

AN ELECTROPHYSIOLOGICAL AND BEHAVIORAL EXAMINATION OF
COGNITIVE CONTROL IN CHILDREN WITH
SPECIFIC LANGUAGE IMPAIRMENT

by

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Abstract

AN ELECTROPHYSIOLOGICAL AND BEHAVIORAL EXAMINATION OF
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by

Baila Tropper

Advisors: Richard G. Schwartz, Ph.D. and Valerie L. Shafer, Ph.D.

There is accumulating evidence that children with specific language impairment (SLI) are deficient in managing internal, cognitive conflict that arises as they process information (e.g., Bishop & Norbury, 2005). This ability is referred to as *cognitive control*, a higher-order skill that encompasses the detection and resolution of conflict among competing response alternatives (Miller & Cohen, 2001). A deficit in cognitive control would likely have wide-ranging ramifications for the efficiency of language and non-language processing and might underlie poor information processing in the SLI population. The goal of the present investigation was to examine whether children with SLI are deficient in managing conflict between competing response tendencies that are invoked during processing of linguistic and non-linguistic stimuli. A behavioral method involving a GO/No-GO paradigm was employed simultaneously with the collection of event-related potentials (ERP). The N2 component was utilized as a neural index of the ability to detect conflict between the tendencies to make a speeded response (GO) and to refrain from responding (No-GO).

Behavioral measures of hit rates and false-alarm rates in response to linguistic and non-linguistic stimuli did not distinguish children with SLI from children with typical language development of the same age (TLD-A). By contrast, analysis of the N2 component revealed absent, or attenuated, and delayed divergence of GO and No-GO amplitudes in SLI relative to TLD-A children in response to linguistic stimuli presented at various probability levels. The N2 effect in children with SLI resembled that of children with typical language development who were on average three years younger. This finding suggests that school-age children with SLI exhibit a maturational lag in detecting conflict among competing response alternatives when processing linguistic information. Deficient conflict detection may, in turn, hinder SLI children's ability to resolve conflict among semantic representations that are activated during language processing. An understanding of this limitation in cognitive control elucidates information processing deficits in SLI and bears promise to enhance our knowledge of how to remediate this developmental disorder.

Dedication

I dedicate this work to the two special individuals to whom I am most indebted – my dear parents, Mr. Martin and Mrs. Helen Tropper. Without their unwavering encouragement, love, and generosity, I could not have reached this milestone. My accomplishments belong to them.

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Table of Contents

Abstract.....	iv
Dedication.....	vi
Acknowledgments.....	vii
List of Tables.....	xii
List of Figures.....	xiv
List of Appendices.....	xv
CHAPTER 1.	
INTRODUCTION.....	1
1.1 Overview.....	1
1.2 Specific Language Impairment (SLI)	2
1.3 Cognitive Control.....	5
1.4 Event-Related Potentials (ERP) Methodology.....	7
1.5 ERPs in the Study of Cognitive Control.....	9
1.5.1 Electrophysiological Correlates of Cognitive Control.....	9
1.6 Cognitive Control and its Electrophysiological Correlates in Children.....	17
1.7 Cognitive Control Skills in Children with SLI.....	21
CHAPTER 2. METHOD.....	27
2.1 Introduction.....	27
2.2 Participants.....	27
2.3 Materials.....	31
2.4 Procedure and Apparatus.....	32
2.5 Behavioral Data Analyses.....	37
2.6 ERP Data Analyses.....	38
2.7 Correlational Analyses.....	42
2.8 Predictions.....	43
2.8.1 Behavioral Data.....	43
2.8.2 ERP Data.....	45
2.8.3 Correlational Data.....	47
CHAPTER 3. LINGUISTIC EXPERIMENT: RESULTS.....	49
3.1 Behavioral Results.....	49

3.2	ERP Results.....	51
3.2.1	N2 Within-Group Analyses.....	51
	<i>TLD-A Children</i>	52
	<i>SLI Children</i>	54
	<i>TLD-Y Children</i>	56
	<i>Summary of N2 Within-Group Analyses</i>	58
3.2.2	N2 Between-Group Analysis.....	58
	<i>Summary of N2 Between-Group Analysis</i>	60
3.2.3	P2 Analysis.....	61
	<i>Summary of P2 Analysis</i>	64
3.2.4	N2-P2 Analysis.....	64
3.2.5	N2 Equal <i>n</i> Analysis.....	69
3.2.6	P3 Analysis.....	69
	<i>Summary of P3 Analysis</i>	71
3.2.7	N1 Analysis.....	72
3.3	Correlational Analyses.....	73
3.4	Discussion.....	77
3.4.1	Behavioral Data.....	77
3.4.2	ERP Data	
	<i>N2 Results</i>	78
	<i>P2 Results</i>	81
	<i>N2-P2 Results</i>	82
	<i>P3 Results</i>	83
	<i>N1 Results</i>	88
3.4.3	Correlational Data.....	89
CHAPTER 4.	NON-LINGUISTIC EXPERIMENT: RESULTS.....	91
4.1	Behavioral Results.....	91
4.2	ERP Results.....	93
4.2.1	N2 Within-Group Analyses.....	93
	<i>TLD-A Children</i>	94
	<i>SLI Children</i>	95
	<i>TLD-Y Children</i>	97
	<i>Summary of N2 Within-Group Analyses</i>	98
4.2.2	N2 Between-Group Analysis.....	99
	<i>Summary of N2 Between-Group Analysis</i>	101
4.2.3	P2 Analysis.....	101
	<i>Summary of P2 Analysis</i>	102

4.2.4	N2-P2 Analysis.....	103
4.2.5	N2-P2 Equal <i>n</i> Analysis.....	105
4.2.6	P3 Analysis.....	105
	<i>Summary of P3 Analysis</i>	108
4.2.7	N1 Analysis.....	108
4.3	Correlational Analyses.....	109
4.4	Discussion.....	113
4.4.1	Behavioral Data.....	113
4.4.2	ERP Data.....	114
	<i>N2 Results</i>	114
	<i>P2 Results</i>	116
	<i>N2-P2 Results</i>	117
	<i>P3 Results</i>	119
	<i>N1 Results</i>	121
4.4.3	Correlational Data.....	122
CHAPTER 5.	GENERAL DISCUSSION.....	124
5.1	Introduction.....	124
5.2	Cognitive Control.....	124
5.3	Inhibition Versus Conflict Monitoring.....	126
5.4	The Relationship Between Working Memory and Inhibition.....	132
5.5	The Role of Attention in Cognitive Control.....	135
5.6	The Development of Cognitive Control.....	138
5.6.1	Immature Conflict Detection in SLI.....	138
5.6.2	Immature Conflict Detection in Younger Relative to Older Children	140
5.7	Cognitive Control in Relation to Other Deficits in SLI.....	144
5.8	Evidence for SLI as a Domain-General Disorder.....	148
5.9	Clinical Implications.....	150
5.10	Future Directions.....	153
APPENDICES		156
REFERENCES		193

List of Tables

Table		Page
1	Number of retained trials (standard deviation) per condition in the Linguistic and Non-linguistic experiments.	39
2	Sensor net channels included in ERP statistical analyses, their correspondence with the 10-10 International System, and their scalp location (sagittal and coronal).	41
3	Mean hit rate, RT, and false-alarm rate (standard deviation) per group and condition in the Linguistic experiment.	49
4	Mean amplitudes of N2 (400-560 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of stimulus probability in the Linguistic experiment (<i>SD</i> = standard deviation).	52
5	Results of Tukey's Unequal N post-hoc test for analysis of the N2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Linguistic experiment.	60
6	Results of Tukey's Unequal N post-hoc test for analysis of the N2-P2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Linguistic experiment.	66
7	Results of the repeated measures ANOVA for N2-P2 responses using mean amplitude values at frontal sites in the Linguistic experiment.	67
8	Mean amplitudes of P3 (1000-1100 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of stimulus Condition in the Linguistic experiment (<i>SD</i> = standard deviation).	71
9	Results of the repeated measures ANOVA for the P3 component (600-1200 ms) using mean amplitude values at frontal sites in the Linguistic experiment.	72
10	Correlations between reaction time (RT) and mean amplitudes of the N2 to GO stimuli per condition in the Linguistic experiment (* = significant at $p < .01$).	73
11	Correlations between false-alarm rates and mean amplitudes of N2 difference waves (No-GO - GO) per condition in the Linguistic experiment.	74
12	Correlations between standardized language test scores and mean amplitudes of N2 difference waves (No-GO - GO) and reaction time (RT) to GO stimuli per condition in the Linguistic experiment.	75

13	Correlations between mean amplitudes of N2 and P3 difference waves (No-GO - GO) and between false-alarm rates and P3 difference waves per condition in the Linguistic experiment.	76
14	Mean hit rate, RT, and false-alarm rate (standard deviation) per group and condition in the Non-linguistic experiment.	91
15	Mean amplitudes of N2 (400-560 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Non-linguistic experiment (<i>SD</i> = standard deviation).	93
16	Results of Tukey's HSD post-hoc test for the N2 effect (GO vs. No-GO) using mean amplitude values at frontal sites in the Non-linguistic experiment.	100
17	Results of the repeated measures ANOVA performed for the N2-P2 effect (400-560 ms) using mean amplitude values at frontal sites in the Non-linguistic experiment.	104
18	Results of Tukey's HSD post-hoc test for the N2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Non-linguistic experiment.	105
19	Mean amplitudes of the P3 (1000-1100 ms) for GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Non-linguistic experiment (<i>SD</i> = standard deviation).	107
20	Results of the repeated measures ANOVA for the P3 component (600-1200 ms) using mean amplitude values at frontal sites in the Non-linguistic experiment.	108
21	Correlations between reaction time (RT) and mean amplitudes of the N2 to GO stimuli per condition in the Non-linguistic experiment.	109
22	Correlations between false-alarm rates and mean amplitudes of N2 difference waves (No-GO - GO) per condition in the Non-linguistic experiment.	111
23	Correlations between standardized language test scores and mean amplitudes of N2 difference waves (No-GO - GO) and reaction time (RT) to GO stimuli per condition in the Non-linguistic experiment.	111
24	Correlations between mean amplitudes of N2 and P3 difference waves (No-GO - GO) and between false-alarm rates and P3 difference waves per condition in the Non-linguistic experiment (* = significant at $p < .01$).	112

List of Figures

Figure		Page
1	64-channel Geodesic sensor net (EGI, Inc.)	40
2	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by TLD-A children in the Linguistic experiment.	53
3	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by SLI children in the Linguistic experiment.	55
4	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by TLD-Y children in the Linguistic experiment.	57
5	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in TLD-A children in the Non-linguistic experiment.	95
6	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in SLI children in the Non-linguistic experiment.	96
7	Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in TLD-Y children in the Non-linguistic experiment.	98

List of Appendices

Appendix	Page
A	156
	Table A1. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores for participants with typical language development matched on group mean age (TLD-A) with children with specific language impairment (SLI).
	Table A2. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores for participants with specific language impairment (SLI).
	Table A3. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores for 8-10 year-old participants with typical language development (TLD-Y) matched on group mean composite language scores and non-verbal intelligence with TLD-A children.
B	159
	Items presented as picture stimuli in the Linguistic experiment.
C	160
	Parent/Guardian Consent for Child Participation in an ERP Experiment
D	162
	Child Assent for Participation in an ERP Experiment
E	163
	Experimental paradigm for the Linguistic and Non-linguistic experiments.
F	164
	Diagram of experimental trial: Linguistic experiment
	Diagram of experimental trial: Non-linguistic experiment
G	165
	Table G1. Mean reaction times of TLD-A children in each condition of the Linguistic and Non-linguistic experiments (M = mean; SD = standard deviation).
	Table G1. Mean reaction times of SLI children in each condition of the Linguistic and Non-linguistic experiments (M = mean; SD = standard deviation).
	Table G1. Mean reaction times of TLD-Y children in each condition of the Linguistic and Non-linguistic experiments (M = mean; SD = standard deviation).
H	168
	Figure H1. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-A children in the Linguistic experiment (red - positive; blue - negative).
	Figure H2. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in SLI children in the Linguistic experiment (red -

positive; blue - negative).

Figure H3. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-Y children in the Linguistic experiment (red - positive; blue - negative).

- | | | |
|---|--|-----|
| I | <p>Figure I1. Grand average waveforms of TLD-A children ($n = 21$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment.</p> <p>Figure I2. Grand average waveforms of SLI children ($n = 12$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment.</p> <p>Figure I3. Grand average waveforms of TLD-Y children ($n = 16$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment.</p> | 171 |
| J | <p>Table J1. Results of the ANOVA performed for the N2 (400-560 ms) using mean amplitude values at frontal sites in TLD-A ($n = 11$) and SLI ($n = 11$) children matched on age, gender, handedness, and non-verbal intelligence in the Linguistic experiment.</p> <p>Table J2. Results of Tukey's post-hoc test for the time analysis of the N2 effect (GO vs. No-GO) using mean amplitude values at frontal sites in TLD-A ($n = 11$) and SLI ($n = 11$) children matched on age, gender, handedness, and non-verbal intelligence in the Linguistic experiment.</p> | 174 |
| K | <p>Figure K1. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-A children in the Linguistic experiment (red - positive; blue - negative).</p> <p>Figure K2. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in SLI children in the Linguistic experiment (red - positive; blue - negative).</p> <p>Figure K3. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-Y children in the Linguistic experiment (red - positive; blue - negative).</p> | 178 |
| L | <p>Figure L1. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-A children in the Non-linguistic experiment (red - positive; blue - negative).</p> <p>Figure L2. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in SLI children in the Non-linguistic experiment (red - positive; blue - negative).</p> <p>Figure L3. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-Y children in the Non-linguistic experiment (red - positive; blue - negative).</p> | 181 |

M	Figure M1. Grand average waveforms of TLD-A children ($n = 22$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment. Figure M2. Grand average waveforms of SLI children ($n = 11$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment. Figure M3. Grand average waveforms of TLD-Y children ($n = 14$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment.	184
N	Table N1. Results of Tukey's HSD post-hoc test for analysis of the N2-P2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in TLD-A ($n = 10$) and SLI ($n = 10$) children matched on age, gender, handedness, and non-verbal intelligence in the Non-linguistic experiment. Table N2. Results of the ANOVA for the N2-P2 using mean amplitude values at frontal sites in TLD-A ($n = 10$) and SLI ($n = 10$) children matched on age, gender, handedness, and non-verbal intelligence in the Non-linguistic experiment.	187
O	Figure O1. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-A children in the Non-linguistic experiment (red - positive; blue - negative). Figure O2. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in SLI children in the Non-linguistic experiment (red - positive; blue - negative). Figure O3. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-Y children in the Non-linguistic experiment (red - positive; blue - negative).	190

Chapter 1 Introduction

1.1 Overview

Considering the diverse clinical profiles of specific language impairment (SLI), it is unsurprising that numerous hypotheses have been proposed to explain its underpinnings. One firmly ensconced theory of SLI is that children with this disorder are deficient in processing information (for a review, see Leonard, 1998; Schwartz, 2009). An abundance of empirical evidence demonstrates that this deficit is often pervasive, affecting both linguistic and non-linguistic performance across a wide range of experimental tasks. Although information processing deficits have been the focus of intensive research, the nature of this impairment remains shrouded by contradictory views.

