ($F < 1$). Single trials were rejected from the averaging routine when the EOG or EEG signal was saturated (i.e., clipping). On average, fewer than 9% of correct trials were lost for this reason, and there were no significant differences between groups, stimulus types, or experimental conditions in the number of rejected trials ($F_s < 1.52$). The data were further subjected to digital filtering operating in the frequency domain (without windowing) with the high filter set at 15 Hz (-3 dB setting).

ERP Scoring

The ERP analysis focused on a negative wave (N450) having maximum peak amplitude over frontal and central sites between 325 to 650 ms post-stimulus in the grand average waveforms. Previous work (e.g., Miles & Stelmack, 1994) has demonstrated that N450 differentiates between children who meet criteria for distinct LD subtypes based on patterns of academic achievement. Maximum peak amplitude for N450 was measured at F_3 , F_4 , and C_z , using a computer scoring routine. The latency and amplitude values were subsequently confirmed visually using manual scoring techniques.

Data Analyses

Mixed analyses of variance (ANOVAs) were conducted using STATISTICA for Windows software (StatSoft, 1995) with group (NC, RS, A) as the independent grouping variable and repeated measures on stimulus type (words, pictures), condition (congruent, associated, incongruent), or electrode site, depending on the factor of interest. The Greenhouse-Geisser correction for repeated measures, reported as adjusted p -values, was applied when

necessary. Post-hoc comparisons were made using the Newman-Keuls procedure. Specific questions were addressed by way of planned comparisons that isolated the effects of interest. The .05 level of confidence was applied to all statistical tests.

Results

Behavioural Task: Word- and Picture-List Naming

When asked to name lists of words and pictures as quickly and accurately as possible, the children were significantly slower to name pictures (58 s) than to read words (36 s), $F(1, 22) = 94.06$, $MSE = 61.08$, $p < .0001$. In addition, a greater percentage of errors was made during picture-naming (4.1%) than word-reading (3.1%), $F(1, 22) = 4.95$, $MSE = 3.29$, $p < .05$. However, examination of the means (see Table 4.2) revealed that only Group A made significantly more naming errors for pictures than words, $t(6) = 2.46$, $p < .05$.

On the word list, controls (Group NC) and Group A both made significantly fewer naming errors than Group RS, $F(2, 22) = 5.46$, $MSE = 3.99$, $p < .01$. Group NC was also significantly faster at word-reading than Group RS, whereas Group A occupied an intermediate position, $F(2, 22) = 6.29$, $MSE = 103.42$, $p < .01$. On the picture list, Group NC made significantly fewer naming errors, $F(2, 22) = 4.50$, $MSE = 9.10$, $p < .05$, and were significantly faster, $F(2, 22) = 8.87$, $MSE = 53.85$, $p < .005$, than either Group RS or A who did not differ. Mean percent error and naming speed data for the list naming tasks for the three groups are presented in Table 4.2.

Table 4.2 List Naming: Mean Percentage of Errors and Naming Speed (SDs) for Normally Achieving Children and Learning Disability Subtypes

Group	Error Rate (%)		Naming Speed (seconds)	
	Words	Pictures	Words	Pictures
NC	1.9 (1.5)	1.9 (1.5)	28.1 (4.4)	50.1 (5.7)
RS	4.9 (2.5)	5.7 (3.8)	45.1 (16.6)	62.0 (9.2)
A	2.7 (2.0)	5.4 (3.6)	37.3 (5.2)	63.4 (7.1)
All Groups	3.1 (2.3)	4.1 (3.4)	36.1 (12.2)	57.6 (9.4)

Note. NC = Normally-achieving Controls; RS = Reading-Spelling disabled; A = Arithmetic disabled

Table 4.3 Naming during ERP Tasks: Mean Percentage of Errors (SDs) for Normally Achieving Children and Learning Disability Subtypes

Group	Control Conditions		Attend Conditions	
	Words	Pictures	Words	Pictures
NC	0.0 (0.0)	7.0 (3.8)	0.4 (0.5)	9.8 (6.2)
RS	6.3 (7.2)	10.0 (5.3)	7.6 (6.1)	15.7 (5.8)
A	1.7 (1.5)	12.3 (6.7)	3.4 (3.0)	15.3 (7.2)
All Groups	2.4 (4.7)	9.6 (5.5)	3.5 (4.7)	13.3 (6.8)

Note. NC = Normally-achieving Controls; RS = Reading-Spelling disabled; A = Arithmetic disabled

Naming Errors during ERP Tasks

During the ERP tasks, Group NC made significantly fewer naming errors across tasks (4.3%) than either Group RS (9.9%) or A (8.2%), who did not differ from one another, $F(2, 23) = 6.00$, $MSE = 49.79$, $p < .01$. Across groups, a greater percentage of naming errors was again made for pictures (11.7%) than words (3.2%), $F(1, 23) = 69.80$, $MSE = 26.36$, $p < .0001$. Similarly, a greater percentage of naming errors was made during attend (8.7%) than control (6.2%) conditions, $F(1, 23) = 15.15$, $MSE = 10.65$, $p < .001$. Mean error rates for the three groups for the ERP tasks are presented in Table 4.3.

Separate task analyses of group differences indicated that, when reading individually presented words, Group RS made a significantly greater percentage of errors than either Group NC or A, who did not differ from one another, $F(2, 23) = 5.51$, $MSE = 16.36$, $p < .01$. When attending to words in the superimposed stimulus pairs, Group RS again made significantly more reading errors than Group NC. The error rate for Group A was intermediate to, but not significantly different from, the other two groups, $F(2, 23) = 8.36$, $MSE = 13.99$, $p < .005$. There were no significant group differences on the control picture or attend-picture tasks ($ps < .12$).

ERPs to Individually Presented Words and Pictures

Group differences. Grand average ERP waveforms to individually presented words and pictures in the control condition for the three groups are presented in Figure 4.2. Mean N450 amplitude values can be found in Table 4.4. Examination of the waveforms indicated that controls (Group NC) exhibited long latency negative waves across anterior electrode sites to both words and pictures. When reading individually presented words, Group NC showed much greater N450 amplitude across frontal and central electrode sites than did either Group RS or A, who did

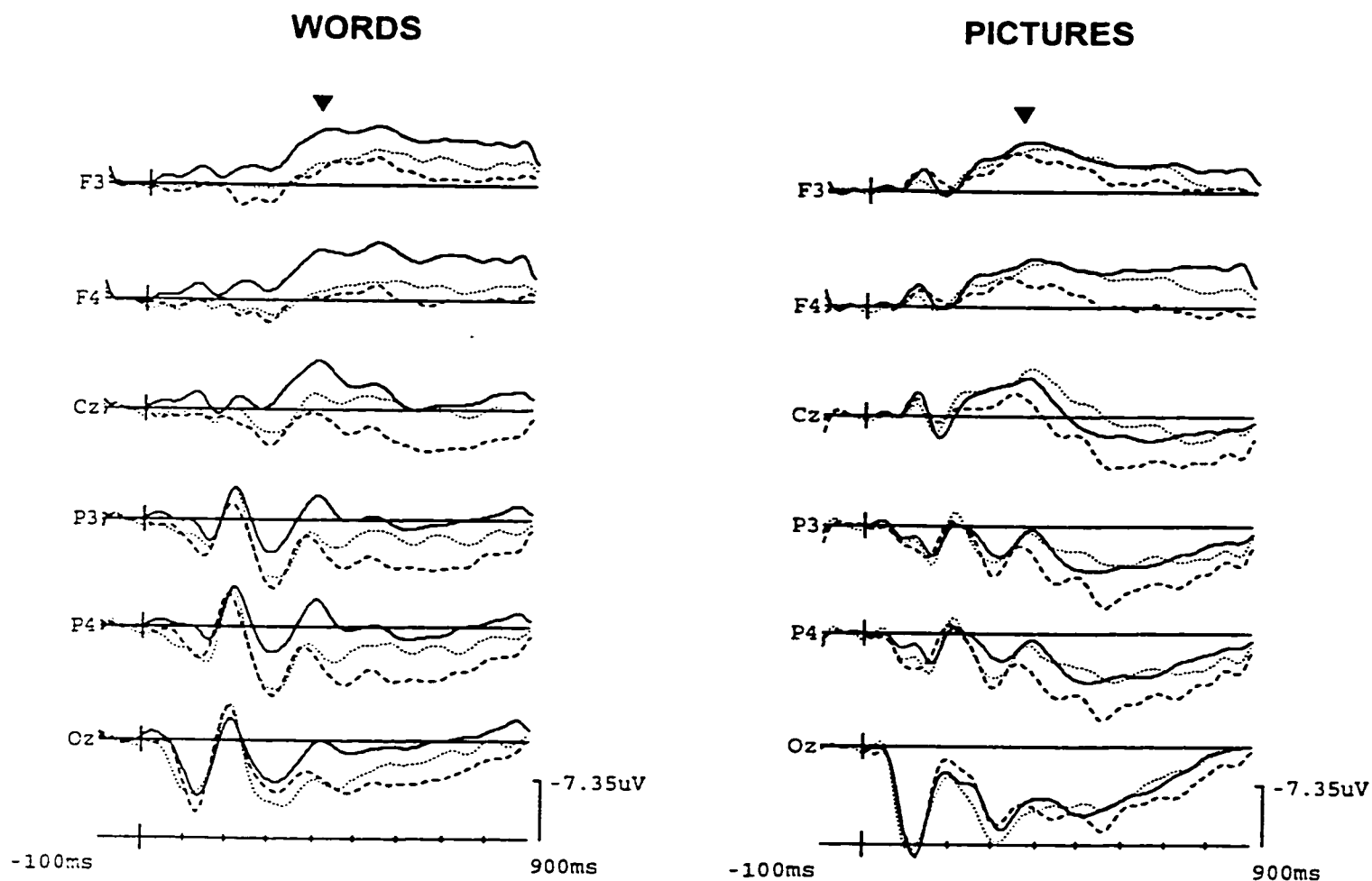


Figure 4.2 Grand average ERP waveforms illustrating group differences in N450 amplitude to individually presented words and pictures for normally achieving controls (—), reading disabled (.....), and arithmetic disabled (-----) children. All children exhibit anterior N450 waves. Note that for words, N450 waves are significantly greater in amplitude for controls (NC) than for reading disabled (RS) or arithmetic disabled (A). For pictures, N450 waves are similar for NC and RS. There was a trend for smaller N450 amplitude for Group A.