One plausible explanation for processing deficits in SLI is that children with this disorder may have a general cognitive impairment in the ability to monitor and exercise control over conflicting response alternatives. The need to manage conflict during information processing is ubiquitous and thus, poor processing in SLI may be due to deficits in the detection and resolution of conflict. The locus of this impairment would likely be in the elaborate neurocognitive network that orchestrates *cognitive control*. This managerial system, housed within the prefrontal cortex, is considered responsible for conflict detection and resolution, among other higher-order cortical tasks (for a review, see Miller et al., 2001). Presumably, a deficit in cognitive control would have considerable ramifications for the efficiency of linguistic and non-linguistic processing. The potential for this hypothesis to account for several deficits in SLI warrants an investigation of its validity and explanatory prowess.

The aim of this study was to elucidate cognitive control skills employed during processing in children with SLI and in children with normal language abilities. The implementation of cognitive control is not necessarily manifested by behavioral performance. Examination of cognitive control is thus challenging because it requires a methodology that is capable of obtaining data when there is no overt behavioral performance. The collection of event-related potentials (ERPs) is a suitable method because it reveals the electrical brain activity that is tied to a stimulus, whether or not a behavioral response is executed. This investigation therefore supplemented behavioral measures of accuracy and reaction time with the collection of ERPs. The ERP methodology was expected to provide a signature of the neural correlates underlying cognitive control as they were implicated with the experimental manipulations of the present study. Results of this investigation elucidate the nature of processing deficits in children with SLI, which is essential to understanding the intervention needs of this clinical population.

1.2 Specific Language Impairment

Since the first half of the 19th century, researchers have studied a population of children with a language disorder that is now referred to as SLI (for a review, see Leonard, 1998). Children with SLI lag behind their peers in the acquisition and use of language in spite of normal intelligence and do not exhibit obvious neurological damage, hearing impairment, mental retardation, or severe environmental deprivation. To date, SLI has been explained by a plethora of hypotheses, yet we remain in need of a theory

that can adequately account for the multiplicity of deficits that is characteristic of this disorder.

A common finding within and across the diverse subgroups of this population is that children with SLI are impaired in processing information. A wealth of evidence indicates that this impairment affects both language and non-language performance in numerous experimental tasks (Leonard, 1998). For example, many SLI children exhibit weaknesses in the language areas of syntax, morphology, semantics, phonology, and pragmatics (e.g., Aram & Eisele, 1994; Leonard, 1998; Marchman, Wulfeck, & Weismer, 1999; Rapin, 1996). There is also evidence that children with SLI have non-language deficits in perception (e.g., Tallal, Stark, Kallman, & Mellits, 1981), motor abilities (e.g., Hill, 2001), and mental representation (e.g., Johnston & Ramstad, 1983). To account for the wide range of deficits in these children, some investigators have characterized SLI as a limitation in processing capacity (e.g., Leonard et al., 1992). Whereas some models of SLI posit a general deficit in processing information, others claim that only specific cognitive functions, such as language abilities, have limited processing capacity in these children.

Advocates for general processing deficits maintain that children with SLI have more limited global processing capacities and employ less efficient processing strategies than their normal-language counterparts (Johnston, 1994; Leonard, 1998). Empirical support for general limitations in processing capacity is largely inferred from consistent findings that children with SLI respond more slowly than their age-matched peers on a wide range of linguistic and non-linguistic tasks (e.g., Johnston & Ellis Weismer, 1983; Montgomery, Scudder, & Moore, 1990; Reynolds & Fucci, 1998; Sininger, Klatzky, &

Kirchner, 1989; Stark & Montgomery, 1995). This phenomenon supports what is aptly referred to as the *generalized slowing hypothesis*. Based on reaction time data from a variety of tasks, this hypothesis has been described as a proportional and linear increase of 10-30% in the reaction time of children with SLI relative to chronological-age peers. This finding has been interpreted as a reflection of a *general* factor of cognitive processing that is non-task specific (Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001; Windsor & Hwang, 1999).

Support for general processing limitations in SLI, however, has not gone undisputed. Several investigators have contended that general limited capacity models do not clearly explain certain linguistic deficits exhibited in children with SLI (Gopnik & Crago, 1991; Rice & Oetting, 1993; Ullman & Gopnik, 1999; van der Lely & Ullman, 2001). Furthermore, it is not understood why a general impairment of cognitive capacity would impair specific non-linguistic functions while apparently sparing others. Perhaps the most notable caveat is that the construct of a general limited capacity can be applied to numerous disorders and thus, cannot inform our knowledge of how to empirically ascertain its validity in relation to SLI (Johnston, 1994).

In contrast to hypotheses of general processing deficits, it has been claimed that processing in specific cognitive domains underlies the impairments observed in SLI. Tallal and colleagues (Merzenich, Schreiner, Jenkins, & Wang, 1993; Tallal, Miller, & Fitch, 1993; Tallal & Piercy, 1973, 1974), for example, characterized SLI in terms of a temporal or perceptual processing disorder, particularly for stimuli that are rapidly presented or that are of brief duration. Others have asserted that SLI can be explained by speech processing deficits that result in the development and subsequent use of degraded

phonological representations (Joanisse & Seidenberg, 1998). Another view of SLI as a processing deficit in a specific mechanism was advanced by Gathercole & Baddeley (1990). These researchers proposed that SLI is characterized by a deficit in the storage of phonological information in working memory.

Research on information processing in SLI is highly specialized because various linguistic and non-linguistic areas have mostly been studied in isolation. Consequently, the literature reports a lengthy list of deficits for this disorder with few attempts to construct a coherent theory that accounts for its wide range of deficits. One goal of this study is to provide a broader perspective that can serve as the common thread for many of the observed difficulties in SLI. Based on the hypothesis that a global, cognitive impairment underlies SLI, this study turns to evidence of a deficit that has relevance for a wide spectrum of cognitive deficits associated with this disorder - impaired cognitive control.

1.3 Cognitive Control

Cognitive control is the ability to direct thoughts and actions according to internal objectives, especially in tasks that are novel, challenging, or that involve conflict (Miller, 2000). The study of cognitive control is often subsumed under the rubric of *executive function*, a term used to describe supervisory operations that control high-level cognitive processes, such as inhibition, planning, and cognitive flexibility. Thus, executive function *involves* cognitive control. Research on executive function, though, is plagued by its lack of specificity and low construct validity. By contrast, cognitive control refers to specific functions and its components are dissociable. According to the *conflict-monitoring theory*

(Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004), the functions of cognitive control are divided into two roles: A regulative component activates and executes control processes and an evaluative component monitors and signals the need for control. Examples of regulative functions include maintaining task requirements in working memory, selectively allocating attentional resources, and preparing to override predominant response tendencies (Cohen, Barch, Carter, & Servan-Schreiber, 1999). Evaluative processes comprise functions that monitor performance to detect processing conflicts. For example, a task that requires one to override a predominant response tendency often involves competition, or conflict, between the correct response and the one that must be overcome. In such a task, the evaluative component triggers adjustments in control to improve task performance. Together, the regulative and evaluative roles of cognitive control constitute a dynamic process that is invoked when successful completion of a task requires adaptation of performance in response to conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Two critical questions concerning this process are: Where does it occur and how is it measured?

The regulative and evaluative roles of cognitive control are managed by specific brain structures in the prefrontal cortex (PFC). The regulative role is coordinated by the dorsolateral prefrontal cortex (dlPFC; Botvinick et al., 2001) and the evaluative role is widely attributed to the anterior cingulate cortex (ACC), a region within the medial frontal cortex of the PFC.

To measure cognitive control, a methodology that permits the direct assessment of cognitive processes is required. In addition, the method must be capable of examining performance that is not necessarily represented by overt behavior, such as the act of

overriding a predominant response. Clearly, conventional behavioral methods do not meet these criteria. There are, however, several neuroimaging techniques that allow for the examination of cognitive control processes. For example, functional magnetic resonance imaging (fMRI) is used to measure changes in blood flow and oxygenation (hemodynamic responses) that occur in response to experimental stimuli. Several studies have demonstrated the utility of fMRI for examining the engagement of the ACC and dlPFC in tasks that involve the detection and resolution of cognitive conflict (MacDonald, Cohen, Stenger, & Carter, 2000). In some of these studies, though, the hemodynamic response signals were examined in approximately two-second intervals due to the temporal limitations of fMRI, whereas the behavioral responses in the task were typically executed in less than one second (MacDonald et al., 2000). The fMRI method is thus limited in its ability to measure cognitive control processes that occur at the millisecond level, although it provides spatially sensitive information about neural activity.

In contrast to fMRI and other hemodynamic measures of neural activity, event-related potentials (ERPs) enable direct examination of brain electrical activity with remarkable temporal precision. A brief discussion of the fundamentals of ERPs will be provided as a basis for understanding the usefulness of this methodology in the study of cognitive control.

1.4 *Event-Related Potentials Methodology*

Electroencephalography (EEG) is a technique that uses scalp electrodes to record the voltages at the surface of the skull that are generated by neuronal currents in the

brain. To record this activity on the scalp, a sufficiently large number of neurons must fire in synchrony and a threshold of activity from post-synaptic excitatory and inhibitory potentials must be reached. By time-locking a stimulus to a point in the ongoing EEG and repeating that stimulus, voltage fluctuations that are not tied to the stimulus become eliminated in an averaging process. What remains is the electrical brain activity that is directly related to the specific stimulus, or event, called an *event-related potential* (ERP). Different patterns of electrical brain activity, as measured during performance of a task, are believed to reflect differences in processing (Coles & Rugg, 1995). Furthermore, the ERP technique offers superb temporal resolution and is therefore beneficial for examining rapid neural activity, which underlies cognitive control processes. Considering that the technique is non-invasive, ERPs are especially well-suited for the examination of processing in children. Although ERPs provide limited spatial resolution, recent technological advances, including the development of high-density arrays and programs for source analysis (Berg & Scherg, 1994), enable researchers to infer the neural sources of ERP activity (e.g., Fox, Schmidt, & Henderson, 2000; Nelson & Monk, 2001).

An ERP waveform comprises a series of voltage deflections, which are displayed as peaks and troughs. These deflections represent the aggregate electrical activity of several underlying components in the brain, which are presumably tied to stimulus variables. The analysis of ERP waveforms involves classification of specific components according to their polarity (positive or negative), the latency of their initial or peak occurrence (in milliseconds), and their topographical distribution over the scalp (e.g., frontal, central, posterior; Otten & Rugg, 2005). According to one taxonomy, the label

N2, for example, refers to a negative component that occurs as the second negativity within the waveform.

1.5 *ERPs in the Study of Cognitive Control*

There are two principal advantages of employing the ERP methodology in cognitive control research. Firstly, as noted above, ERPs reveal the neural activity underlying the detection and resolution of conflict even in the absence of a behavioral response. In addition, the remarkable temporal sensitivity of ERPs offers fine-grained, online information about the sub-processes leading to a response. This feature enables analysis of the neural correlates that *contribute* to cognitive control, in contrast to behavioral measures that merely reflect the *outcome* of stimulus analysis and response preparation.

1.5.1 *Electrophysiological Correlates of Cognitive Control*

Several investigations have capitalized on the temporal sensitivity of ERPs to dissociate the constituent processes of cognitive control. The regulative processes of allocating attention in challenging tasks and maintaining goal and task representations have been observed in slow-wave ERPs that vary depending on attentional demands (Curtin & Fairchild, 2003). Apparently, this slow-wave activity reflects biasing of processing toward more attentionally demanding tasks (West, 2003). Furthermore, the slow-wave activity has been found to distinguish correct trials, during which sufficient control was presumably applied, from incorrect trials, reflecting deficient regulation of

control, in a cued Stroop task (Cohen et al., 1999). This evidence supports the notion that slow-wave activity indexes the regulative processes of cognitive control (West, 2003).

Most investigations of the ERP correlates of cognitive control have centered on the evaluative processes, specifically, conflict detection and response monitoring. The tasks used in these studies reliably invoked response conflict, which occurs when two or more incompatible response tendencies are simultaneously active. A classical task that has been used to examine conflict detection is the Eriksen flanker task (Eriksen & Eriksen, 1974). In this task, a target stimulus presented at center is *flanked* by either congruent (e.g., < < < < <) or incongruent (e.g., > > < > >) stimuli. Participants are typically required to press a button using either their left or right hand, depending on the direction to which the central target points. Conflict invoked during incongruent trials of this task has been linked with an ERP component called the N2 (van Veen & Carter, 2002a, 2002b).

The N2 is a negative deflection in the ERP waveform that occurs at approximately 300 ms post-stimulus onset, with its maximum amplitude at fronto-central scalp sites. The amplitude of the N2 is largest when response conflict is high and is associated with demands to withhold a predominant incorrect response. Using source localization, the scalp distribution of the N2 has been linked with a source of activation stemming from the caudal portion of the ACC (van Veen et al., 2002b). This finding is consistent with evidence of ACC engagement in tasks that involve conflicting response tendencies (e.g., Braver, Barch, Gray, Molfese, & Snyder, 2001), which has been described as “one of the most firmly established findings in all of cognitive neuroscience” (Botvinick et al., 2004, p. 539). Furthermore, there is evidence that ACC

activation is greater on trials that involve high response conflict and low top-down control versus low response conflict and high top-down control (e.g., Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; MacDonald et al., 2000). This supports the view that ACC activation reflects the evaluative role of conflict detection, rather than the regulative role of top-down control. Thus, there is ample support for use of the N2 as an electrophysiological index of conflict detection, which is firmly tied to the ACC's role as a conflict detector.