Table 4.4 Mean N450 Amplitude (μ V) (SD) as a Function of Stimulus Type, Electrode Site, and Condition for Normally Achieving Children and Learning Disability Subtypes

Condition	Group								
	NC			RS			A		
	F ₃	F ₄	C _z	F ₃	F ₄	C _z	F ₃	F ₄	C _z
Words									
Individual	-7.9 (2.9)	-7.9 (2.5)	-6.6 (3.3)	-5.1 (4.8)	-3.7 (4.1)	-4.0 (4.0)	-4.6 (3.4)	-3.3 (3.0)	-0.9 (4.5)
Congruent	-8.9 (3.3)	-8.5 (3.6)	-7.6 (5.1)	-6.0 (5.8)	-6.8 (5.4)	-5.6 (5.4)	-3.5 (4.4)	-2.2 (3.9)	-0.7 (4.4)
Associated	-9.2 (3.0)	-9.0 (3.1)	-8.3 (3.4)	-6.0 (4.0)	-5.6 (3.3)	-4.2 (4.5)	-6.3 (2.5)	-4.9 (2.1)	-3.8 (3.0)
Incongruent	-8.5 (3.8)	-8.2 (4.4)	-7.6 (5.0)	-5.5 (3.3)	-5.8 (4.2)	-5.8 (5.1)	-6.7 (1.5)	-5.2 (2.6)	-4.2 (2.9)
Pictures									
Individual	-7.2 (3.7)	-7.4 (4.7)	-6.1 (2.8)	-6.7 (4.9)	-6.7 (4.4)	-6.6 (5.1)	-5.5 (2.0)	-4.2 (2.0)	-3.7 (3.4)
Congruent	-8.8 (6.1)	-8.8 (6.0)	-8.1 (5.2)	-9.0 (3.0)	-9.4 (2.3)	-7.5 (4.5)	-5.3 (7.8)	-3.9 (8.2)	-3.0 (7.8)
Associated	-10.0 (6.5)	-10.6 (6.0)	-9.6 (3.8)	-8.5 (3.8)	-7.8 (3.9)	-7.2 (6.2)	-2.9 (6.2)	-1.7 (5.4)	-1.5 (5.7)
Incongruent	-6.9 (4.6)	-7.7 (3.1)	-6.7 (3.5)	-6.2 (4.0)	-6.0 (3.7)	-5.2 (5.5)	-5.0 (6.8)	-3.4 (6.5)	-2.7 (6.3)

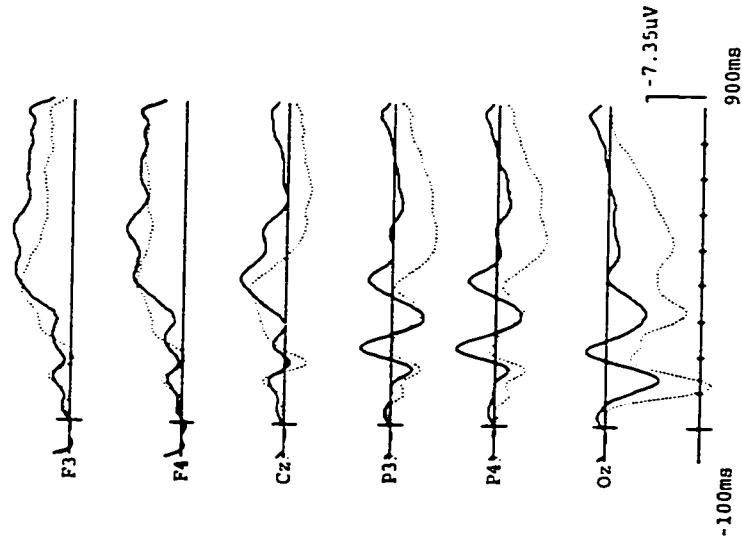
Note. NC = Normally-achieving Controls; RS = Reading-Spelling disabled; A = Arithmetic disabled

not differ from one another, $F(2, 23) = 4.75$, $MSE = 31.91$, $p < .05$. When naming individually presented pictures, the ERP waveforms across anterior electrode sites for Group RS closely resembled those of Group NC, whereas Group A continued to exhibit smaller negativities, particularly at F_4 and C_z . However, these amplitude differences did not reach statistical significance ($ps < .10$ and $.12$ for F_4 and C_z , respectively). There were no significant group differences in N450 latency for individually presented words or pictures. For both words and pictures, Group A exhibited a long-lasting positive shift in the waveforms after 400 ms at central and posterior electrode sites that appeared more prominent than for either Group NC or RS. Group differences at early latencies at the occipital site appeared unremarkable.

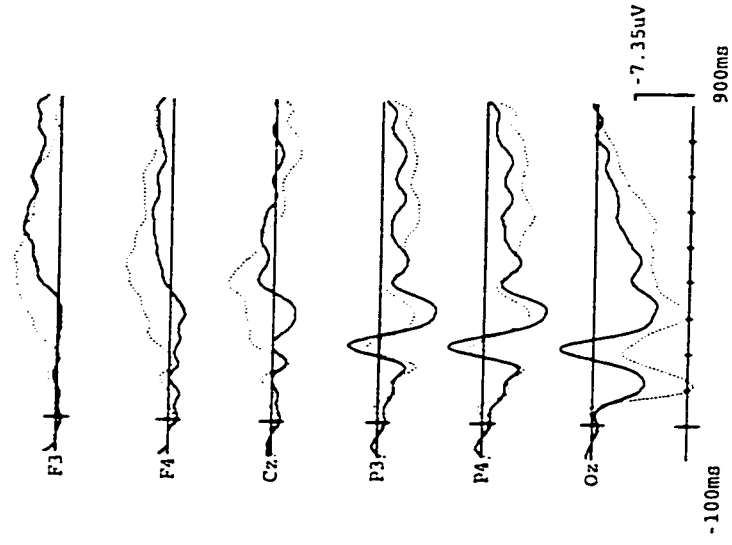
Words versus pictures. Differences in N450 amplitude and latency for individually presented words and pictures were examined for each group separately. The grand average waveforms can be found in Figure 4.3, revealing different N450 patterns for each group. For Group NC, marginally faster N450 latency was observed to individually presented pictures than words ($p < .08$), however, N450 amplitude to words and pictures did not differ ($F < 1$). This was in contrast to a previously reported effect on the same task for normally achieving English-speaking children who exhibited greater amplitude N450 waves to pictures than words (Greenham & Stelmack, 1999). For Group RS, individually presented pictures elicited significantly shorter N450 latency than words, $F(1, 7) = 6.89$, $MSE = 6112.17$, $p < .05$. Although N450 amplitude to pictures and words did not differ significantly for Group RS ($p < .13$), the difference was in the expected direction with greater N450 amplitude to pictures than words. For Group A, N450 amplitude was greater for individually presented pictures than words, but this effect was significant only at C_z , $F(2, 14) = 4.71$, $MSE = 0.97$, $p < .05$. N450 latency

Figure 4.3 Grand average ERP waveforms to individually presented words (—) and pictures (.....), presented separately for normally achieving controls (NC), reading disabled (RS), and arithmetic disabled (A) children.

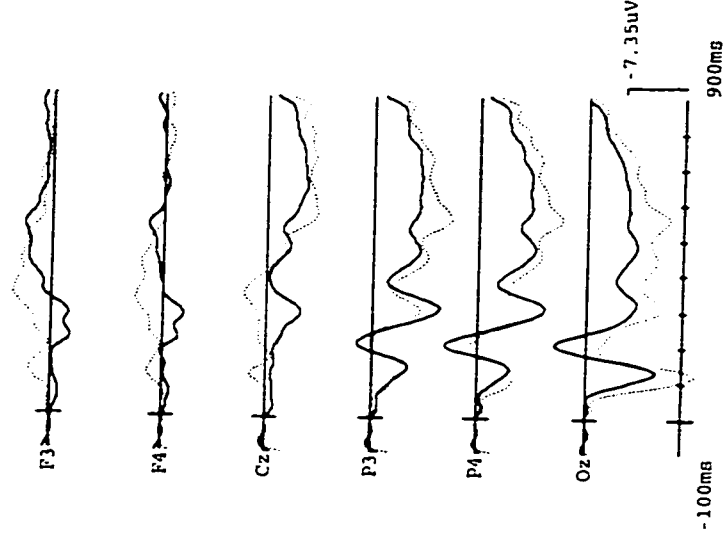
GROUP NC



GROUP RS



GROUP A



was significantly shorter for individually presented pictures than words, $F(1, 7) = 31.78$, $MSE = 3422.82$, $p < .001$. Inspection of the waveforms (see Figure 4.3) also indicated that all groups exhibited long latency positive waves over posterior electrode sites that appeared greater in amplitude for pictures than words. This was consistent with previous reports of greater positivities for pictures than words (Greenham & Stelmack, 1999; Kok & Rooyakkers, 1986; Noldy et al., 1990).

Hemispheric differences. Groups RS and A both exhibited a left-greater-than-right frontal asymmetry for N450 amplitude when reading individually presented words, $F_s(1, 23) = 5.86$ and 5.31 , $MSE = 1.34$, $ps < .05$, whereas only Group A showed this asymmetry when naming individually presented pictures, $F(1, 23) = 4.69$, $MSE = 1.43$, $p < .05$. Group NC did not exhibit hemispheric differences for either words or pictures.

ERPs to Attended Words and Pictures

Group differences. Grand average ERP waveforms for the three groups to attended words and pictures presented in superimposed pairs (collapsed across levels of semantic relatedness) are presented in Figure 4.4. When attending to words in the superimposed stimulus pairs, controls exhibited larger anterior N450 waves than did Groups RS and A, $F(1, 23) = 7.34$, $MSE = 92.07$, $p < .05$, who did not differ significantly from one another, ($F < 1$). In contrast, when attending to pictures, controls and Group RS did not differ significantly in N450 amplitude ($F < 1$). However, both groups had significantly larger anterior N450 waves than Group A, $F(1, 23) = 5.72$, $MSE = 193.77$, $p < .05$.

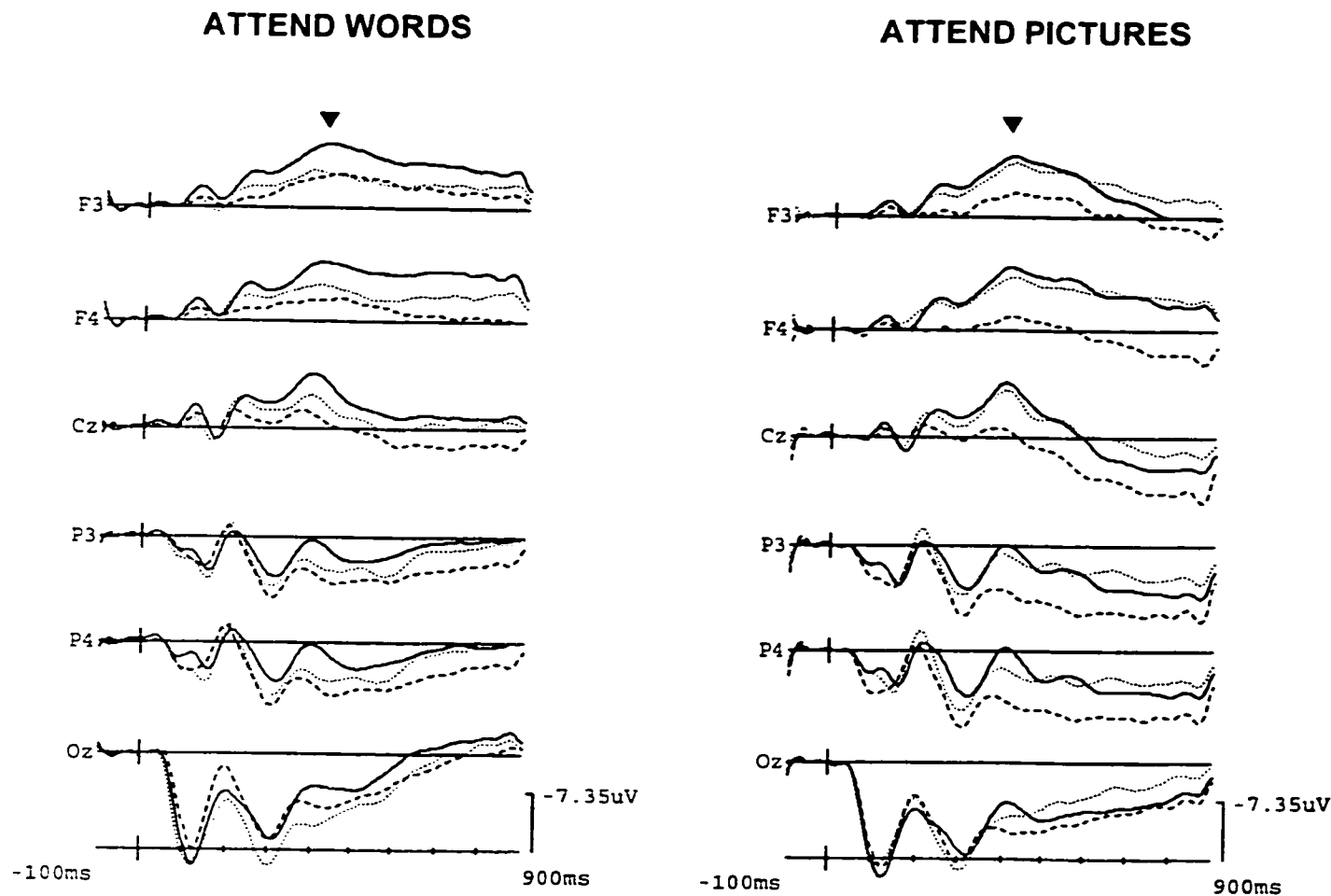


Figure 4.4 Grand average ERP waveforms illustrating group differences in N450 amplitude to attended words and pictures for normally achieving controls (—), reading disabled (.....), and arithmetic disabled (----) children. For attended words, N450 waves are significantly greater in amplitude for Group NC than for Groups RS or A, who do not differ. For attended pictures, N450 waves are significantly greater in amplitude for Groups NC and RS than for Group A.

Semantic effects. To explore effects of semantic relation on the ERPs, difference waveforms were created by subtracting the ERPs to individually presented words and pictures from the ERPs to congruent, associated, and incongruent attended words and pictures. This procedure displays the effect of the distractor pictures or words, respectively. These difference waveforms are presented for each of the three groups in Figure 4.5. Separate analyses of semantic relation on the N450 wave were carried out for the attend-word and attend-picture conditions for each group.

For controls, the distractor pictures had some effect on the early portions of the attend-word waveform, but had no significant effect on the N450 wave ($F < 1$). That is, the picture meanings did not influence N450 amplitude to attended words. In contrast, controls exhibited effects of semantic relation on N450 in the attend-picture condition, suggesting that they processed the meanings of the distractor words. Larger N450 waves were observed at frontal sites for pictures superimposed by associated than incongruent (but not congruent) distractor words. $F(2, 18) = 3.69$, $MSE = 11.98$, $p < .05$, and at C_z for pictures superimposed by associated than congruent and incongruent distractor words. $F(1, 9) = 6.33$, $MSE = 4.81$, $p < .05$. These effects were also apparent over the parietal sites. Indeed, attended pictures in the associated condition appeared to elicit a long-lasting, overlapping negativity in the difference waveforms that extended across the recording epoch starting at approximately 100 ms post-stimulus (see Figure 4.5).

Group RS appeared to exhibit a larger effect of the distractor pictures at early latencies (200-300 ms) over anterior sites in the difference waveforms for attended words than was observed for controls. However, as was the case for controls, no significant effects of semantic

relation were observed for N450 amplitude for Group RS when attending to words ($F < 1$). That is, there was little evidence that they processed the picture meanings. In contrast, when attending to pictures, Group RS exhibited significant semantic effects on frontal N450 amplitude, $F(2, 14) = 4.00$, $MSE = 10.20$, $p < .05$. Pictures superimposed by incongruent words elicited smaller N450 amplitude at frontal sites than pictures superimposed by congruent and (to a degree) associated words. These semantic effects differed from those observed for controls both in magnitude as well as with respect to the overall pattern. Specifically, the difference waveform to attended pictures in the associated condition appeared to be reduced for Group RS relative to controls.

Only Group A exhibited effects of semantic relation when attending to words. Across anterior sites, larger N450 amplitude was observed for words superimposed by associated and incongruent distractor pictures as compared to congruent pictures, $F(1, 7) = 6.76$, $MSE = 21.95$, $p < .05$. Again, similar effects were apparent over parietal sites. Indeed, ERPs to attended words in the associated and incongruent conditions were characterized by a sustained overlapping negativity in the difference waveform that extended across the recording epoch. This suggested that Group A processed the meanings of the distractor pictures, despite instructions to ignore them. In contrast, there was little evidence that Group A processed the meanings of the distractor words, as there were no significant effects of semantic relation on the N450 wave to attended pictures ($F < 1$). However, examination of the difference waveforms indicated long latency negativities between 500 and 600 ms that appeared larger for pictures superimposed by congruent and incongruent words as compared to associated words.