Many studies on the evaluative processes of cognitive control have examined the N2 via a GO/No-GO task. In this task, participants are required to make a speeded response to one stimulus type (GO) and to withhold a response to another stimulus type (No-GO). The widespread use of this paradigm in ERP research has yielded abundant information on the electrophysiological characteristics of the N2. Most notably, the N2 is significantly enhanced on No-GO trials relative to GO trials (e.g., Eimer, 1993; Jodo & Kayama, 1992; Kok, 1986; Pfefferbaum, Ford, Weller, & Kopell, 1985). In the GO/No-GO task, the N2 peaks between approximately 250-350 ms post-stimulus onset and its maximum amplitude occurs over fronto-central scalp locations.

The N2 has been associated with a top-down inhibition mechanism that is engaged to suppress an inappropriate response tendency (e.g., Falkenstein, Hoormann, & Hohnsbein, 1999; Jodo et al., 1992; Kok, 1986). Support for this *inhibition hypothesis* has been drawn from evidence that N2 amplitudes correlate with inhibition efficiency (e.g., van Boxtel, van der Molen, Jennings, & Brunia, 2001). Falkenstein et al. (1999), for example, observed that the N2 was attenuated and delayed in individuals with high false-alarm rates, relative to those with low false-alarm rates. In addition, children with

attention deficit hyperactivity disorder (ADHD), which is characterized by poor inhibitory control (Barkley, 1998), showed reduced N2 amplitudes as compared with normally developing children (Pliszka, Liotti, & Woldorff, 2000).

More recently, the notion that the N2 represents an inhibitory process has been challenged by the *conflict monitoring theory*, which posits that the N2 reflects conflict between the execution and inhibition of a response. This proposal is supported by evidence from a study that employed a GO/No-GO task in which the frequency of GO and No-GO trials varied among 20%, 50%, and 80% (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). In addition to observing the expected N2 in the 20% and 50% No-GO conditions, the investigators observed an increase in N2 amplitude following GO stimuli in the 80% No-GO condition. The interpretation advanced for this finding is that the N2 manifests the conflict engendered by the requirement to respond to a low-probability stimulus, which must compete with a more dominant, high-probability stimulus. Thus, N2 enhancement should occur for infrequent stimuli, regardless of whether the stimuli are assigned to the GO or No-GO response. The presence of the N2 effect in the 50% condition, in which GO and No-GO trials were presented with equal frequency, is accounted for by the conflict monitoring theory, assuming that there is a bias toward the GO response in GO/No-GO tasks.

Additional evidence that challenges the inhibition hypothesis was forwarded by Bruin, Wijers, and van Staveren (2001). These investigators observed N2 enhancement on No-GO trials following primes that cued subjects not to respond. Thus, the N2 effect was elicited when no inhibition of a behavioral response was necessary. The conflict

monitoring hypothesis can account for this finding by explaining that the N2 in this context reflects the response conflict between the No-GO prime and the tendency to *GO*.

In addition to the N2, Bruin et al. (2001) examined the P3 component. The P3 in GO/No-GO tasks is characterized by enhanced fronto-central amplitudes in the latency range of 300-500 ms on No-GO trials, as compared with a parietal maximum on GO trials. This effect has been demonstrated by adults (Bekker et al., 2004; Bokura et al., 2001; Bruin et al., 2001; Donkers & van Boxtel, 2004; Smith et al., 2007) and normally developing 7-12 year-old children (Dimoska et al., 2003; Johnstone et al., 2005, 2007; Jonkman, 2006).

The functional interpretation of the P3 is controversial. Many studies have associated the P3 in GO/No-GO tasks with inhibitory processes (e.g., Bruin et al., 2001; Karlin, Martz, & Mordko, 1969; Roberts, Rau, Lutzenberger, & Birbaumer, 1994; Schupp, Lutzenberger, Rau, & Birbaumer, 1994). For example, Bruin et al. (2001) observed an enhanced No-GO P3 for strongly primed responses, which presumably require greater inhibition, and therefore, they associated this component with response inhibition. Notably though, Kopp et al. (1996) reported that response priming did not modulate the P3. Differences between the primes and response probabilities across these two experiments may account for the discrepant findings (Bruin et al., 2001).

A number of researchers have contended that the P3 does not reflect the inhibition process. Falkenstein et al. (1999), for example, argued that the latency of the P3 in GO/No-GO tasks typically occurs much later than the behavioral response and thus appears to be too late to reflect an inhibition mechanism. Furthermore, the lack of consistent No-GO P3 effects in good versus poor inhibitors questions the interpretation of

the P3 as an inhibition component. Instead, these investigators interpreted the P3 as reflecting the closure of an inhibitory process. Others have posited that the P3 represents performance evaluation in the post-response phase (Roche, Garavan, Foxe, & O'Mara, 2005).

Another interpretation of the P3 is that GO/No-GO differences might arise due to overlapping negativity from the motor response that is performed for GO but not No-GO trials. In cued GO/No-GO paradigms, activity during the cue-target interval that is related to response expectation or preparation, reflected by CNV amplitude, might interfere with activity during the P3 region; negativity might persist in GO responses but not in No-GO responses, resulting in larger positive amplitudes for No-GO waveforms (Kok, 1986; Kopp et al., 1996; Simson et al., 1977). This has been dismissed as a confounding factor based on the following evidence. Similar No-GO P3 effects have been found in a condition that required a motor response relative to a condition that required covert counting of GO stimuli. In addition, No-GO P3 effects have been observed in GO/No-GO tasks that did not include cues, and therefore no CNV activity occurred (Pfefferbaum et al., 1985). Moreover, the No-GO P3 effect remained following subtraction of preparatory CNV activity from the P3 (Roberts et al., 1994).

In comparison with the N2, the interpretation of the P3 is less clear, despite numerous studies that have examined its characteristics (e.g., Bokura, Yamaguchi, & Kobayashi, 2001; Bruin & Wijers, 2002; Kopp, Mattler, Goertz, & Rist, 1996; Strik, Fallgatter, Brandeis, & Pascual-Marqui, 1998). Furthermore, debates between the inhibition and conflict monitoring hypotheses to explain cognitive processes involved in

GO/No-GO tasks are limited to ERP activity identified in association with the N2 component.

In addition to conflict detection, another evaluative process that has been well-investigated using ERPs is response monitoring. A negative deflection with a fronto-central scalp distribution (Dehaene, Posner, & Tucker, 1994; Falkenstein, Hoorman, Hohnsbein, & Blanke, 1991) that peaks 50-150 ms following the commission of an error or the omission of a correct response has been identified as an index of error monitoring (Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996). This component is referred to as the error-related negativity (ERN) or error negativity (Ne) and is reported to be pre-attentive (Dehaene et al., 1994; Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997). Early accounts tied the ERN to an error detection mechanism (e.g., Bernstein, Scheffers, & Coles, 1995; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990). This perspective has been challenged by findings of small-amplitude activity resembling the ERN on *correct* trials, referred to as the correct response negativity (CRN; Davies, Segalowitz, & Gavin, 2004). To account for this evidence, more recent proposals posit that the ERN reflects an on-line evaluation of each response (e.g., Carbonnell & Falkenstein, 2006), which allows an individual to adjust performance to increase future accuracy. Because the ERN has been elicited across various stimulus and response modalities, it is thought to index the activity of a generic response monitoring mechanism (Bernstein et al., 1995; Dehaene et al., 1994; Falkenstein et al., 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000).

There is consistent evidence from source localization that the ERN is generated in the caudal ACC (e.g., Herrmann, Rommler, Ehrlis, Heidrich, & Fallgatter, 2004; van Veen

et al., 2002b), akin with the N2. Given the abundant neuroimaging evidence suggesting that the ACC's role in cognitive control is chiefly evaluative, this finding supports the notion that the ERN manifests an evaluative function. Furthermore, Nieuwenhuis et al. (2003) found that the ERN and N2 were co-localized in a GO/No-GO task, consistent with the idea that these components represent overlapping processes. Recent evidence, however, shows a dissociation between response conflict and changes in ERN amplitude (Carbonnell et al., 2006; Christ, Falkenstein, Heuer, & Hohnsbein, 2000; Luu, Flaisch, & Tucker, 2000; Masaki & Segalowitz, 2004; Pailing & Segalowitz, 2004a), whereas response conflict and N2 amplitude are clearly associated (e.g., Ciesielski et al., 2004; Donkers & von Boxtel, 2004). Thus, the ERN does not appear to reflect the conflict induced by coactivation of incompatible responses, in contrast to the N2. Instead, the ERN may manifest affective responses to errors, as demonstrated via its modulation by motivational factors, such as error value (e.g., Hajcak, Moser, Yeung, & Simons, 2005; Pailing & Segalowitz, 2004b), and its enhancement in several clinical conditions characterized by affective distress, such as obsessive-compulsive disorder (Gehring, Himle, Nisenson, 2000; Ruchow, Grön, Reuter, Spitzer, Hermle, & Kiefer, 2005; Santesso, Segalowitz, & Schmidt, 2006).

To summarize, a wealth of electrophysiological evidence demonstrates that the evaluative processes orchestrated by the ACC are measurable. Whereas interpretations of the P3 and ERN remain controversial, the N2 appears to be a reliable index of cognitive control in adults. This leaves open the question of whether these components can inform our knowledge of cognitive control skills in children.

1.6 Cognitive Control and its Electrophysiological Correlates in Children

Cognitive control emerges in early childhood and matures beyond adolescence, thus showing a highly protracted developmental course (see Zelazo & Müller, 2002, for a review). The most thoroughly investigated aspect of cognitive control in children is inhibition, which appears to develop gradually with frontal lobe maturation (Becker, Isaac, & Hynd, 1987; Bjorklund & Harnishfeger, 1990; Dempster, 1992; Stuss, 1992). Casey and her colleagues (Casey et al., 1997) demonstrated this gradual maturation in an fMRI study comparing the performance of 7-12 year-old children and 21-24 year-old adults in a GO/No-GO task. Although both groups showed activation of the prefrontal cortex following No-GO trials, the average volume of activation was larger for children. This finding was observed in similar studies (Casey, Thomas, Davidson, Kunz, & Franzen, 2002; Durston, Thomas, Yang, Ulug, Zimmerman, & Casey, 2002) and was presumed to reflect children's greater investment of effort to inhibit interfering stimuli, as well as the use of different task strategies in children versus adults (Thomas et al., 1999).

Relative to fMRI, the ERP methodology has been employed as a more time-sensitive measure of cognitive control in children. Ciesielski et al. (2004) examined GO/No-GO performance in 6-12 year-old children and adults in an auditory and visual task. Results showed a higher percent of false-alarm errors to No-GO stimuli in children, in line with evidence that children show greater difficulty than adults in inhibiting incorrect predominant responses (Casey et al., 1997; Bedard, Nichols, Barbosa, Schachar, Logan, & Tannock, 2002; Ridderinkhof, Band, & Logan, 1999). In addition, Ciesielski and her colleagues found that adults showed a frontal distribution for the N2 effect, whereas children displayed a more posterior distribution for this effect. This finding is

consistent with the idea that inhibitory control develops slowly with the growth of cortical-cortical connections between the frontal and parietal areas and the striatum (Mesulam, 1990).

In contrast to the above results, Johnstone, Pleffer, Barry, Clarke, and Smith (2005) observed a frontally-maximal N2 to auditory No-GO stimuli in 10 year-old children and two groups of adults (mean ages 20 and 36 years), which was significantly larger in children. In addition, N2 amplitude showed a linear reduction with age, consistent with evidence that children activate more extensive regions of the prefrontal cortex in the GO/No-GO task, relative to adults (Tamm, Menon, & Reiss, 2002). Contrastingly, Jonkman, Lansbergen, and Stauder (2003) reported no effect of age on the visual No-GO N2 between 9 year-old children and 20 year-old adults, suggesting that inhibitory control is mature by 9 years of age. This discrepancy may be related to within-study perceptual overlap between GO and No-GO stimuli, as well as modality and stimulus frequency differences between the investigations (Johnstone et al., 2005). The majority of developmental research using GO/No-GO tasks has in fact shown a decrease in N2 amplitude, as well as latency, with age (Davis et al., 2003; Johnstone et al., 2005; Jonkman et al., 2003; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006). This finding is aligned with the hypothesis that neural mechanisms of inhibitory control become more efficient with development (e.g., Casey et al., 2000). Furthermore, the reduction of N2 amplitude with age is consonant with the typical developmental pattern of larger ERPs and generally later latencies in children than adults (Courchesne, 1983; Friedman, Putnam, & Sutton, 1989; Holcomb, Coffey, & Neville, 1992; Howard & Polich, 1985;

Pfefferbaum, Mathalon, Sullivan, Rawless, Zipursky, & Lim, 1993; Segalowitz, Unsal, & Dywan, 1992).

As with the N2, the characteristics of the P3 have been examined in developmental studies of cognitive control. The results of these studies are highly mixed. In a flanker task conducted with 4 year-old children and adults, Rueda, Posner, Rothbart, and Davis-Stober (2004) found that on incongruent trials, children showed a greater effect of P3 amplitude than adults. The peak latency of the P3 on incongruent trials, however, was delayed to a similar degree in both groups. Similarly, Davis, Bruce, Snyder, and Nelson (2003) found that 6 year-old children showed greater P3 amplitude than adults on No-GO trials and relatively difficult GO trials. Surprisingly, the N2 effect was not observed in the children or adults. Conflicting evidence of the absence of a fronto-central No-GO P3 and the presence of an adult-like No-GO N2 in children was presented by Jonkman et al. (2003). Yet another discrepant finding reported by Johnstone et al. (2005) is that children exhibited smaller anterior P3s than adults. Similar to P3 studies in the adult literature, these developmental investigations of the P3 indicate that the features and functional significance of this component require clarification.

Investigations of developmental changes in the ERN are limited. As in adults, the ERN is reported to be maximal fronto-centrally in children (Santesso, Segalowitz, & Schmidt, 2006). A study of 124 children ages 7-18 years showed increasing ERN amplitude through adolescence with considerably smaller ERNs in most 7-12 year-old children in a visual flanker task (Davies, Segalowitz, & Gavin, 2004). Consistent with this evidence, Santesso et al. (2006) reported that 10 year-old children demonstrated smaller ERNs than young adults during error trials. In addition, Ladouceur, Dahl, and

Carter (2004) reported larger ERN amplitudes in a group of late as compared to early adolescents. These age-related differences in the ERN concur with evidence of late maturation of the ACC or late development of its involvement in response monitoring (Santesso et al., 2006).