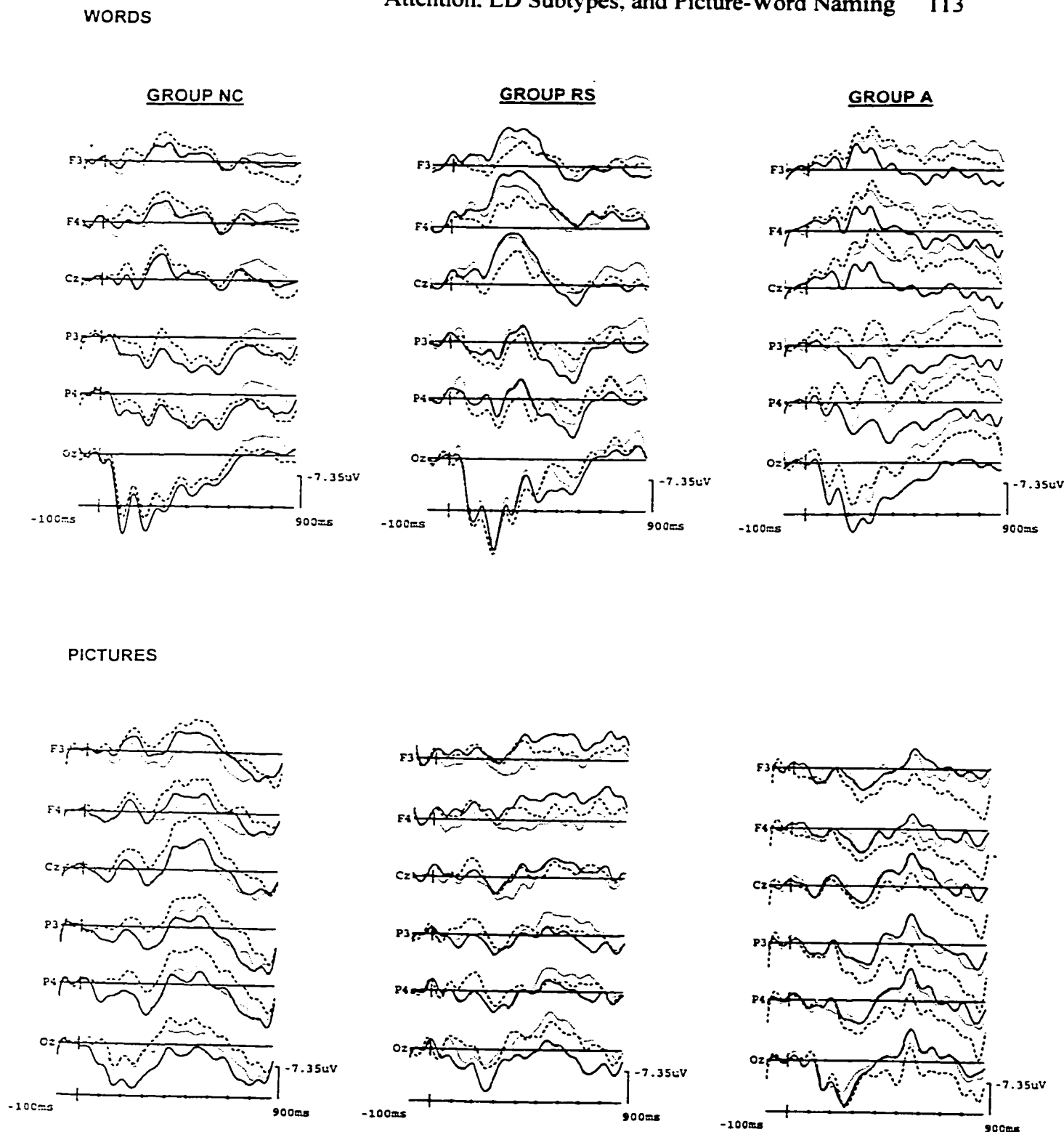


Figure 4.5 Difference waveforms for attended words and attended pictures for normally achieving controls (NC), reading disabled (RS), and arithmetic disabled (A) children. These waveforms were formed by subtracting the ERPs to individually presented words and pictures from the ERPs to congruent (—), associated (----), and incongruent (.....) stimuli. The difference waveforms illustrate the influence of the superimposed distractor pictures and words.

Attention effects. Effects of attention were explored by comparing the ERPs to attended words and attended pictures for each group separately. The waveforms are presented in Figure 4.6. If the ERPs that were observed for individually presented words and pictures are maintained for words and pictures presented in superimposed stimulus pairs, then this would provide evidence for the independent attentional processing of words and pictures despite their simultaneous presentation.

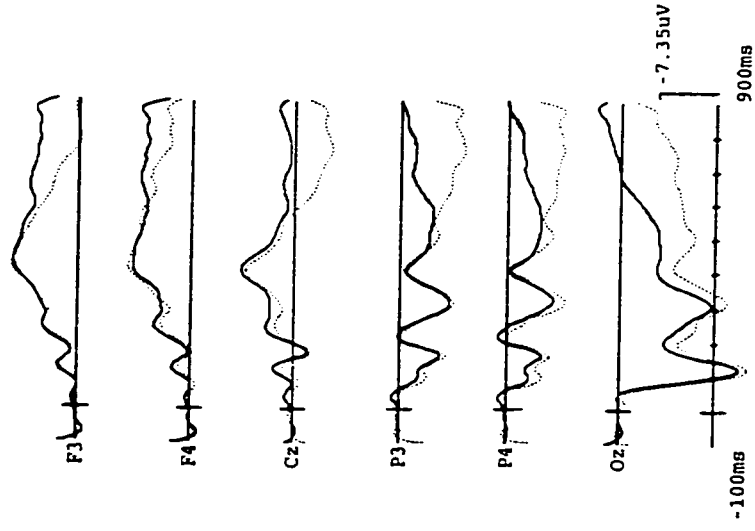
For control children, attended words and pictures did not differ in N450 amplitude over anterior electrode sites ($F < 1$), whereas positive waves were observed over central and parietal sites for attended pictures but not words. Group RS exhibited marginally greater N450 amplitude for attended pictures than words ($p < .08$). For Group A, attended pictures exhibited greater N450 amplitude than attended words but only for the congruent stimulus pairs; for the associated and incongruent stimulus pairs, attended words were more negative than attended pictures. However, this interaction was only marginally significant ($p < .067$). Again, attended pictures appeared to elicit greater positive waves over posterior sites than attended words for Group A.

Hemispheric differences. As was observed for individually presented words and pictures, Group A exhibited a left-greater-than-right hemisphere frontal asymmetry for N450 amplitude when attending to words and pictures in the superimposed conditions, $F_s(1, 23) = 4.97$ and 4.66 , $MSE = 4.78$ and 5.06 , $ps < .05$, respectively. Neither Group NC or RS exhibited this asymmetry for attended words or pictures ($F_s < 1$).

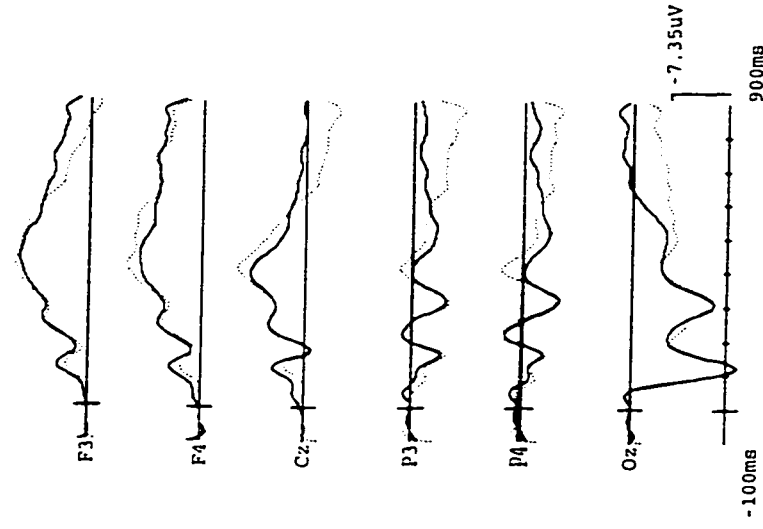
Figure 4.6 Grand average ERP waveforms to attended words (___) and pictures (.....) as a function of semantic relatedness presented separately for normally achieving controls (NC), reading disabled (RS), and arithmetic disabled (A) children.

GROUP NC

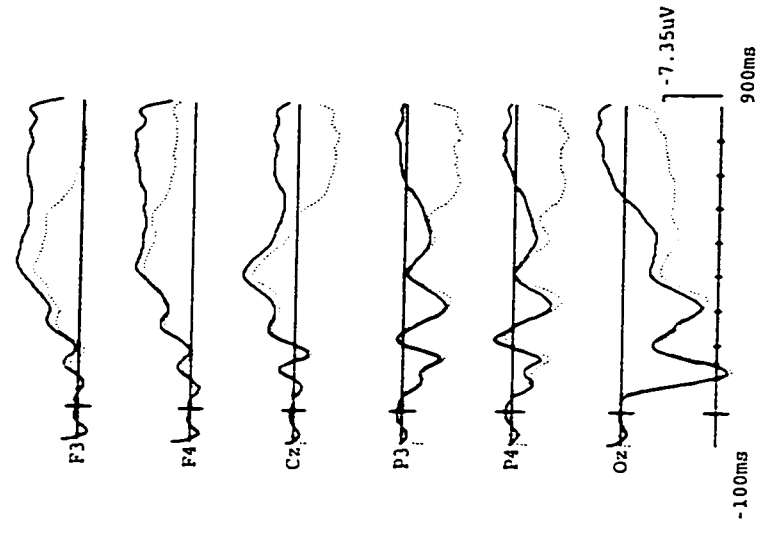
CONGRUENT



ASSOCIATED

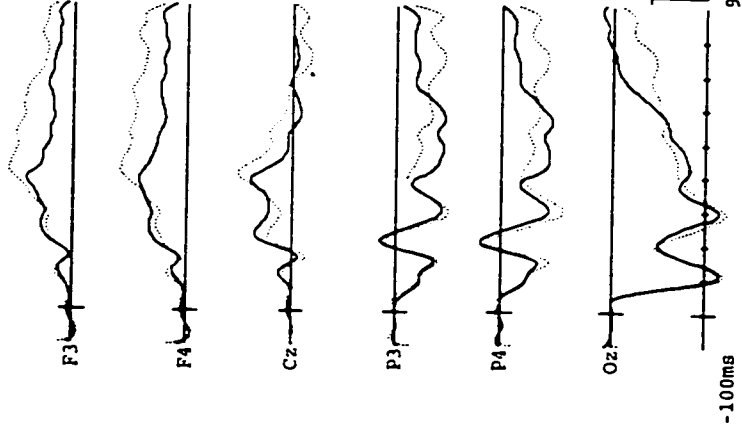


INCONGRUENT

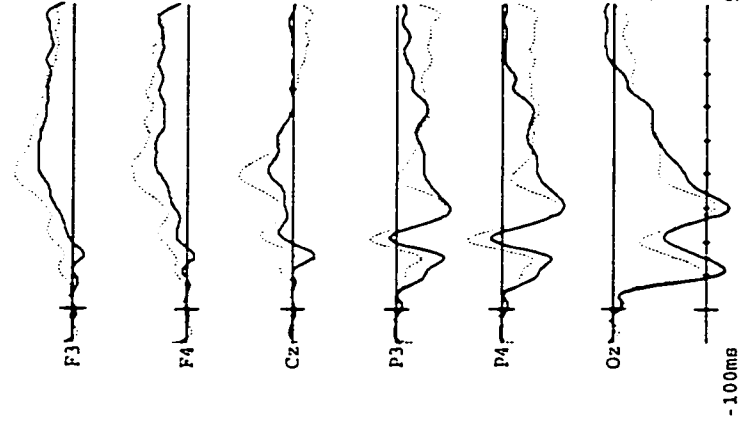


GROUP RS

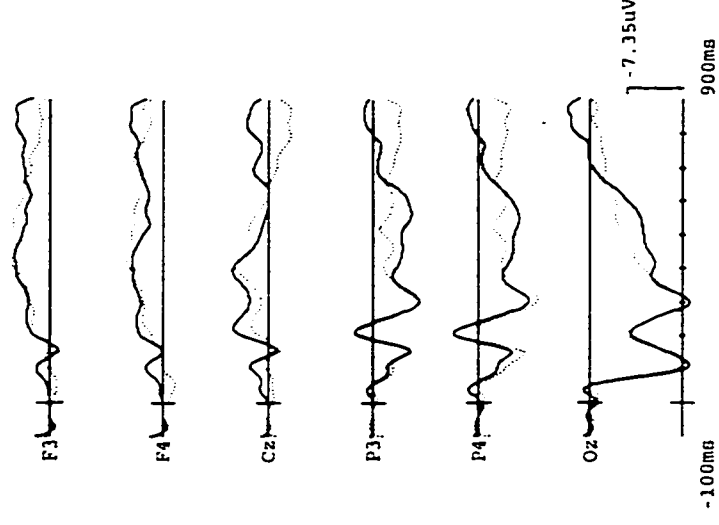
CONGRUENT



ASSOCIATED

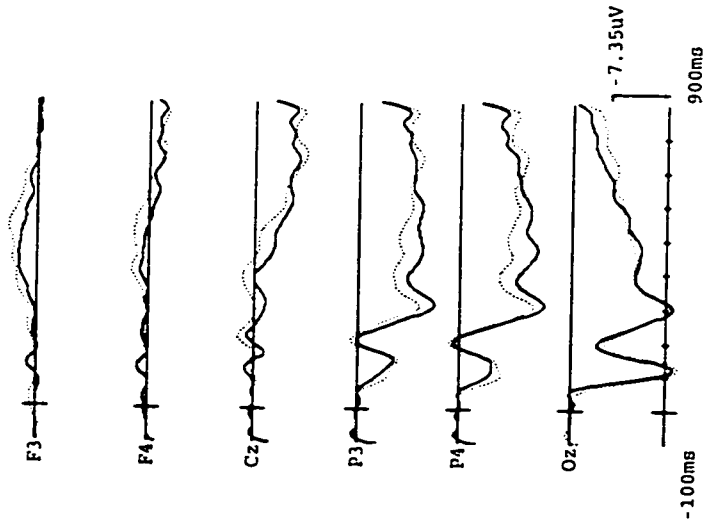


INCONGRUENT

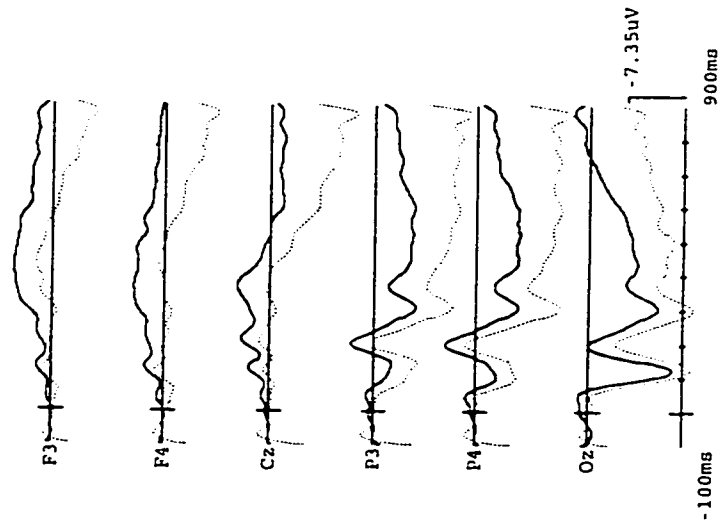


GROUP A

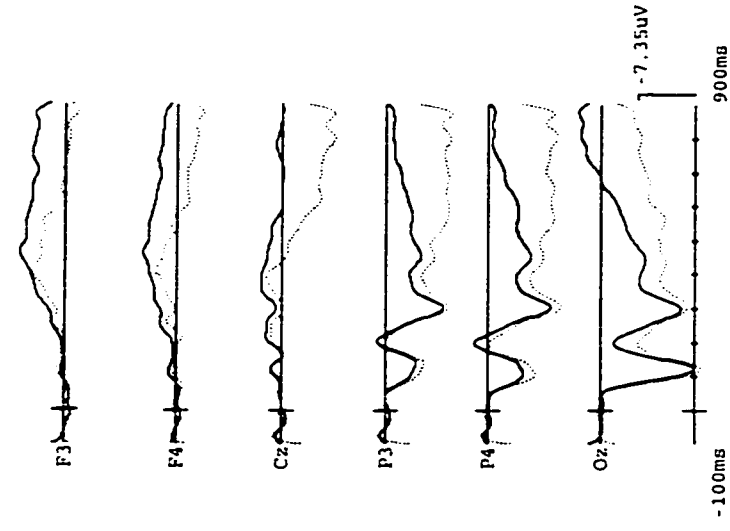
CONGRUENT



ASSOCIATED



INCONGRUENT



Discussion

All of the children in the present study, regardless of their level of academic achievement, took longer to name a list of pictures than to read a list of words. This result affirms the large behavioural literature demonstrating longer naming speed for pictures as compared to words or other lexical stimuli for both children and adults (e.g., Denkla & Rudel, 1974; Fraisse, 1969; Potter & Faulconer, 1975; Smith & Magee, 1980). This difference in naming speed is generally understood in terms of two independent but interconnected representational subsystems for pictures and words (Glaser, 1992; Johnson, Paivio, & Clark, 1996). For normally achieving Dutch-speaking children who participated in this study, the naming speed and error rate for the word- and picture-lists were virtually identical to the data obtained for a comparable sample of normally achieving Canadian children in our previous work (Greenham & Stelmack, 1999). These results confirm the validity of the list-naming task for assessing naming differences between pictures and words across different languages.

Children with specific learning disabilities in reading and spelling (Group RS) were slower on list-naming tasks and made more errors on list-naming and ERP naming tasks than controls (Group NC) for both word- and picture-stimuli. These findings concur with previous reports of naming deficits for objects and lexical stimuli in dyslexics and poor readers relative to non-LD controls (Badian, 1993; Denkla & Rudel, 1976a, 1976b; Katz, 1996; Rubin, Bernstein, & Katz, 1989; Swan & Goswami, 1997; Wolf, 1991). This effect is characteristic of a generalized naming deficit for Group RS, possibly due to phonological processing deficiencies (e.g., Katz, 1996; Murphy, Pollatsek, & Well, 1988; Swan & Goswami, 1997). In contrast, children with specific arithmetic disabilities (Group A) did not differ from controls on the word-

reading tasks. Group A exhibited naming deficits relative to controls only on the picture-naming tasks, an effect that is consistent with a specific naming deficit for nonverbal material. The dissociation of Groups RS and A based on these performance measures endorses Rourke's (1982, 1989) typology of LD.