Developmental research of the ERN has also included children with ADHD, who have shown significantly reduced activation of the ACC (Fallgatter et al., 2004) and might therefore be expected to show deviant ERNs relative to typically developing children. Whereas one study found significantly reduced ERN amplitude in 9-11 year-old males with ADHD (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005), another study reported similar ERNs for 10 year-old males and females with and without ADHD (Wiersema, Van der Meere, & Roeyers, 2005). The relationship between ERN activity and ACC activation in ADHD thus requires further examination.

To recap, prefrontal ERPs, such as the N2, P3, and ERN, are sensitive to developmental differences in the evaluative processes of cognitive control. A critical issue that is frequently neglected in developmental ERP studies, though, is the confound between age-related changes in ERPs that are due to task performance versus those due to the development of a cognitive skill (Lamm, Zelazo, & Lewis, 2006). Furthermore, developmental ERP data may enmesh neural activity that reflects neurocognitive function as compared with cortical growth, such as increases in skull density and thickness. Lamm and her colleagues (2006) addressed these challenges by treating performance on a GO/No-GO task as a covariate in testing for age differences and by comparing N2 amplitude and latency to independent measures of executive function. The results of this

approach suggested that the reduction of N2 amplitude, but not latency, with age reflects the development of cognitive control, rather than extraneous factors.

Above, a detailed description of research on cognitive control was provided, which underscored that the regulative and evaluative components of this skill are measurable and dissociable in both adults and children via ERP methods. This account provides the foundation for a discussion of cognitive control in children with SLI, as related to the research agenda of the present study.

1.7 Cognitive Control Skills in Children with SLI

There is growing evidence suggesting that children with SLI are impaired in cognitive control. A review of studies on cognitive control in SLI may help determine whether the hypothesized deficit is evaluative or regulative in nature. Evidence for poor cognitive control in SLI is drawn from studies that demonstrated *interference* effects (performance decrements due to irrelevant information) in affected children. For example, in a study by Gillam, Cowan, & Day (1995), participants were required to recall lists of digits that increased in length. When a one-syllable word, called a *suffix*, was added after the final digit of a list, recency effects for the final digits were expected to decrease in both participant groups due to interference from the suffix. This *suffix effect* (Crowder & Morton, 1969), however, was exacerbated in SLI children, who exhibited more interference errors than children with normal language. Thus, children with SLI may be especially vulnerable to interference from supplementary or irrelevant material. Similarly, SLI children showed numerous interference errors on a task requiring simultaneous processing of sentences (listening to and encoding new sentences while

rehearsing previously presented sentence-final words; Marton & Schwartz, 2003). The SLI, but not the TLD, participants tended to recall words that were irrelevant to the correct response, such as words from non sentence-final positions or sentence-final words from previously presented sets. Similarly, Marton, Kelmenson, and Pinkhasova (2007) found that in an immediate sentence recall task, 7-10 year-old SLI children repeated more words that were previously relevant and that reflected contextual distraction, relative to age- and language-matched peers. In line with these results, Ellis Weismer, Evans, and Hesketh (1999) suggested that the intrusion errors of SLI children in their study reflect a deficit in inhibiting irrelevant lexical items that were the focus of previous searches.

A small number of studies have examined cognitive control in SLI through tasks that require *inhibition*, an active dampening process used for the suppression of irrelevant information and predominant responses. In a subset of these studies, inhibition was tested for *verbal* material. SLI children (classified as *language/learning disabled*) showed greater difficulty than normal language controls in inhibiting irrelevant information during a sentence processing and memory task (Lorsbach, Wilson, & Reimer, 1996). Along these lines, Norbury (2005) demonstrated that SLI relative to TLD children were impaired in suppressing contextually irrelevant information. This was tested by comparing accuracy and reaction times for rejecting irrelevant ambiguous pictures following an ambiguous sentence (e.g., “John stole from the *bank*” – picture of a *river*) with those following a non-ambiguous sentence (e.g., “John stole from the *shop*” – picture of a *river*). This comparison, though, was confounded by a group difference in knowledge of subordinate word meanings.

Inhibition of *non-verbal* material has also been investigated in children with SLI. Noterdaeme, Amorosa, Mildenberger, Sitter, and Minow (2001) reported that SLI children exhibited normal performance in inhibiting predominant responses (interference task) and in inhibiting motor responses when presented with irrelevant stimuli (GO/No-GO task). Notably, though, both of these tasks involved low levels of cognitive conflict because either an equal number of compatible and incompatible presentations were displayed (interference task) or stimulus frequency was set at 50% (GO/No-GO task). In contrast to the above, evidence for poor inhibition of non-verbal material was reported by Im-Bolter, Johnson, and Pascual-Leone (2006). These researchers found that SLI children displayed poor inhibition of an automatic eye movement (saccade) in a task that has shown sensitivity to prefrontal dysfunction (see Roberts, Hager, & Heron, 1994, for a review). In addition, a set-shifting paradigm, used to measure executive control needed to shift between two tasks, revealed that SLI children had difficulty inhibiting their actions when a stimulus attribute was incompatible with the correct response.

Bishop and Norbury (2005) tested the inhibitory skills of SLI children for *both* verbal and non-verbal responses using two subtests of the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1998; Manly, Anderson, Nimmo-Smith, Turner, Watson, & Robertson, 2001). SLI as compared with TLD children were impaired on a task requiring inhibition of a predominant verbal response and on an inhibition task requiring sustained attention but no verbal response. This finding supports the view of SLI as a general cognitive impairment that affects both language and non-language performance.

In sum, there is considerable evidence suggesting that information processing in SLI may be adversely affected by impaired control of cognitive conflict. However, the nature of this deficit is unclear and it is not known if this deficit is in the evaluative or regulative roles of the PFC. Moreover, the aforementioned studies have not determined how a deficit in cognitive control is associated with the language deficits in SLI. Notably, a number of studies in non-clinical populations have revealed a relationship between poor inhibition and poor language processing (e.g., Gernsbacher et al., 1999). Cognitive control, though, is a general skill and may therefore also account for non-linguistic deficits in SLI. For example, the finding of slowed processing across language and non-language tasks in SLI (Kail, 1994; Miller et al., 2001; Windsor et al., 1999) might reflect a deficit in detecting or resolving conflict between competing response alternatives. Furthermore, if SLI children are impaired in suppressing irrelevant information, their working memory is likely to become overburdened and therefore, less efficient. This may account for the well-documented finding of impaired working memory in children with SLI (Gathercole et al., 1990).

Poor cognitive control in SLI may also be associated with a general deficit in selective attention, a process that involves the selection of stimuli to be further processed (excitation) while others are suppressed (inhibition). The precise relationship between cognitive control and attention is unclear. According to Posner and Petersen (1990), a specialized network of human attention orchestrates executive control to monitor and resolve conflict during information processing. Functional MRI studies of this network have reported activation of the ACC, as well as several other brain areas, including the lateral prefrontal cortex, in tasks requiring attentional control (Fan, McCandliss, Fossella,

Flombaum, & Posner, 2005). Intuitively, the detection and monitoring of information for the presence of conflict seem contingent on attentional processes.

Various paradigms have been used to examine selective attention in children with SLI (classified as *learning disabled* in the earlier literature), including Hagen's Central-Incidental Memory Task (Hagen, 1967; e.g., Taranowski, Prinz, & Nay, 1986; Tarver & Hallahan, 1974), dichotic listening tasks (Lasky & Tobin, 1973; Niemi, Gundersen, Leppäsaari, & Hugdahl, 2003), the Embedded Figures Test (e.g., Goldman & Hardin, 1982), Stroop tasks (Stroop, 1935; e.g., Lazarus, Ludwig, & Aberson, 1984), the flanker task (Eriksen & Eriksen, 1974; e.g., Richards, Samuels, Turnure, & Ysseldyke, 1990), and the Speeded Classification Test (Garner & Felfoldy, 1970; e.g., Taranowski et al., 1986). These investigations have generally yielded the same conclusion: Selective attention in children with SLI is poorer than in normally developing children (e.g., Krupski, 1986; Hallahan & Reeve, 1980). These results corroborate evidence suggesting that children with SLI may have a broad deficit in attention, which comprises cognitive control. For example, SLI children were found to have deficits in auditory selective attention, as well as in tasks requiring auditory sustained attention and shift of attention, as compared with controls matched by age, gender, and non-verbal IQ (Noterdaeme et al., 2001). An attention task that measured the costs and benefits of spatial cues also revealed poorer performance in SLI children relative to normal controls (Nichols, Townsend, & Wulfeck, 1995). More sensitive measures of attention using ERPs suggest that children with SLI are impaired in auditory attention for speech sounds (Shafer, Morr, Datta, Kurtzburg, & Schwartz, 2005; Shafer, Ponton, Datta, Morr, & Schwartz, 2007). Collectively, the aforementioned evidence of attentional deficits in SLI and the

relationship between attention and cognitive control constitute a compelling reason to explore cognitive control skills in this population.

One striking aspect of the studies reviewed in this section is their lack of specificity in testing the components of cognitive control in SLI. This limitation can be attributed to two factors: In some of the studies described (e.g., Marton et al., 2003), evidence for impaired cognitive control was incidental to the main research questions. Secondly, the aforementioned studies relied on behavioral measures, which confound the evaluative and regulative functions of cognitive control. In general, behavioral measures merely reflect the *outcome* of stimulus analysis and response preparation. In the proposed study, the neural correlates that *contribute* to cognitive control were examined by employing ERP measures. This study is unique in its ability to assess specifically the evaluative component of cognitive control (detection and triggering of control), separate from its regulative counterpart. This was achieved through the use of the N2 electrophysiological component, detailed above. The N2 brain response indexes cognitive control by increasing in amplitude on trials that require withholding a response (in a GO/No-GO paradigm) and this modulation is attributed to the ACC (e.g., Nieuwenhuis et al., 2003). Recall that the ACC is activated for the evaluative function of cognitive control. The current investigation has paved the way for future studies that might determine if the regulative component is also impaired in SLI. Furthermore, the present study details the time course of information processing in SLI and may thereby elucidate the common finding of slowed processing in this disorder.

Chapter 2 Method

2.1 *Introduction*

A speeded button response task and an ERP method were used to explore the ability of SLI and TLD children to control cognitive conflict. The study was divided into two experiments, *Linguistic* and *Non-linguistic*. A two-alternative GO/No-GO paradigm was used in each experiment for each task. Upon seeing stimuli, participants were required to either press a button (GO) or withhold a motor response (No-GO) according to pre-test instructions. The stimuli of each task were presented in three conditions that differed in stimulus probability. Reaction time (RT), hit rates, false-alarm rates, and ERP recordings were analyzed.

These experiments assessed whether: 1) SLI children are impaired in controlling cognitive conflict induced by various stimulus probabilities relative to TLD children; 2) SLI children demonstrate similar patterns of performance in controlling cognitive conflict in a *Linguistic* versus a *Non-linguistic* task relative to TLD children; 3) correlations exist between behavioral measures of cognitive control (RT and accuracy), the amplitude of ERP responses, and specific language skills, as measured via a standardized language test; and 4) ERP measures are a useful on-line method for evaluating information processing in children.

2.2 *Participants*

Fifty participants were included; 12 children with SLI between the ages of 10-12 years (mean (M) = 11;7 [years; months]; standard deviation (SD) = 1.01), 22 children with typical language development (TLD-A) matched group-wise on age (M = 11;2; SD

= .89; $F(1, 32) = 1.55$, $p > .05$, $\eta_p^2 = .05$.), and 16 younger children with typical language development between the ages of 8-9 years (TLD-Y; $M = 8;9$; $SD = .58$), matched group-wise with the SLI children on receptive and expressive language, as detailed below.

The age range of 10-12 years for the SLI and TLD-A groups was selected in view of the experimental tasks' level of difficulty and because 10 year-old children with normal language abilities have shown the experimental (No-GO N2) effect under study (Johnstone et al., 2005; Jonkman et al., 2003). Moreover, data on normative development show stability in resolving cognitive conflict after 7 years of age up to adulthood (see Rueda et al., 2004). Thus, homogeneity in conflict resolution skills between 10-12 years of age within the TLD-A group was expected. A younger, typically developing group (TLD-Y) was included as a control to determine if impaired performance in the SLI group resembles the performance of younger TLD children and thus, is due to maturational lags. This is of particular importance because the cognitive control mechanisms under study are age-sensitive due to the relatively late maturation of the prefrontal cortex (Dempster & Corkill, 1999).

All participants were healthy, monolingual speakers of English with normal or corrected vision. Eligibility criteria for all participants also included normal binaural hearing (as per a screening: 500, 1k, 2k, and 4k Hz at 25 dB; American National Standards Institute, 1989) and normal non-verbal cognition, indicated by performance within normal limits (standard score = 85-115) on the Test of Nonverbal Intelligence-Third Edition (TONI-3; Brown, Sherbenou, & Johnsen, 1997). The Conners' Parent Rating Scale-Revised, Long version (CPRS-R:L; Conners, 1997) was administered to parents/guardians of all participants. This instrument uses parent ratings to screen for

attention deficit/hyperactivity disorder (ADHD) and behavioral problems. The scale contains eighty items that assess oppositional behavior, cognitive problems, hyperactivity, anxiety/shyness, perfectionism, social problems, and psychosomatic symptoms. Children who met the criteria for ADHD on the Conners or who had a reported diagnosis of ADHD were excluded from the study. Additionally, children with reported phonological, motor, or neurodevelopmental disorders, such as autism, were not eligible to participate in the study.

Complete language testing was administered to each participant. This included all six main subtests of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003) for 8 year-old children, namely; Concepts and Following Directions, Word Classes-Receptive, and Sentence Structure (receptive language measures), as well as Word Structure, Recalling Sentences, and Formulated Sentences (expressive language measures). Children between the ages of 9-12 were administered the following five main subtests of the CELF-4 for individuals ages 9-21: Concepts and Following Directions and Word Classes-Receptive (receptive language measures), as well as Recalling Sentences, Formulated Sentences, and Word Classes-Expressive (expressive language measures). Children were classified as SLI if they scored greater than -1.3 *SD* on at least two of the CELF-4 receptive or expressive subtests or if their receptive or expressive composite language scores were greater than -1.5 *SD*. Children who earned a language composite score of 85 or higher (average range = 85-115) on the CELF-4 were classified as children with TLD. The Peabody Picture Vocabulary Test-Third Edition (PPVT-III; Dunn & Dunn, 1997) or the fourth edition of

this test (PPVT-4; Dunn & Dunn, 2007) was also administered to all participants to assess single word receptive vocabulary knowledge but was not used for classification.

The SLI group scored significantly lower than the TLD-A group on the CELF-4 Receptive Language composite score, $F(1, 32) = 72.67, p < .00001, \eta_p^2 = .69$; on the CELF-4 Expressive Language composite score, $F(1, 32) = 96.61, p < .00001, \eta_p^2 = .75$; and on the CELF-4 Core Language (total language) score, $F(1, 32) = 147.06, p < .00001, \eta_p^2 = .82$. Of the 38 TLD participants (22 TLD-A + 16 TLD-Y), only three children scored below the average range on one of the CELF-4 subtests. Single word receptive vocabulary knowledge, as measured via the PPVT-III/4, was lower in the SLI group relative to both the TLD-A group, $F(1, 32) = 16.28, p < .001, \eta_p^2 = .34$, and the TLD-Y group, $F(1, 26) = 35.41, p < .00001, \eta_p^2 = .58$.

The SLI and TLD-Y groups were matched on raw scores of two subtests of the CELF-4: the receptive language subtest, Concepts and Following Directions, which assesses the ability to point to pictures according to verbally presented instructions, $F(1, 26) = .97, p > .05, \eta_p^2 = .04$, and the expressive language subtest, Formulated Sentences, a measure of the ability to verbally generate a sentence in relation to a picture shown using a target word or phrase provided by the examiner, $F(1, 26) = .15, p > .05, \eta_p^2 = .006$. The SLI group demonstrated lower non-verbal intelligence scores than both the TLD-A group, $F(1, 32) = 10.08, p < .01, \eta_p^2 = .24$, and the TLD-Y group, $F(1, 26) = 9.70, p < .01, \eta_p^2 = .27$. The gender, ages, and standardized scores for each participant on the CELF-4, PPVT-III/4, and TONI-3 are presented in Appendix A.

2.3 Materials

The stimuli for the *Linguistic* experiment were 20 color line drawings of common fruits and vegetables (e.g., *peach*, *lettuce*, etc.; 8 mono-syllabic and 12 bi-syllabic) and twenty color line drawings of common items that are worn (e.g., *shirt*, *jacket*, etc.; 9 mono-syllabic and 11 bi-syllabic). The names of the experimental stimuli are listed in Appendix B. To ensure consistency of naming and categorization of the pictures, 10 TLD children, ages 8-12 (the ages for both TLD groups), were asked to identify each picture presented individually on a computer screen. These participants were then shown the same pictures one at a time on a computer screen and were asked to categorize each one. Name agreement was 100% for approximately 34/40 items. For 6/40 items, the pilot participants either substituted the target word with a similar, acceptable word (e.g., *pants* for *jeans*) or incorrectly labeled the picture (e.g., *plum* for *peach*). The categorization agreement, however, was 100% for all pilot participants. In view of the nature of the task (i.e., categorization, not explicit naming) all items were retained for the final set of experimental stimuli. Twelve lists comprising the names of the pictures were created and pseudo-randomized such that no consecutive stimulus items began with the same initial phoneme and no item was presented more than once within five consecutive stimuli.

The stimuli for the *Non-linguistic* experiment were forty geometric shapes (e.g., circle, triangle, etc.), which were created in Microsoft PowerPoint and were modified in Adobe PhotoShop. The shapes were divided into two groups of 20 shapes. In one group, all of the 20 shapes contained either one or two vertical lines (10; 10). The other group included the identical 20 shapes, which contained either one or two horizontal lines (10; 10). The one or two lines within each shape varied in their location within the shape (e.g.,

left, centered, right) and shapes that contained two lines had varying widths between the lines. The shapes had an approximate height and width of 8.82 cm. Ten sets of shapes were created for the vertical and horizontal categories (5; 5). The sets differed only in the color of the shapes, with both the vertical and horizontal categories including sets of orange, blue, yellow, green, and pink shapes that were borderless and contained vertical or horizontal, thick black lines that were approximately .18 cm wide.

2.4 Procedure and Apparatus

The experimenter first described the experimental procedure to the parents or caregivers of the participants, after which they were asked to sign informed consent forms (see Appendix C). The experimenter then described the procedure to the participants in child-friendly terms and obtained their oral consent (see Appendix D). Next, the participants were fitted with a 64-channel Geodesic Sensor Net (Electrical Geodesics). They were then comfortably seated in a sound- and electrically-shielded booth that was dimly lit. Participants faced a computer screen positioned at eye level at a distance of 70 cm. Impedances were then measured to ensure that they were at or below 40 k Ω . Electrode impedances of 40 k Ω are appropriate for EEG recording performed with a modern high input impedance amplifier (Ferree, Luu, Russell, & Tucker, 2001). All instructions were presented orally by the examiner, as detailed above.

Participants performed two experimental tasks, the order of which was mostly randomized and counterbalanced among the participants. The *Linguistic* experiment tested semantic categorization of common fruits and vegetables and of items that are worn. Half of the participants in each group were required to press the button on a

response box (GO) when they saw a picture of a fruit or vegetable and withhold a response (No-GO) when they saw a picture of an item that is worn. The remaining participants in each group were assigned the reverse stimulus-response correspondence (i.e., GO for an item that is worn, No-GO for a fruit or vegetable). Assignment of participants to stimulus-response categories was mostly randomized and counterbalanced. The use of pictures in the *Linguistic* task was founded on the notion that pictures invoke access of semantic representations because the participants were instructed to categorize semantically (see Schmitt, Schiltz, Zaake, Kutas, & Munte, 2001, for a justification of using pictorial stimuli without overt naming in a semantic GO/No-GO task).

Prior to beginning the *Linguistic* experiment, the participants completed two familiarization tasks. The experimenter first told the participant the name of the category of pictures to be presented (e.g., “pictures of things that grow, such as fruits and vegetables;” “pictures of things that we wear”). The pictures from an entire category were then presented on a computer screen and the participants were instructed to label the pictures aloud. This procedure was repeated for the second category of pictures. Next, the participants were told that they would see the pictures from both categories in a “mixed-up order” and should label the pictures as either *grows* or *wear*. All errors produced in each of the tasks were pointed out and corrected by the experimenter, who recorded the participants’ responses online.

In the *Non-linguistic* task, participants were required to press the button on a response box (GO) when they saw a shape with one or more vertical lines (“lines that go from top to bottom”) and withhold a response (No-GO) when they saw a shape with one or more horizontal lines (“flat lines that go from side to side”). When explaining the task

instructions, the experimenter used her hands to demonstrate the line orientation for each stimulus-response assignment. The assignment of line orientation to the GO and No-GO response categories was randomized and counterbalanced across the participant groups. Prior to all tasks, the participants were instructed to respond with the index finger of their dominant hand. The importance of both speed and accuracy was stressed. The purpose of emphasizing speed was to increase the inhibitory demand of the task and thereby enhance the amplitudes of the N2 in response to rare stimuli (Jodo et al., 1992). In addition, the participants were told that at the conclusion of testing, they would be awarded small prizes commensurate with their performance and that if they “do the wrong thing” (i.e., failing to respond to a GO picture or pressing the button for a No-GO picture), they would lose two points.

Both experimental tasks (*Linguistic* and *Non-linguistic*) were performed under three conditions: 80 GO/20 No-GO, 50 GO/50 No-GO, and 20 GO/80 No-GO, as illustrated in Appendix E. In the 80 GO/20 No-GO condition, stimulus probability was 80% for GO stimuli and 20% for No-GO stimuli. This ratio was expected to engender difficulty competing with and overcoming the preponderant tendency to *GO* on the less common No-GO trials. In the 50 GO/50 No-GO condition, GO and No-GO stimuli were each presented at a probability of 50%. This condition served as a baseline to determine if there was a bias toward one response type (GO vs. No-GO) in the absence of a bias in frequency (50% GO, 50% No-GO). In the 20 GO/80 No-GO condition, the stimulus probability was reversed relative to the 80 GO/20 No-GO condition: 20% for GO stimuli and 80% for No-GO stimuli. Because the GO response was rare in this condition, it was anticipated that stimuli corresponding to GO would elicit difficulty overriding the

dominant tendency to refrain from responding (*No-GO*). Balancing the 80 GO/20 No-GO condition with the 20 GO/80 No-GO condition was intended to avoid confounding stimulus probability with response type; all frequent stimuli would have otherwise been associated with the GO response and all rare stimuli would have been associated with the No-GO response.

Each of the three conditions within both experimental tasks was preceded by a block of 20 practice items in which GO and No-GO stimuli were randomly presented with equal frequency. Participants who achieved an accuracy score below 80% on any practice block repeated the block until they scored 80% or higher, with the allowance of no more than four practice blocks (beyond which testing would have been terminated, although this did not apply to any of the participants). Each condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) was tested in four blocks, each containing 100 trials. Thus, each experiment included four blocks of 100 trials for each of three conditions, amounting to 1200 trials per experiment. The presentation order of the conditions was randomized. All of the stimuli were presented according to pseudo-randomized lists, as detailed above (see *Materials*). In the *Non-linguistic* experiment, the practice block comprised the sets of vertical and horizontal pink shapes. Each of the four experimental blocks per condition comprised one set of shapes (orange, blue, yellow, or green) and the blocks were presented in random order.

Each experimental trial proceeded as follows (see Appendix F): A picture stimulus was presented in the center of the computer screen for 700 ms, followed by display of a blank screen for 1000 ms, after which the next trial ensued. There was a 30-second break between blocks of the same frequency and a 3-minute break between blocks

of different frequencies. The longer break time for the latter case was intended to prevent overlap of experimental effects between blocks of different frequencies.

Feedback was delayed within each experiment until the conclusion of each block in order to minimize learning effects. To avoid bias toward either response category, an equal number (2) of points was deducted if participants responded incorrectly by either producing a button press on a No-GO trial or by refraining from responding on a GO trial. Feedback was displayed on the screen as a cumulative accuracy score followed by the message, “Take a 30 second break.” The instructions for stimulus-response assignment were repeated by the experimenter at the conclusion of each 3-minute break between the conditions.

The presentation of stimuli and behavioral response collection were controlled by a PC with E-Prime software, Version 1.0, connected to a Serial Response Box from Psychology Software Tools, Inc. (Schneider, Eschman, Zuccolotto, 2002). The pictures were displayed on a 17-inch computer screen with a white background. Behavioral performance was monitored by the experimenter via a video screen situated outside of the booth. EEG data were collected using an Electrical Geodesics 200 system with a 64-channel Geodesic Sensor Net composed of silver/silver-chloride (Ag/AgCL) plated electrodes encased in electrolyte-wetted sponges. Two of the electrodes were positioned under each eye to monitor eye movements. The EEG data were continuously recorded at a sampling rate of 250 Hz. All ERP responses were time-locked to the onset of each stimulus. Recordings were referenced to Cz and re-referenced to linked mastoids off-line. Electrode impedances were maintained below 40 k Ω , as measured prior to testing and between the two experiments. The EEG signal was amplified using a hardware bandpass

filter set at 0.1 – 30 Hz and was digitized using 12-bit resolution. All EEG recordings were stored on a hard disk for further analysis.

2.5 Behavioral Data Analysis

Performance measures included hit rates and RT to GO stimuli and false-alarm rates to No-GO stimuli. Hit rates to GO stimuli were calculated by multiplying 100 x the number of correct hits and then dividing by the total number of GO stimuli. False-alarm rates were computed by multiplying 100 x the number of incorrect hits and then dividing by the total number of No-GO stimuli. Button presses to GO stimuli between 200 to 1700 ms post-stimulus onset were scored as correct. A response made to No-GO stimuli during this window was scored as a false-alarm.

RT was calculated from the onset of each GO stimulus to the button press. Hit rates in each of the groups were at or near ceiling levels, as reported below, and were therefore not entered into statistical analyses. RT to GO stimuli and false-alarm rates were examined in separate ANOVAs with the between-group variable, Group (TLD-A, SLI, TLD-Y), and the within-group variable, Condition (80% GO, 50% GO, 20% GO) for the Linguistic and Non-linguistic experiments separately. To determine whether participants exhibited a speed/accuracy trade-off, Pearson correlations between the false-alarm rates and RT to GO stimuli for each condition in each group were examined for both of the experiments. Due to the presence of ceiling effects for hit rates, signal-detection analysis (Green & Swets, 1966) could not be applied to distinguish sensory sensitivity from response bias. Notably, though, each of the groups demonstrated high hit

rates and low false-alarm rates, suggesting high sensitivity with no indication of response bias.

2.6 ERP Data Analysis

Following recording, the continuous EEG was segmented off-line into 1900 ms epochs for each trial of all the experimental conditions. The epochs were baseline-corrected (to a mean amplitude of 0) using the pre-stimulus baseline interval. Epochs comprised a 200 ms pre-stimulus baseline and continued for 1700 ms from stimulus onset. The 200 ms pre-stimulus period was characterized by a duration of silence prior to stimulus onset. All segments for each participant underwent artifact decontamination procedures. Net Station (EGI, Inc.) software was used to mark channels as contaminated if the fast average amplitude exceeded 200 μV , if the differential amplitude exceeded 100 μV , or if the channel had zero variance. Channels marked as contaminated in more than 20 percent of the trials were subsequently marked as such in all trials. These channels were deleted and replaced with data by means of the spherical spline interpolation. Trials that contained greater than 10 contaminated channels or that contained lateral eye movements accounting for amplitudes greater than 100 μV were marked for rejection.

Next, single subject recordings underwent an eyeblink subtraction procedure based on Independent Component Analysis (Bell & Sejnowski, 1995) by means of the ICA Blink Toolbox 1.21 and EEGLAB (Delorme & Makeig, 2004). Net Station artifact detection software was then used to re-examine the recordings. The data from each participant's remaining trials per condition were averaged and re-referenced to the newly computed average. The data of participants with fewer than 22 trials (27.5%) retained in

any of the conditions were excluded from analysis. In the Linguistic experiment, this applied to one TLD-A child and in the Non-linguistic experiment, this applied to one SLI child and two TLD-Y children. The average number of retained trials and their corresponding standard deviations per condition in each of the groups are presented in Table 1.

Table 1. Number of retained trials (standard deviation) per condition in the Linguistic and Non-linguistic experiments.