Current cognitive models of object or picture naming (e.g., Johnson et al., 1996) generally include three stages of processing, including identification of the object, activation of one or more name representations, and generation of an overt response. Given that Group A did not exhibit a deficit for word reading, it appears that the processes involved in name activation and response generation are intact. Their picture naming deficit may be attributed to deficiencies in the process of object identification. Difficulties with object identification may result, in part, from inefficient visual processing required to extract stimulus information (Johnson et al., 1996), processing proposed to be deficient for Group A (Rourke, 1989). Analysis of the ERPs recorded during the picture naming task may be helpful in assessing this hypothesis.

ERPs of Normally Achieving Children

Normally achieving children in this study exhibited prominent anterior negative waves when attending to and naming words and pictures that were presented individually and in superimposed picture-word pairs. These data contrast with those obtained on the same task with adults (Greenham et al., 1999), who exhibited smaller anterior negativities to words as compared to children, and posterior positive waves to individually presented pictures. Overall, these results concur with developmental ERP work that demonstrates large anterior negative waves for children, but not adults, in response to a variety of visual stimuli on tasks of naming, classification, recognition memory, and lexical decision (see Courchesne, 1983, and Taylor,

1995, for reviews). The functional significance of these negative waves remains poorly understood (Taylor, 1995). Clearly, however, a common element in these tasks is the activation of semantic or lexical processes (e.g., Berman & Friedman, 1993; Friedman et al., 1992).

The ERPs of the normally achieving Dutch-speaking children in the present study are also remarkably similar to those of a comparable sample of normally achieving Canadian children who completed the same tasks in English (Greenham & Stelmack, 1999). Both groups exhibited large amplitude N450 waves to pictures and words presented individually and in superimposed pairs. The Canadian children exhibited greater N450 amplitude to pictures than words in both control and attend conditions, whereas this wave did not differentiate pictures and words for the Dutch-speaking controls. Overall, however, the waveforms for each task were highly comparable between the groups. These data attest to the reliability of the paradigm for normally achieving children, as well as the generalizability of the data.

Individually Presented Words and Pictures

Greater amplitude negative waves for pictures than words appears to be a typical finding for normally achieving children (Berman, Friedman, & Cramer, 1990; Greenham & Stelmack, 1999; Robertson, Mahensen, & Campbell, 1990). This effect is thought to reflect differences between pictures and words in the effort involved in stimulus identification or automaticity of lexical access. The finding that individually presented words and pictures elicited similar amplitude N450 waves for control children in this study thus appears anomalous. In the present case, the failure to observe greater N450 amplitude to pictures than words for Group NC cannot be attributed to differences in the speed of lexical access. List-naming speed and error rate for

pictures and words were virtually identical for the Canadian and Dutch normally achieving children. This null effect for N450 for the Dutch controls is not easily explained.

Children in Group RS exhibited smaller N450 amplitude relative to Group NC when naming individually presented words. Their ERPs to individual pictures, however, were similar to controls. The smaller N450 waves to words for Group RS cannot be explained by an inability to read the words as only correct naming trials were included in these waveforms. This effect is consistent with previous work with children who met criteria for Group RS (Stelmack & Miles, 1990), and with the view that children with reading disabilities exhibit specific deficiencies in processing linguistic material (Ollo & Squires, 1986; Stelmack et al., 1995). Group RS also exhibited a naming deficit for pictures on the list-naming task. They nevertheless had normal N450 waves to pictures. This suggests that the generalized naming deficit observed on performance measures for these children occurs at a later stage of processing than is reflected by the N450 wave, possibly during the generation of a naming response.

Children in Group A exhibited smaller N450 waves relative to Groups NC and RS when naming individually presented pictures. This confirms the observation previously reported by Miles and Stelmack (1994). Group A also exhibited smaller N450 waves relative to controls when naming individually presented words, but they did not differ from Group RS. This was an unexpected result, as children with specific arithmetic disabilities but normal word recognition and spelling skill are thought to have intact processing of printed text (Rourke, 1982, 1989). Further, Group A did not differ from controls in individual word naming speed or error rate. It is possible that the nature of the task demands may have contributed to a general reduction in N450 for Group A. In the control condition, the words and pictures were presented randomly. Thus,

each trial was unpredictable and the children in Group A may have experienced difficulty with the novel aspects of this visual-spatial task. Different results may have been observed if the words and pictures were presented in blocks, as were the stimuli in the behavioural list-naming task.

Superimposed Words and Pictures

Analysis of the ERP waveforms recorded during a naming task for individually presented words and pictures confirmed that N450 amplitude differentiated children with specific LD in reading and spelling versus arithmetic from one another and from normally achieving controls. The presentation of superimposed pictures and words provided a means with which to assess subtype-specific deficits in selective attention to these stimuli. Analysis of the ERPs in the more complex attentional tasks revealed the same pattern of group differences. That is, normally achieving controls were differentiated from the two LD groups, who were differentiated from one another. Children in Group RS exhibited smaller N450 waves relative to Group NC for attended words but not for attended pictures, whereas children in Group A exhibited smaller N450 waves in both attend-tasks. Thus, the superimposed picture-word naming task was also successful in differentiating LD subtypes.

Manipulation of the children's attentional focus to words or pictures in the superimposed pairs did not result in clear effects of attention on the ERP waveforms for any of the children who participated in the present study. This contrasted with clear effects of attention that were previously observed for adults and normally achieving children in an English version of this task (Greenham & Stelmack, 1999). That is, distinct ERPs were observed for words and pictures, and these waveforms were maintained for superimposed words and pictures. Nevertheless, the

controls and children with LD exhibited different effects on N450 amplitude by congruent, associated, and incongruent stimulus pairs that further discriminated the groups.

When normally achieving controls attended to words, N450 amplitude was the same regardless of whether the superimposed pictures were congruent, associated, or incongruent in meaning. The same result was obtained for Group RS. This effect suggests that these two groups of children inhibited or did not process the meaning of the pictures. For Group RS, this suggests that their ability to inhibit or ignore the picture meanings was intact. In contrast, when controls and Group RS attended to pictures, the meaning of the superimposed distractor words differentially modulated N450 amplitude, suggesting that the word meanings were processed. For controls, N450 amplitude was greater for associated superimposed words than for incongruent superimposed words. This pattern of semantic effects for attended pictures were generally consistent with those observed previously for normally achieving children (Greenham & Stelmack, 1999). Compared to controls, Group RS exhibited attenuated N450 amplitude to attended pictures that were superimposed by associated distractor words. No differences between controls and Group RS in N450 were apparent for congruent or incongruent distractor words. This effect concurs with the previously reported observation that Group RS was not sensitive to semantic priming by spoken words or pictures that shared associative meaning with target words (Miles & Stelmack, 1994).

Children in Group A exhibited a different pattern of semantic effects in the attend-word and attend-picture tasks compared to controls and Group RS. Group A exhibited greater N450 amplitude when attending to words superimposed with associated and incongruent pictures than when attending to words superimposed with congruent pictures. This effect suggested that Group

A processed the meanings of the distractor pictures when attending to words. Thus, unlike controls or Group RS, Group A did not appear able to inhibit the picture meanings.

Previous ERP work with Group A investigated the effects of picture priming on the processing of target words (Miles & Stelmack, 1994). In this task, primed words were preceded by pictures that shared an associative meaning with the words. For normally achieving children, N450 amplitude to picture-primed words was smaller compared to unprimed words. In contrast, children in Group A failed to benefit from the effects of picture priming, suggesting that these children had deficient visual-spatial processing for pictures. It was somewhat surprising, therefore, that the semantic effects observed for Group A when they attended to words were consistent with what would be expected for N450; namely increased N450 amplitude when the words were superimposed by incongruent pictures. This effect suggested that the children in Group A were able to process the meanings of the pictures. In the current study, the children in Group A may have been able to process picture meanings for immediate or concurrent use, but it may be the case that they were unable to retain this information in working memory or use it effectively at later stages of processing in the priming task, resulting in a lack of priming by pictures that shared associative meaning with the target words.

In contrast to the semantic effects observed when Group A attended to words, there were no differences in N450 amplitude for congruent, associated, or incongruent superimposed words when these children attended to pictures. However, the meaning of the distractor words may have influenced processing at longer latencies, as a widely distributed negativity that appeared sensitive to semantic meaning developed between 500 and 600 ms post-stimulus. Group A also showed little evidence of an earlier frontal negative wave between 200 and 300 ms to attended

pictures that was observed for controls and Group RS in this task. Negative waves at this latency are thought to reflect effortful processes involved in discriminating a task-relevant stimulus (Greenham et al., 1999; Mangun & Hillyard, 1987; Rugg, Milner, Lines, & Phalp, 1987). Thus, children in Group A may not have been fully engaged in the processes required to discriminate the attended pictures. Alternatively, these processes may be deficient.

Hemispheric Differences

Lateral placement of frontal electrodes allowed an exploration of possible asymmetries for the N450 wave. Normally achieving controls did not exhibit hemispheric differences on any of the tasks in the present study. A left-greater-than-right asymmetry was observed for children in Group RS, but only when naming individually presented words. This effect was not evident on any other task, including attended words. These results were atypical, in that on tasks involving visually presented words, normally achieving controls typically exhibit this pattern of asymmetry (left > right) whereas children with reading disabilities do not (see Stelmack et al., 1995, for a review). In the present study, the greater N450 amplitude over the left hemisphere when reading words may represent a form of compensatory mechanism related to deficient language processing for Group RS (Lovrich et al., 1996, 1997; Neville et al., 1993). The failure to see this asymmetry during the attend-word task may be a result of greater visual-spatial processing demands of this task, thus engaging the right hemisphere. In contrast, children in Group A exhibited a left-greater-than-right hemisphere asymmetry across all tasks, consistent with the view that these children demonstrate right hemisphere processing deficiencies (Mattson et al., 1992; Rourke, 1982, 1989).