		<u>TLD-A</u>	<u>TLD-Y</u>	<u>SLI</u>
Linguistic	80 GO	300 (16)	285 (21)	277 (36)
	20 No-GO	61 (10)	54 (12)	54 (12)
	50 GO	184 (17)	176 (19)	183 (20)
	50 No-GO	174 (25)	168 (23)	179 (23)
	20 GO	73 (6)	70 (7)	71 (9)
	80 No-GO	288 (31)	284 (27)	284 (25)
Non-Linguistic	80 GO	298 (18)	299 (25)	298 (14)
	20 No-GO	56 (13)	52 (11)	54 (17)
	50 GO	184 (19)	182 (11)	184 (13)
	50 No-GO	174 (20)	174 (13)	174 (13)
	20 GO	71 (12)	72 (6)	73 (7)
	80 No-GO	281 (50)	292 (21)	296 (16)

Previous GO/No-GO studies of TLD children have reported an N2 within approximately 200-350 ms post-stimulus onset at frontal sites (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Jonkman, Lansbergen, & Stauder, 2003). Given the greater complexity of the stimuli and the use of categorization tasks in this study, it was expected that the N2 would surface later, at approximately 350-500 ms following stimulus onset. Visual inspection of the individual participants' data and the grand average waveforms

for each group within each experiment and condition revealed the following: Firstly, the N2 was maximal beginning at approximately 400 ms post-stimulus onset and returned to baseline at approximately 560 ms. To avoid confounding measurement of the N2 with any possible preceding GO/No-GO differences, a peak-to-baseline time interval from 400-560 ms was selected for further analyses. Secondly, the expected N2 effect (difference between GO and No-GO waveforms) appeared predominantly at frontal and fronto-central sites. Differences between GO and No-GO waveforms also appeared at central sites, although not according to predictions based on previous N2 findings. Based on examination of each group's grand average waveforms, groups of frontal, fronto-central, and central electrodes where the N2 effect was present and where the signal relative to baseline noise was relatively high were selected for statistical analyses. Figure 1 shows the electrode sites included in each region and Table 2 indicates the

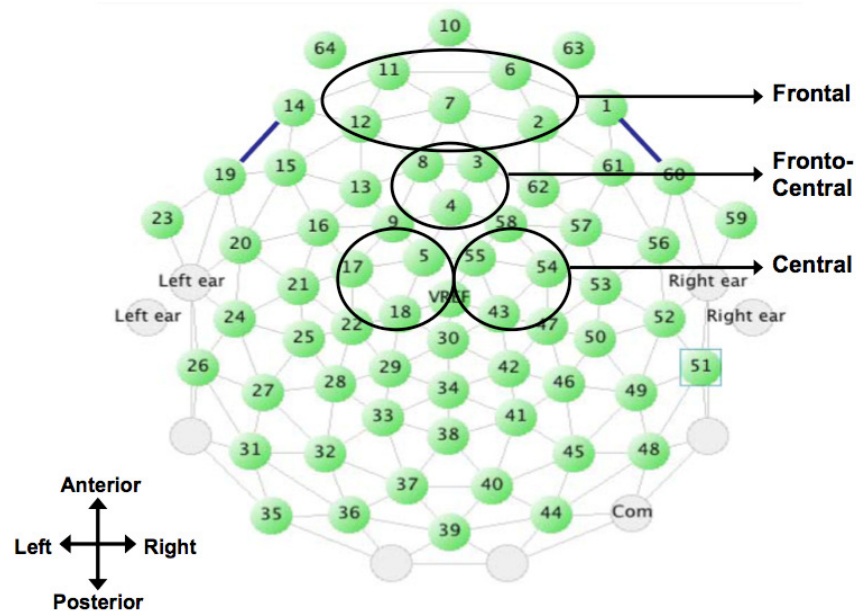


Figure 1. 64-channel Geodesic sensor net (EGI, Inc.).

correspondence between these electrodes, which comprise the Geodesic system, and the electrode placements of the International 10-10 system (Luu & Ferree, 2000), as well as their locations across the scalp.

Table 2. Sensor net channels included in ERP statistical analyses, their correspondence with the 10-10 International System, and their scalp location (sagittal and coronal).

Sensor Net Channel (EGI, Inc.)	10-10 International System Equivalent	<u>Scalp Location</u>	
		Sagittal	Coronal
2	AF4	Right	Frontal
6	FP2, FPz	Right	Frontal
7	AFz	Midline	Frontal
11	FP1	Left	Frontal
12	AF3	Left	Frontal
3	Fz, F2	Right	Fronto-Central
4	Fcz	Midline	Fronto-Central
8	Fz, F1	Left	Fronto-Central
43	Cp2, C2	Right	Central
54	FC4, C4	Right	Central
55	C2	Right	Central
18	CP1, C1	Left	Central
17	C3, C1	Left	Central
5	C1	Left	Central

Mean amplitudes were calculated for the N2 time region (400-560 ms) of all GO and No-GO waveforms for trials with correct behavioral responses only. Each group's data were statistically analyzed individually to ascertain whether the expected N2 effect was borne out in the three conditions of stimulus probability (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) at frontal, fronto-central, and central sites. For each group, mean amplitude values for the N2 time region were submitted to a repeated measures ANOVA with three within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) and Region (frontal, fronto-central, and central).

Significant interactions were followed up by Tukey's Honestly Significant Difference (HSD) post-hoc test. Results for the TLD-Y (8-10 year-olds) group were evaluated relative to those of the SLI (10-12 year-olds) group to distinguish between atypical performance that was maturational versus developmentally deviant. This procedure was performed for the Linguistic and Non-Linguistic experiments separately.

Because analysis of the individual groups' data revealed that N2 effects were most consistent with adult-like patterns and were robust in the frontal region, subsequent analyses across groups were limited to this area. To compare cognitive control abilities as indexed by the N2 across groups, a repeated measures ANOVA was performed with the between-group variable, Group (TLD-A, SLI, TLD-Y), and the within-group variables, Response Type, (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (400-440, 440-480, 480-520, 520-560 ms). The primary purpose of including time as a variable was to determine if the latency of the N2 effect differed across the groups.

A two-tailed significance level of $p = .05$ was adopted for all analyses. To correct for violation of the sphericity assumption, the Greenhouse-Geisser adjustment was applied to probability values.

2.7 Correlational Analyses

Four main correlational analyses were performed within each experiment. One analysis examined whether there were associations between RT for GO responses and mean amplitudes of the N2 in response to GO stimuli. Correlations were computed for each group using the average RT for GO responses in each condition (80 GO, 50 GO, 20

GO) and mean amplitudes of the N2 (400-560 ms) in the frontal region for 80 GO, 50 GO, and 20 GO waveforms. A second analysis tested whether there were associations between false-alarm rates in each condition and the No-GO minus GO difference waveforms for correct responses in each condition. An additional correlational analysis examined whether there were associations between the participants' language test scores, including the receptive, expressive, and composite standardized scores of the CELF-4 and the average RT to GO stimuli in each condition, as well as between the aforementioned CELF-4 scores and mean amplitudes of the N2 difference waves (No-GO - GO) in the frontal region in each condition. This analysis has clinical value because it allowed investigation of the relationship between electrophysiological markers of cognitive control skills and specific language abilities in TLD and SLI children.

Lastly, correlations were computed for the P3 component in the time region during which its amplitude was maximal, 1000-1100 ms. To determine whether the N2 and P3 components are associated, as suggested by previous studies (Jonkman et al., 2003), correlations were calculated between the mean amplitudes of the N2 and P3 difference waves in each condition. Correlations between false-alarm rates and P3 difference waves in each condition were computed to evaluate whether the P3 is related to a measure of behavioral inhibition.

2.8 Predictions

2.8.1 Behavioral Data

The accuracy scores of all three participant groups were expected to be high (> 90%). This prediction was based on evidence of low rates of omission and commission

errors in GO/No-GO tasks in normally developing (Jonkman et al., 2003; Johnstone et al., 2005) and SLI children (Noterdaeme et al., 2001) between 9-12 years of age. The percentage of false-alarms to No-GO stimuli was expected to decrease across conditions with an increase in the frequency of No-GO trials. In addition, the TLD-Y group was expected to exhibit higher false-alarm rates than the TLD-A group due to the protracted development of inhibitory control over motor responses during childhood (e.g., Dempster et al., 1999). Accuracy was not expected to be significantly lower in the SLI group as compared with accuracy in the groups of typically developing children.

In line with previous evidence (Nieuwenhuis et al., 2003), RT in response to GO stimuli was expected to increase across conditions with an increase in the frequency of No-GO trials. The RT of the TLD-Y group was expected to be significantly longer than that of the TLD-A and SLI groups. Most notably, responses of the SLI group were expected to be significantly slower than those of the TLD-A group for the linguistic and non-linguistic tasks. This expectation was founded on evidence that SLI children perform 10-30% more slowly than their age-matched peers, with performance being slower to the same degree on linguistic and non-linguistic tasks (Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001; Windsor et al., 1999). Findings of slower RT in SLI lead to non-specific interpretations that are limited in their ability to enhance our understanding of the nature of this disorder. This factor underscores the benefit of compounding behavioral measures with ERP measures to examine processing in the SLI population.

2.8.2 ERP Data

The classical finding of enhanced negativity for No-GO waveforms as compared with GO waveforms was firmly predicted for the 80 GO/20 No-GO condition. This *No-GO N2* effect is thought to index the requirement to withhold a response (No-GO) in the face of another response that is predominant (GO) in the task at hand. In the 50 GO/50 No-GO condition, the N2 responses to No-GO stimuli were expected to be slightly greater than to GO stimuli, considering evidence that a slight bias to the GO response appears to be present in speeded response tasks (Nieuwenhuis et al., 2003). The No-GO rather than the GO response was preponderant in the 20 GO/80 No-GO condition and therefore, greater N2 amplitude was expected for the GO waveforms. This would confirm evidence that the N2 reflects processes involved in the detection of conflict invoked by infrequent stimuli and that it is not dependent on the nature of the response (GO vs. No-GO) per se (e.g., Nieuwenhuis et al., 2003). Based on evidence that the N2 effect in children (but not adults) is primarily determined by stimulus probability (Ciesielski et al., 2004), it was predicted that the participants would exhibit sensitivity to the manipulation of stimulus probability.

An interaction between group and condition was anticipated; analyses were expected to reveal that SLI children show smaller differences between N2 mean amplitudes for GO versus No-GO waveforms than same-age controls in the 80 GO/20 No-GO condition relative to the 50 GO/50 No-GO (baseline) condition. Reduced N2 amplitude in this task is thought to reflect impaired conflict control according to the conflict-monitoring theory (e.g., Donkers et al., 2004), or impaired response inhibition. It was predicted that this impairment would be manifested in both the *Linguistic* and *Non-*

linguistic experiments, in view of SLI as a general cognitive deficit. However, the group difference was expected to be greater for performance on the *Linguistic* task. This is because linguistic stimuli require the online extraction of linguistically relevant information from the speech stream. Because SLI is characterized by slowed processing, the time-dependent nature of language input should induce greater conflict costs than non-language input in affected children (see Miller et al., 2001). Evidence of attenuated N2 amplitudes would instantiate weak conflict detection, thereby confirming the study's hypothesis that impaired processing in SLI is characterized by deficient cognitive control.

Due to the expected bias toward the GO response, it was predicted that it would be easier to refrain from *not* responding in the 20 GO/80 No-GO condition than to refrain from responding in the 80 GO/20 No-GO condition. Therefore, no differences between the TLD-A and SLI groups were expected for N2 amplitude in the 20 GO/80 No-GO condition. For the analysis of N2 latency, no interaction between group and condition was expected. Although SLI children commonly show longer reaction times, N2 latency has not been found to be a direct correlate of behavioral RT. In fact, studies using the N2 to measure responses to auditory distraction have found that amplitude (perhaps reflecting the buildup of activity) is more highly correlated with RT than is latency (e.g., Melara, Rao, & Tong, 2002). This factor will be explored in a correlational analysis.

Additional expectations were posited regarding the maturation of N2 characteristics from 8-12 years of age. Higher N2 amplitudes and later latencies in the TLD-Y group relative to the TLD-A group were anticipated, in accordance with developmental research (e.g., Johnstone et al., 2005). The precise developmental trajectory for the amplitude and latency of the N2 between the ages of 8-12 years is

unknown, precluding further predictions for performance across the groups. Notably, though, age differences in neural activity might reflect maturational differences in task performance or changes in skull density or thickness, both of which are extraneous to the current study of cognitive control. These factors could thus confound comparison of cognitive control performance in the TLD-Y and SLI groups. A recent study (Lamm et al., 2006) addressed this issue by comparing N2 amplitudes and latencies to performance on four independent measures of executive function/cognitive control. Decreases in N2 amplitude, but not N2 latency, with age were associated with the development of cognitive control, rather than with the aforementioned confounding factors. The N2 effect that is central to the present study relates to amplitude differences. In comparing performance of the TLD-Y group with that of the TLD-A and SLI groups, latency differences were interpreted with caution. Lastly, no between- or within-group differences were anticipated for topography in either of the experiments. A .05 level of significance was set for all analyses involving clear predictions. Due to the multiple comparisons performed, a more stringent .01 level of significance was set for all analyses that did not involve firm predictions.

2.8.3 Correlational Analyses

Mean amplitudes of the N2 were expected to correlate negatively with false-alarm rates. This prediction was based on evidence of No-GO N2 attenuation in participants with high false-alarm rates (Falkenstein et al., 1999). Because this analysis involved a clear prediction, the level of significance was set at .05. No firm predictions were posited

for any other correlations and therefore, the .01 level of significance was applied to all other correlational analyses.

Chapter 3 Linguistic Experiment: Results

3.1 Behavioral Results

Mean hit rates, RT to GO stimuli, and false-alarm rates to No-GO stimuli with their corresponding standard deviations (*SD*) for each of the participant groups are presented in Table 3. Hit rates in all of the groups were at or near ceiling level ($> 96\%$) in each of the conditions and were therefore not entered into statistical analyses. False-alarm rates in the 20 GO/80 No-GO condition were likewise near ceiling level ($< 1\%$) and were therefore excluded from statistical analyses.

Table 3. Mean hit rate, RT, and false-alarm rate (standard deviation) per group and condition in the Linguistic experiment.

	<u>80 GO/20 No-GO</u>			<u>50 GO/50 No-GO</u>			<u>20 GO/80 No-GO</u>		
	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)
TLD-A	99.57 ($< .01$)	438.89 (44.89)	20.26 (.11)	99.13 (.01)	481.21 (45.62)	2.60 (.01)	98.41 (.01)	516.18 (48.19)	.58 ($< .01$)
SLI	99.18 (0.01)	451.29 (56.78)	20.00 (.10)	98.85 (.02)	492.00 (53.81)	1.90 (.01)	97.81 (.03)	522.74 (57.34)	.48 ($< .01$)
TLD-Y	98.48 (.02)	473.79 (63.83)	26.67 (.13)	97.16 (.04)	511.15 (54.91)	5.53 (.04)	96.72 (.04)	558.30 (55.98)	.99 (.01)

To identify non-representative outliers, Tukey's (1977) method was applied. This involved calculating the 25%, 50%, and 75% quartiles (Q1, Q2, and Q3) and the interquartile range (IRQ; $Q3 - Q1$) and then establishing cut-off points beyond the IRQ range. Values between $Q3 - 1.5\text{IRQ}$ and $Q3 - 3.0\text{IRQ}$ were considered possible outliers and values beyond $Q3 - 3.0\text{IRQ}$ were considered extreme outliers (Tukey, 1977). This

method identified the following numbers of outliers and extreme outliers for false-alarm rates in the 50 GO/50 No-GO condition: Two outliers and one extreme outlier were present in the TLD-A group; two extreme outliers were present in the SLI group; and one outlier was present in the TLD-Y group. The values for these outliers were excluded from the following analysis.

A repeated measures ANOVA for false-alarm rates with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factor, Condition (80 GO/20 No-GO, 50 GO/50 No-GO), revealed a main effect of Condition, $F(1, 41) = 150.36$, $p < .00001$, $\eta_p^2 = .79$. This effect arose from significantly higher false-alarm rates in the 80 GO/20 No-GO condition as compared with the baseline condition in each of the groups. The main effect of Group, $F(2, 41) = 2.76$, $p = .075$, $\eta_p^2 = .12$, was marginally significant, owing to higher false-alarm rates in the TLD-Y group. The interaction of Group x Condition, $F(2, 41) = .56$, $p > .05$, $\eta_p^2 = .03$, was not significant.

For the analysis of RT, the Tukey (1977) method for identifying outliers was used, as described above. One outlier in the TLD-A group was identified for the 80 GO/20 No-GO condition only and was therefore excluded from the analysis. A 3 x 3 (Group: TLD-A, SLI, TLD-Y x Condition: 80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) repeated measures ANOVA with RT scores revealed a main effect of Condition, $F(2, 92) = 130.49$, $p < .001$, $\eta_p^2 = .74$, $\epsilon = .74$. This effect was driven by increasingly shorter RTs from the 20 GO/80 No-GO condition to the 50 GO/50 No-GO condition and then to the 80 GO/20 No-GO condition across groups. Tukey's HSD post-hoc test indicated that this effect was driven by significant differences among all of the three conditions ($p < .001$). The main effect of Group, $F(2, 46) = 2.90$, $p = .06$, $\eta_p^2 = .11$, $\epsilon = .75$, characterized by

significantly longer RTs in TLD-Y relative to TLD-A children, approached statistical significance. The interaction of Condition x Group, $F(4, 92) = .59, p > .05, \eta_p^2 = .02$, was not significant. The individual participants' mean reaction times for each condition are presented in Appendix G.

Pearson correlations between false-alarm rates and RT to GO stimuli revealed a significant moderate, negative correlation in the 80 GO/20 No-GO condition for the TLD-Y group only ($r = -.54$). This finding suggests that participants in the TLD-Y group may have exhibited a speed/accuracy trade-off by committing fewer false-alarms at the expense of increasing RT or by committing more false-alarms as a consequence of decreasing RT. No other significant correlations ($p > .05$) were found, indicating that additional speed/accuracy trade-offs were not exhibited.

3.2 ERP Results

3.2.1 N2 Within-Group Analyses

Mean amplitudes and their corresponding standard deviations spanning the N2 time window (400-560 ms) for GO and No-GO waveforms at frontal, fronto-central, and central sites in each of the conditions are presented in Table 4. Below, each group's results for a repeated measures ANOVA with the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Region (frontal, fronto-central, and central) are presented. These data are accompanied by Tukey's HSD post-hoc test results for significant interactions.

Table 4. Mean amplitudes of N2 (400-560 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Linguistic experiment (*SD* = standard deviation).

		TLD-A		SLI		TLD-Y	
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
Frontal	80 GO	-1.36	8.27	-4.81	6.24	-4.54	6.72
	50 GO	-4.91	8.48	-4.89	6.48	-5.09	7.62
	20 GO	-7.21	7.30	-7.93	5.56	-8.71	8.98
	80 No-GO	-2.57	6.53	-6.39	6.80	-7.13	5.98
	50 No-GO	-3.42	7.15	-7.81	5.85	-8.18	5.92
	20 No-GO	-5.69	6.82	-6.90	8.78	-8.11	6.22
Fronto-Central	80 GO	-3.91	6.97	-7.22	5.32	-3.79	5.01
	50 GO	-6.21	8.47	-7.60	6.43	-4.82	5.85
	20 GO	-6.63	8.65	-10.01	8.29	-6.32	7.25
	80 No-GO	-3.58	6.31	-9.16	5.08	-6.34	4.65
	50 No-GO	-4.04	7.02	-9.57	4.91	-7.22	4.80
	20 No-GO	-6.32	7.60	-10.11	7.05	-6.43	5.39
Central	80 GO	0.99	7.03	-1.67	5.42	-1.07	4.66
	50 GO	-0.38	8.90	-1.32	6.99	-1.11	4.77
	20 GO	0.17	8.63	-2.49	7.30	-3.61	4.67
	80 No-GO	-0.52	5.93	-5.16	4.44	-2.65	3.91
	50 No-GO	-0.40	7.01	-4.61	4.71	-3.68	4.47
	20 No-GO	-0.80	8.07	-3.03	7.78	-3.06	5.78

TLD-A Children.

The repeated measures analysis described above revealed a main effect of Region, $F(2, 40) = 22.23$, $p < .00001$, $\eta_p^2 = .53$, $\varepsilon = .63$, characterized by significantly greater amplitude in the frontal and fronto-central regions as compared with the central region ($p < .001$). A significant interaction between Response Type and Condition was found, $F(2, 40) = 11.00$, $p < .001$, $\eta_p^2 = .35$, resulting from a difference between GO and No-GO waveforms in the 80 GO/20 No-GO condition ($p < .05$). Post-hoc pairwise comparisons within response type revealed significant differences between 80 GO and 20 GO waveforms only ($p < .01$). No pairwise comparisons within the No-GO response type were significant ($p > .05$).

A significant interaction among Region x Response Type x Condition was also revealed, $F(4, 80) = 15.54$, $p < .0001$, $\eta_p^2 = .44$, $\varepsilon = .52$, as shown in Figure 2. In the frontal region, TLD-A children showed the expected N2 effect of greater amplitude for rare responses (20 GO or 20 No-GO) withheld in the presence of predominant responses (80 GO or 80 No-GO), irrespective of the response type ($p < .001$). No significant difference between response type was observed in the 50 GO/50 No-GO condition ($p > .05$), contrary to the prediction that No-GO amplitude would be slightly more negative than GO amplitude in response to equiprobable stimuli. Overall, TLD-A children showed robust, adult-like N2 responses in the frontal region.

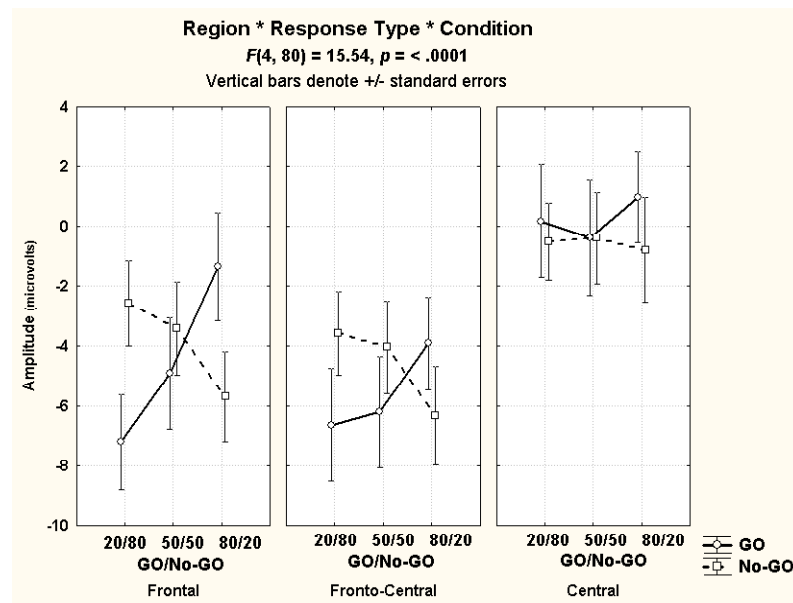


Figure 2. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by TLD-A children in the Linguistic experiment.

GO and No-GO responses in the fronto-central region showed the same pattern of amplitude differences as in the frontal region for the 80 GO/20 No-GO ($p < .01$) and 20

GO/80 No-GO ($p < .001$) conditions, but showed a significant difference in the 50 GO/50 No-GO condition ($p < .01$), characterized by greater negative amplitude for the GO response. Previous GO/No-GO studies that found response type differences in this baseline condition reported the opposite pattern of greater negative amplitude for No-GO responses (e.g., Jodo & Kayama, 1992; Nieuwenhuis et al., 2003), interpreted as reflecting a bias to *GO* in a speeded response task, whereas, here, the GO response was greater in amplitude. In the central region, pairwise comparisons of GO/No-GO responses showed no significant differences ($p > .05$).

The main effects of Response Type, $F(1, 20) = .09$, $p > .05$, $\eta_p^2 < .01$, and Condition, $F(2, 40) = .33$, $p > .05$, $\eta_p^2 = .02$, $\epsilon = .75$, and the interactions of Region x Response Type, $F(2, 40) = 2.55$, $p > .05$, $\eta_p^2 = .11$, $\epsilon = .57$, and Region x Condition, $F(4, 80) = 1.70$, $p > .05$, $\eta_p^2 = .08$, $\epsilon = .62$, were not significant. In summary, these results indicate that TLD-A children showed adult-like N2 effects in the frontal and fronto-central regions for the 80 GO/20 No-GO and 20 GO/80 No-GO conditions. As Figure 2 illustrates, these effects were more robust in the frontal region.

SLI Children.

A repeated measures ANOVA for the SLI group revealed a main effect of Region, $F(2, 22) = 12.37$, $p < .001$, $\eta_p^2 = .53$, $\epsilon = .61$, due to greater amplitude in the frontal ($p < .05$) and fronto-central ($p < .001$) regions as compared with the central region. Overall enhanced negativity for No-GO responses was suggested by the marginal significance of the main effect of Response Type, $F(1, 11) = 5.05$, $p = .05$, $\eta_p^2 = .31$. A significant interaction of Region x Response Type x Condition, $F(4, 44) = 6.31$, $p = .001$, $\eta_p^2 = .36$,

was found. Post-hoc pairwise comparisons indicated that this interaction arose from the following significant differences. In the frontal region, GO/No-GO responses differed in the 50 GO/50 No-GO condition only ($p < .01$) due to greater negative amplitude for the No-GO response. Only the 80 GO/20 No-GO condition elicited differential responses in the fronto-central region, characterized by greater negative amplitude for the No-GO response ($p < .01$). Although some of the SLI group's responses in the frontal and fronto-central regions did not show the expected statistical differences as shown by the TLD-A group, the pattern of greater negative amplitude for less frequent responses (20 No-GO and 20 GO) was demonstrated, as depicted in Figure 3.

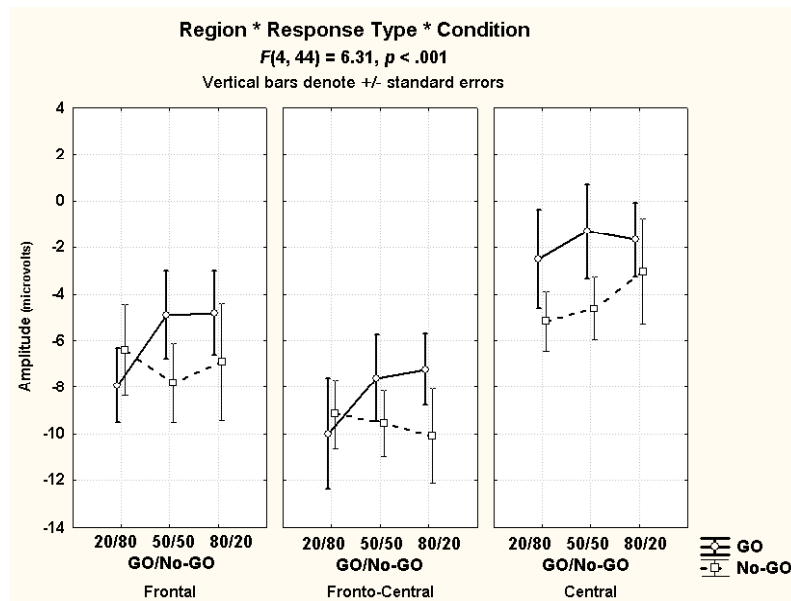


Figure 3. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by SLI children in the Linguistic experiment.

In the central region, greater negative amplitude for the No-GO compared to GO response was exhibited in the 50 GO/50 No-GO ($p < .001$) and 20 GO/80 No-GO ($p < .001$)

.01) conditions only. The finding of greater amplitude for the *frequent* No-GO response in the 20 GO/80 No-GO condition is surprising and contrasts with the expectation of rare N2 responses showing greater amplitude than frequent N2 responses.

The main effect of Condition, $F(2, 22) = .63, p > .05, \eta_p^2 = .05$, and interactions of Region x Response Type, $F(2, 22) = 1.11, p > .05, \eta_p^2 = .09$, Region x Condition, $F(4, 44) = .15, p > .05, \eta_p^2 = .01, \epsilon = .57$, and Response Type x Condition, $F(2, 22) = 1.62, p > .05, \eta_p^2 = .53, \epsilon = .61$, were not significant.

To summarize, the SLI group showed a similar pattern of responses for the 80 GO/20 No-GO and 20 GO/80 No-GO conditions in the frontal and fronto-central regions as compared with the adult-like pattern demonstrated by the TLD-A group. Notably, though, most pairwise comparisons of GO and No-GO responses were not statistically significant. In addition, the baseline condition was characterized by greater negative amplitude for the No-GO response, whereas TLD-A children showed undifferentiated responses to equiprobable GO and No-GO stimuli.

TLD-Y Children.