Conclusions

In the current study of picture-word naming, children presenting with specific LD for reading and spelling versus arithmetic were differentiated from each other and from normally achieving children on a task of selective attention to superimposed pictures and words. Basic deficits in word and picture naming, along with subtype-specific deficits in selective attention to words and pictures, were endorsed by the current results. The most salient findings were observed for the arithmetic disabled children (Group A), a group otherwise described as exhibiting the syndrome of nonverbal learning disabilities (Rourke, 1989). The pattern of deficits exhibited by these children on both performance and ERP measures is consistent with the visual-spatial processing deficiencies ascribed to this LD subtype (Ozols & Rourke, 1988; Rourke, 1982, 1989; 1993; Rourke & Finlayson, 1978). In particular, Group A's poor picture-naming performance coupled with the failure to develop early frontal negative waves to attended pictures suggests that these children had difficulty at early stages of visual-spatial processing, possibly at the level of object identification (Johnson et al., 1996). These early processing differences were also reflected in smaller amplitude N450 wave across tasks.

The reading disabled children (Group RS) exhibited a generalized deficit for naming words and pictures, affirming this well-established effect (e.g., Denkla & Rudel, 1976a, 1976b, Wolf, 1991). The observed processing deficits for Group RS on ERP tasks were specific to linguistic information, as their ERPs to pictures were intact. Furthermore, there was evidence for deficient processing of associative picture-word pairs, replicating a previous finding (Miles & Stelmack, 1994).

Overall, the use of ERPs, and N450 in particular, complemented traditional performance measures in differentiating the LD subtypes from one another and from controls. For each subtype, ERPs provided additional information not available from naming speed and percent error data alone. Furthermore, the superimposed picture-word paradigm was successful in differentiating LD subtypes. This procedure, and the use of pictures and words in general, appears to have potential for further delineating subtype-specific deficits. For example, degraded pictures or pictures varying in complexity could be presented to LD subtypes to explore the processes involved in the object identification stage of picture naming. This would be particularly useful in examining the visual-spatial processing deficits of Group A. Alternatively, object decision and lexical decision tasks could be administered to children in Groups RS and A to examine subtype-specific deficits in linguistic versus visual-spatial processing in another type of task than naming. It would also be interesting to compare directly the effects of picture-word naming with picture-word categorization in the same groups of children, as there are some reports that children with LD are adept at categorizing pictures (Murphy et al., 1988).

In summary, the superimposed picture-word naming paradigm was successful in discriminating children with language-based LD from those with nonverbal LD. Both LD subtypes also differed from a group of normally achieving children. Along with performance measures of naming, an analysis of the ERP waveforms and anterior N450 waves in particular, provided evidence for subtype-specific deficits for linguistic versus visual-spatial processing for Groups RS and A, respectively. These results provide further validation for Rourke's (1982, 1989) LD typology.

CHAPTER 5

General Discussion and Conclusions

The major objective of this thesis was to explore deficits in selective attention to words and pictures that were specific to LD subtypes. This work was motivated by the proposal that children with LD who present with reliable and valid patterns of academic and neurocognitive skills and deficits also exhibit predictable patterns of attentional deficits for auditory-verbal versus visual-spatial material (Rourke, 1982, 1989). To examine this proposal, a series of studies of picture-word naming was conducted. The goals of the first two studies with adults and normally achieving children were, first, to establish the independent attentional processing of pictures and words, and second, to understand the effects of normal development on picture-word processing. The goal of the third study was to explore subtype-specific deficits in selective attention to words and pictures for two LD subtypes, Groups RS and A. A summary of the salient effects from these three studies follows.

Summary of Salient Findings

Adults. Results of the first study affirmed the independent processing of pictures and words for adults. As in previous research, distinct ERP waveforms were observed when adults named individually presented pictures and words, and these ERP differences were maintained when adults named pictures and words that were presented in superimposed pairs. In both tasks, words elicited greater amplitude N450 waves over frontal electrode sites than pictures, an effect that was independent of the physical stimulus array. This effect was thus indicative of independent attentional processing, and endorses the endogenous nature of the N450 wave.

Adults processed words and pictures that were presented in superimposed arrays somewhat differently than they processed individually presented stimuli. An obvious difference

was that when attending selectively to words or pictures, it was necessary to simultaneously ignore or inhibit the irrelevant stimulus. This additional processing resulted in the development of an early latency negative wave (N280) over anterior electrode sites that was not evident in the ERPs to individual words and pictures. N280 was thought to reflect the discrimination of the task-relevant word or picture from the complex, superimposed stimulus pair. N280 did not appear to differ whether words or pictures were the focus of attention, nor was this wave modulated by the semantic relationship between the superimposed stimuli. This suggests that the processing reflected by the N280 wave likely occurs prior to the activation of semantic information.

The amplitude of the N450 wave was, however, modulated by the semantic relationship between the superimposed stimuli. When adults attended to pictures, superimposed incongruent words elicited larger N450 waves than congruent words, whereas the semantic meaning of the superimposed pictures did not modulate N450 amplitude to attended words. In other words, adults were able to inhibit processing the meanings of the distractor pictures while they attended selectively to words, but they appeared unable to inhibit the distractor words while attending selectively to pictures. This semantic incongruity effect on N450 amplitude was consistent with automatic and controlled processing of words and pictures, respectively.

Normally Achieving Children. Having established the basic effects for adults, the goal of the second study was to further explore effects of attention and semantic relation on picture-word naming for a sample of normally achieving children. Distinct ERP waveforms were also observed for individually presented pictures and words for children. As in previous research, pictures elicited greater amplitude N450 waves than words, an effect that has been attributed to

differences in the automaticity of lexical access or stimulus identification for pictures and words. Clearly, the children's waveforms to pictures were different than those observed for adults in that pictures elicited prominent N450 waves over frontal and central electrode sites in children, rather than positive waves over posterior sites. Despite these developmental differences, children's ERPs to individually presented pictures and words were maintained for superimposed pictures and words. This finding indicated that normally achieving children exhibited the same effect of attention on ERP waves as adults. That is, the distinct waveforms to pictures and words were a result of independent attentional processing, not physical characteristics of the stimuli.

A number of findings in the second study suggested that the children did not process words automatically to the same degree as adults, despite having average or better reading ability. First, children appeared to allocate more resources when attending to words superimposed on pictures than when naming individual words, as N450 was larger for attended than individual words. For adults, N450 did not differ for attended and individual words, suggesting that word-processing was not affected by the presence of superimposed pictures and could therefore be considered automatic. Adults simultaneously attended to words while actively inhibiting the superimposed pictures, whereas children appeared less able to do so. Second, when attending to pictures, the children did not exhibit effects of semantic incongruity on the N450 wave. Unlike adults for whom superimposed incongruent words elicited larger N450 waves than congruent words, children exhibited larger N450 waves to superimposed congruent and associated words. Taken together, these findings support the view that the children were less efficient at managing attentional resources than adults.

Learning Disability Subtypes. Performance measures and ERPs converged in the third study to differentiate LD subtypes RS and A from one another and from normally achieving children. Children in Group RS, who were characterized by poor reading and spelling achievement relative to their arithmetic skill, exhibited a generalized naming deficit for words and pictures on the speeded list-naming task. However, when naming individually presented stimuli during the ERP tasks, reduced N450 waves were observed only for words. N450 waves to individual pictures were normal. On the speeded tasks, this naming deficit may manifest during the activation of phonological codes used in naming both words and pictures (Katz, 1996; Swan & Goswami, 1997). Naming deficits on speeded tasks for Group RS may also reflect deficiencies in temporal processing (Wolf, 1991). In addition, however, it appears that the basic processes involved in lexical access or stimulus identification for words that are reflected by N450 are also deficient for Group RS relative to normally achieving children. Furthermore, these basic linguistic processing deficiencies were also evident on the superimposed naming task, in that N450 to attended words was attenuated for Group RS relative to control children. N450 waves to attended pictures were normal. For Group RS, then, specific deficits were observed for attending selectively to and naming words, but not pictures. Visual-spatial processing was intact.

On the other hand, children in Group A, who were characterized by poor arithmetic achievement relative to average reading and spelling ability, exhibited a specific deficit for naming pictures on the speeded list naming task. Word-naming speed and error rate did not differ from normally achieving children. The picture naming deficit for children in Group A is not likely due to phonological or temporal processing deficits as word naming was normal. Rather, these children may have deficiencies at earlier stages of picture naming, for example, during the

processes involved in object identification (Johnson, Paivio, & Clark, 1996). Indeed, only children in Group A made more naming errors for pictures than words. Further support for this view was provided by the finding that children in Group A showed little evidence of early latency, frontal negative waves (N280) to superimposed words or pictures, a wave thought to reflect the processes involved in discriminating task-relevant stimuli. Children in Group A also exhibited smaller anterior N450 waves to both words and pictures, especially in the superimposed picture-word naming tasks. The overall pattern of results for Group A was consistent with general deficiencies in visual-spatial processing.

Results of the third study provided support for the general view that children with LD have greater difficulty on tasks of selective attention than do normally achieving children. However, by combining performance measures and ERP recording techniques, specific deficits in naming and selective attention to words and pictures were revealed for children who presented with specific LD subtypes. Analysis of either the performance measures or ERPs alone would not necessarily have lead to the same conclusions that were allowed by a concurrent analysis of both measures. Each provided unique information about the processing deficiencies of children in Groups RS and A that discriminated these LD subtypes.

Future Directions

Picture-word naming tasks have proven to be a fruitful means with which to assess the subtype-specific processing deficits of children with LD defined according to patterns of academic achievement. This approach suggests a number of additional possibilities in the investigation of LD subtypes. For example, if, as proposed in this thesis, the visual-spatial processing deficiencies of children in Group A are manifest at the level of object identification, a

series of tasks that manipulates the ease of identification of object pictures may elucidate the nature of this deficiency. Using degraded or incomplete pictures of objects or varying stimulus complexity or presentation time may help to define at what point a novel stimulus is more easily identified and named. Alternatively, in addition to words varying in semantic meaning, pictures could be superimposed by nonsense symbols (e.g., @#%*&), random letters (e.g., ksovh), pronounceable nonwords (e.g., brame), or pseudohomophones (e.g., brane) to examine systematically how object identification is affected by these various visual distractors. This approach might, for example, allow for the separation of orthographic, phonological, and semantic processes from the effects of visual noise. Finally, priming the pictures to be named with other pictures, visually presented words, or spoken words that share denotative or semantically associated meaning might differentially facilitate object identification. Previous priming studies with LD subtypes used target words that were primed by other words or by pictures (Miles & Stelmack, 1994; Stelmack & Miles, 1990). To date there have been no ERP priming studies that compare LD subtypes on target pictures.

Tasks other than naming may be employed to examine the processes involved in object identification. For example, in an object decision task, children decide whether or not a presented object is real. This task is a nonverbal analogue of the lexical decision task, in which decisions are based on whether the presented words are real words or nonwords. Combining object and lexical decision tasks may provide another means with which to compare LD subtypes. One might expect children in Group A to perform more poorly on the object decision task, whereas children in Group RS may perform more poorly on the lexical decision task.

Previous work has often compared tasks of picture-word naming with word and picture categorization tasks (e.g., Glaser & Döngelhoff, 1984; Lovdahl, Brown, McIntyre, & North, 1986; Smith & Magee, 1980). The superimposed picture-word stimuli used in this thesis may also be employed to directly compare processing involved in naming and categorization while attention is directed to either the words or pictures. On performance measures, irrelevant superimposed words interfere with picture naming but not with picture categorization. Conversely, irrelevant superimposed pictures interfere with word categorization but not with word naming. These comparisons have been rarely investigated for children with LD, let alone for LD subtypes. It would be interesting, given some reports that children with LD are adept at picture categorization (Murphy, Pollatsek, & Well, 1988), to examine whether the same effects hold for LD subtypes.

Conclusions

In conclusion, the superimposed picture-word naming task has proven useful in demonstrating the distinct processing of pictures and words. The basic effects of attention and semantic relation on picture-word naming differentiated normally achieving children from adults. This paradigm further discriminated children with linguistic-based versus nonverbal learning disabilities. In combination with performance measures of picture-word naming, analysis of the ERP waveforms provided support for subtype-specific deficits for linguistic versus visual-spatial processing ascribed to these groups of children with LD. As such, this work provides further validation for Rourke's (1982, 1989) typology of LD subtypes.

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APPENDIX

Behavioural List-Naming Tasks

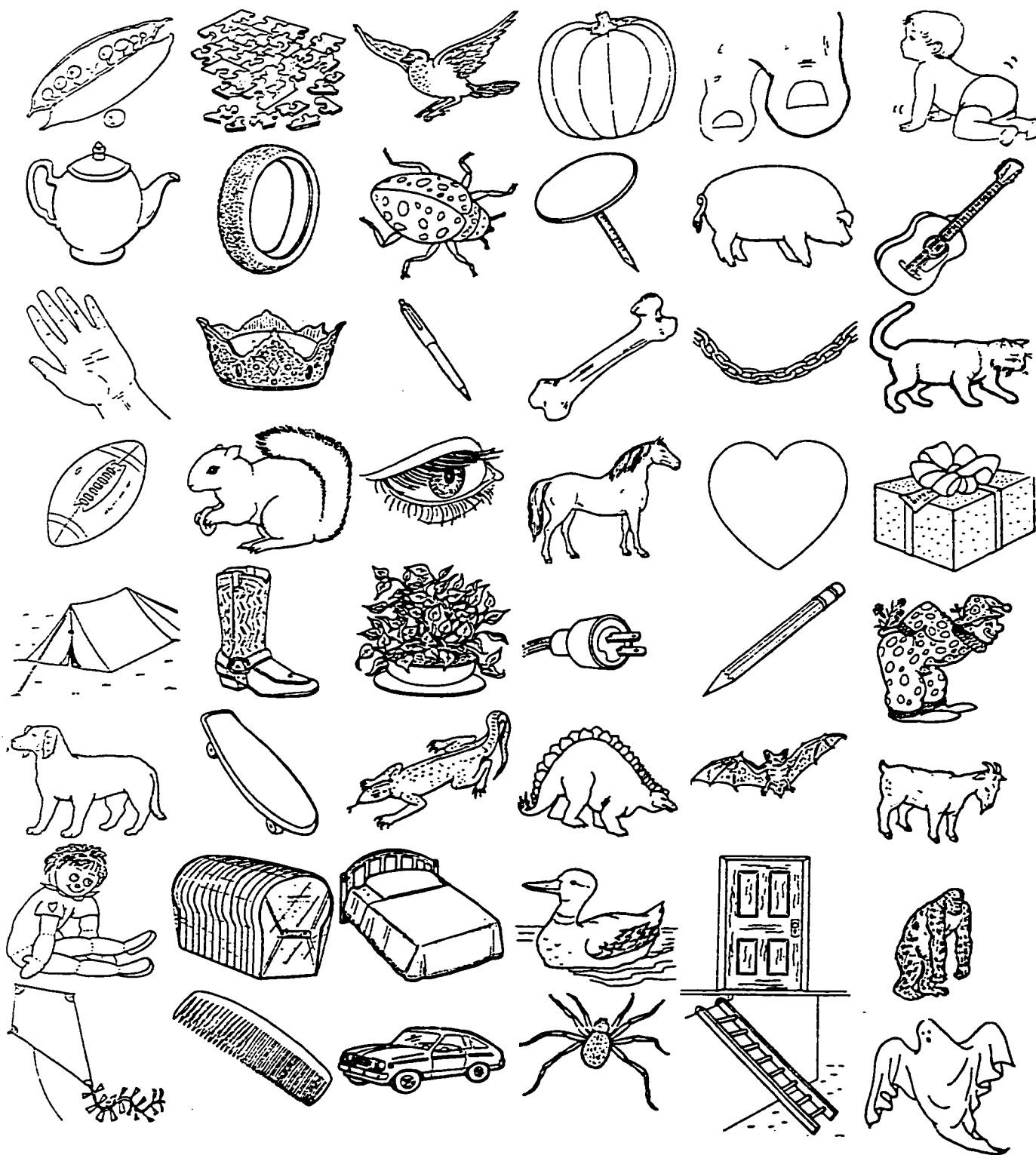
English Word List

HAMMOCK	FLOOR	PLATE
FORK	PIANO	ROAD
DESK	ROCKET	ELBOW
CHECKER	WAGON	PEACH
BAG	SKIRT	SAND
CANOE	BATH	JAM
ACE	FOREST	STONE
GARBAGE	SPOON	WATER
CIRCLE	WINDOW	SOAP
APRON	COOKIE	SOCKS
FROG	ELEPHANT	MOUSE
CANDLE	TRUCK	HORN
FOX	EAR	ZEBRA
BANDAID	JUICE	BUCKET
SWIM	OFFICE	ANCHOR
NEWSPAPER	PAINT	HOUSE

Dutch Word List

HANGMAT	VLOER	BORD
VORK	PIANO	STRAAT
LESSENAAR	RAKET	ELLEBOOG
DAMSPEL	WAGEN	PERZIK
ZAK	ROK	ZAND
KANO	BAD	JAM
AAS	BOS	STEEN
VUILNIS	LEPEL	WATER
CIRKEL	RAAM	ZEEP
SCHORT	BISCUIT	SOKKEN
KIKKER	OLIFANT	MUIS
KAARS	VRACHTWAGEN	HOORN
VOS	OOR	ZEBRA
VERBAND	SAP	EMMER
ZWEMMEN	KANTOOR	ANKER
KRANT	VERF	HUIS

English and Dutch Picture List



CONTRIBUTIONS OF COLLABORATORS

This thesis comprises three separate articles with the following authorship:

Study 1: Greenham, S.L., Stelmack, R.M., & Campbell, K.B. (submitted for publication)

Study 2: Greenham, S.L., & Stelmack, R.M. (submitted for publication)

Study 3: Greenham, S.L., Stelmack, R.M., & van der Vlugt, H.

Collection, scoring, and entry of the data, statistical analyses, and written manuscripts for all three studies were completed by the first author. Second and third authors contributed primarily editorial comments and feedback on written drafts.