Similar to the TLD-A and SLI children, the TLD-Y group showed a main effect of Region, $F(2, 26) = 13.87, p < .0001, \eta_p^2 = .52$, due to greater amplitude in the frontal ($p < .001$) and fronto-central ($p < .01$) regions relative to the central region. The interaction of Response Type x Condition was marginally significant, $F(2, 26) = 3.34, p = .05, \eta_p^2 = .20$. Post-hoc pairwise comparisons revealed no significant differences in response type within conditions ($p > .05$). Pairwise comparisons within response type showed significant differences between 80 GO and 20 GO responses ($p < .05$) and no significant

differences among No-GO responses ($p > .05$). There were no significant findings for the main effect of Response Type, $F(1, 13) = 2.86, p > .05, \eta_p^2 = .18$; and Condition, $F(2, 26) = 1.58, p > .05, \eta_p^2 = .11$; and for the interactions of Region x Response Type, $F(2, 26) = .57, p > .05, \eta_p^2 = .057$; and Region x Condition, $F(4, 52) = 1.18, p > .05, \eta_p^2 = .08, \epsilon = .41$. Likewise, the interaction of Region x Response Type x Condition, $F(4, 52) = 2.04, p > .05, \eta_p^2 = .14, \epsilon = .46$, as illustrated in Figure 4, was not significant. By contrast, this interaction was highly significant in the TLD-A and SLI groups. A comparison of this figure with Figure 3 above reveals close similarities between the SLI and TLD-Y groups' patterns of responses in each condition. To recap, TLD-Y children exhibited marginally significant differences between GO and No-GO responses as a function of condition and demonstrated N2 patterns similar to those of SLI children.

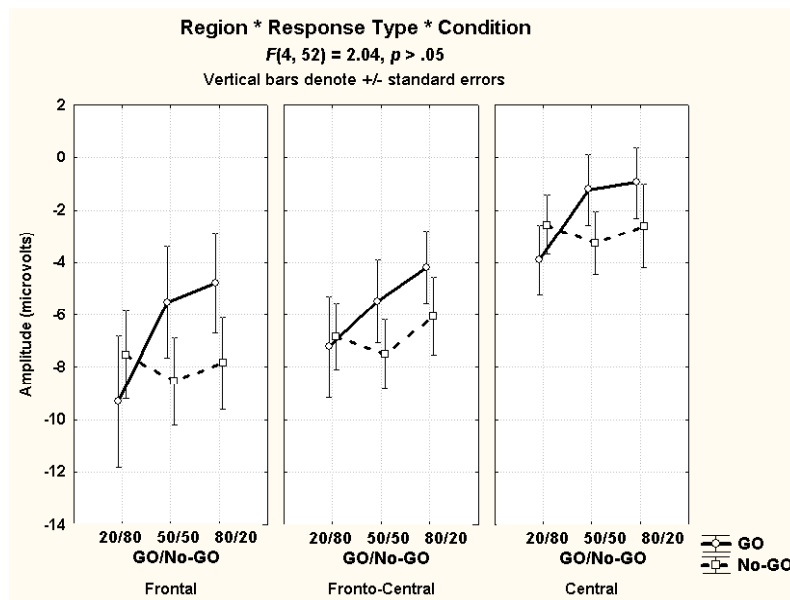


Figure 4. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites shown by TLD-Y children in the Linguistic experiment.

Summary of N2 Within-Group Analyses.

Repeated measures analyses for the individual groups indicated that the expected N2 effect of greater amplitude for ERP responses withheld in the context of dominant responses was borne out, albeit inconsistently. The TLD-A group demonstrated the predicted N2 effect within the frontal region for rare GO and No-GO responses but did not show differential GO/No-GO responses to equiprobable stimuli. Relative to the TLD-A group, the SLI and TLD-Y groups showed the same pattern in response to rare GO and No-GO stimuli but GO/No-GO responses were not statistically different in the 20 GO/80 No-GO condition and they exhibited No-GO > GO responses in the baseline condition. Because the N2 responses in all three of the groups resembled the pattern of adult-like N2 effects most closely in the frontal region, this region was selected for subsequent analyses. Topographical maps illustrating N2 difference waves (No-GO - GO) for each condition in the individual participant groups are presented in Appendix H.

3.2.2 N2 Between-Group Analysis

To investigate group differences in cognitive control, as indexed by the N2, a repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (400-440, 440-480, 480-520, 520-560 ms). Significant interactions were followed up by Tukey's HSD post-hoc test. Only significant effects related to the hypotheses of interest are reported below.

The impact of condition on the N2 effect (GO vs. No-GO) over time was found to be different among the groups, as indicated by a significant four-way interaction of

Response Type x Condition x Time x Group, $F(12, 276) = 2.60$, $p < .05$, $\eta_p^2 = .10$. To enable a fine-grained analysis of N2 effects over time, this interaction was followed up by Tukey's Unequal N HSD post-hoc test (see Table 5). This test revealed that in the 80 GO/20 No-GO condition, the TLD-A group showed greater N2 amplitude for rare No-GO stimuli from 440-560 ms. The TLD-Y group showed the same effect, but beginning earlier, from 400-560 ms ($p < .001$). By contrast, the SLI group did not show an N2 effect in this condition ($p > .05$).

In the baseline (50 GO/50 No-GO) condition, the TLD-A group showed no differences between GO and No-GO responses ($p > .05$), contrary to the expectation of slightly greater No-GO than GO negative amplitude. The TLD-Y group showed No-GO > GO responses from 400-440 ms ($p < .0001$) and from 520-560 ms ($p < .01$), marginally greater negativity for No-GO than GO responses from 440-480 ms ($p = .05$), and no effect from 480-520 ms ($p > .05$). The SLI group similarly showed No-GO > GO responses during two time windows: a marginally significant effect from 480-520 ms ($p = .06$) and a highly significant effect from 520-560 ms ($p < .0001$).

Post-hoc pairwise comparisons of GO/No-GO responses in the 20 GO/80 No-GO condition revealed greater negativity in response to rare GO stimuli from 440-560 ms ($p < .0001$) in the TLD-A group. The TLD-Y and SLI children, contrastingly, showed no differences between GO and No-GO responses from 400-520 ms. During the last time window, from 520-560 ms, the finding of greater GO than No-GO responses was significant in the SLI group ($p < .01$).

Table 5. Results of Tukey's Unequal N post-hoc test for analysis of the N2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Linguistic experiment.

	80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
TLD-A	-	***	***	***	-	-	-	-	-	***	***	***
SLI	-	-	-	-	-	-	-	***	-	-	-	*
TLD-Y	**	**	*	**	***	-	-	*	-	-	-	-

Significance of effects: *** $p < .0001$; ** $p < .001$; * $p < .01$; - $p > .05$

The interaction of Response Type x Condition x Group was significant, $F(4, 92) = 2.65$, $p < .05$, $\eta_p^2 = .103$, $\varepsilon = .85$, indicating that the between-group difference in the impact of condition on the N2 effect was not solely modulated by differences across time. Tukey's Unequal N HSD post-hoc test did not reveal any significant differences for this effect across the groups ($p > .05$). A significant interaction between Response Type and Condition, $F(2, 92) = 19.08$, $p < .00001$, $\eta_p^2 = .293$, $\varepsilon = .85$, confirmed that greater negative amplitude was evident for rare No-GO stimuli in the 80 GO/20 No-GO condition and for rare GO stimuli in the 20 GO/80 No-GO condition ($p < .001$) across the groups. Excluding the main effect of Time, which was not of interest here, no other main effects or interactions in the current analysis were significant ($p > .05$). Appendix I presents the grand average waveforms of each group for the three conditions at frontal sites.

Summary of N2 Between-Group Analysis.

In summary, the TLD-A group showed robust, adult-like N2 effects which statistically contrasted with the N2 patterns demonstrated by the SLI and TLD-Y groups. The TLD-A group showed greater amplitude in response to rare stimuli, regardless of

whether the stimuli corresponded to the GO or No-GO response. Surprisingly, the SLI children showed no N2 effect in the 80 GO/20 No-GO condition and throughout most of the N2 time window for the 20 GO/80 No-GO condition. The TLD-Y group showed the N2 effect in the 80 GO/20 No-GO condition, but similar to the SLI group, showed no effect during most of the N2 time window in the 20 GO/80 No-GO condition. Because the SLI and TLD-Y groups exhibited similar, albeit statistically insignificant, N2 effects for rare GO and No-GO stimuli relative to TLD-A children, their N2 results may be more accurately described as attenuated rather than absent. Another commonality between the results of the SLI and TLD-Y groups is the presence of greater amplitude for No-GO responses in the baseline condition.

Although these stark group differences are intriguing and invite interpretation, there are several considerations that must first be addressed to ensure that the results described above are not spurious. Firstly, differences between the GO and No-GO waveforms at the positive peak between the N1 and N2, referred to as the P2, were exhibited by each of the groups to varying degrees. This warrants consideration of whether differences in the N2 time window were merely after-effects of activity belonging to the P2 component. The following analysis addressed this question.

3.2.3 P2 Analysis

The P2 is a visual sensory response that surfaces at anterior and central scalp locations and is associated with early exogenous processing of a stimulus. When stimuli possess features of a target, the P2 is larger and this effect is enhanced in response to infrequent targets (Luck & Hillyard, 1994). Responses to rare GO and No-GO stimuli

were therefore expected to be greater than those to frequent stimuli and it was predicted that probability might influence GO/No-GO differences. Because the P2 is presumably insensitive to manipulations of cognitive control, subtracting GO/No-GO differences during the P2 time region from those belonging to the N2 would provide a measure of GO/No-GO differences unique to cognitive control. No group differences were predicted for this component.

Based on visual inspection of the grand averages, it was determined that the P2 spanned from 240-300 ms. Mean amplitudes were computed for this time window. A repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO) and Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO).

Mean amplitudes of the P2 were greater for No-GO relative to GO stimuli, as evidenced by a main effect of Response Type, $F(1, 46) = 50.89, p < .0001, \eta_p^2 = .53$. The main effects of Condition, $F(2, 92) = .19, p > .05, \epsilon = .81$, and Group, $F(2, 46) = .66, p > .05, \eta_p^2 = .03$, were not significant.

Condition did not impact P2 responses to GO and No-GO stimuli, $F(2, 92) = 2.43, p > .05, \eta_p^2 = .05$. Likewise, the interactions of Response Type x Group, $F(2, 46) = 1.94, p > .05, \eta_p^2 = .08$; Condition x Group, $F(4, 92) = .82, p > .05, \eta_p^2 = .03$; and among Response Type x Condition x Group, $F(4, 92) = 2.08, p > .05, \eta_p^2 = .08$, were not significant.

As reported above for the between-group analysis of the N2, SLI and TLD-Y children exhibited a No-GO > GO effect during several time windows (SLI: 520-560 ms; TLD-Y: 400-440 and 520-560 ms) in the baseline condition, in contrast to TLD-A

children. This was unexpected considering that previous studies have reported greater amplitude for No-GO stimuli when trial type was balanced, presumably due to a bias toward the GO response in tasks that emphasized response speed (e.g., Nieuwenhuis et al., 2003). Accordingly, further examination of whether the findings for the baseline condition were due to a carryover of GO/No-GO differences during the P2 region was warranted. Although the interaction between Response Type x Condition in the current P2 analysis was not significant, step-down analyses were performed to determine whether response type differences were present for the 50 GO/50 No-GO condition in any of the groups individually.

All of the groups showed a significant main effect of Response Type, TLD-A: $F(1, 20) = 9.79, p < .01$; SLI: $F(1, 11) = 11.02, p < .01$; TLD-Y: $F(1, 15) = 40.19, p < .0001$. The main effect of Condition was not significant in any of the groups, TLD-A: $F(2, 40) = 1.39, p > .05$; SLI: $F(2, 22) = .17, p > .05$; TLD-Y: $F(2, 30) = .73, p > .05$. Whereas the interaction between Response Type x Condition was not significant in the TLD-A and SLI groups, TLD-A: $F(2, 40) = 1.02, p > .05$; SLI: $F(2, 22) = 1.12, p > .05$, it was significant in the TLD-Y group, $F(2, 30) = 3.74, p < .05$. Tukey's HSD post-hoc test revealed that this interaction was due to significant differences between GO and No-GO responses in the 50 GO/50 No-GO and 80 GO/20 No-GO conditions ($p < .01$). Similarly, SLI children showed a significant GO/No-GO difference in the baseline condition ($p < .05$), whereas TLD-A children showed this effect in the 80 GO/20 No-GO condition ($p < .05$). The finding of GO/No-GO differences in P2 responses for the baseline condition in the SLI and TLD-Y groups indicates that the presence of N2 effects in this condition may have arisen due to a lingering response type effect during the P2.

Summary of P2 Analysis.

The finding of adult-like N2 responses in TLD-A, but not SLI and TLD-Y, children was investigated by examining whether the preceding P2 responses impacted the N2 effect. Greater negativity for No-GO relative to GO P2 responses was predicted for rare stimuli only. P2 amplitude was greater in response to No-GO than GO stimuli in all of the conditions.

The GO/No-GO P2 effect did not vary among the groups, suggesting that P2 responses did not significantly offset the ensuing N2 effect differentially across the groups. Step-down analyses, however, indicated that SLI and TLD-Y children exhibited GO/No-GO response differences for the P2 in the baseline condition, calling into question whether the N2 effects described above reflect after-effects of the P2. To address this possibility, the following analysis was performed.

3.2.4 N2-P2 Analysis

Mean amplitudes for the P2 time window (240-300 ms) were subtracted from those of four 40 ms time windows of the N2 (400-440, 440-480, 480-520, 520-560 ms). This allowed examination of whether each of the groups exhibited an N2 effect independent of any preceding GO/No-GO differences during the P2 time interval. A repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (400-440, 440-480, 480-520, 520-560 ms). Significant interactions were followed up by Tukey's HSD post-hoc test.

The main effect of Condition was significant, $F(2, 92) = 3.85, p < .05, \eta_p^2 = .08, \epsilon = .84$. This effect arose from significantly more negative responses in the 20 GO/80 No-GO condition as compared with the 80 GO/20 No-GO condition ($p < .01$). The interaction between Condition x Time was significant, $F(6, 276) = 11.95, p < .00001, \eta_p^2 = .21, \epsilon = .50$. Within each condition, amplitude progressively decreased from one time window to the next across all four time intervals ($p < .001$).

Condition influenced the GO/No-GO effect, $F(2, 92) = 16.64, p < .00001, \eta_p^2 = .27$. This interaction was due to a significant difference between GO and No-GO responses, characterized by greater amplitude for rare GO stimuli in the 20 GO/80 No-GO condition only ($p < .001$). The impact of condition on the N2 effect (GO vs. No-GO) was modulated by Time, [Response Type x Condition x Time, $F(6, 276) = 15.10, p < .00001, \eta_p^2 = .25, \epsilon = .47$]. This effect differed among the three groups, [Response Type x Condition x Time x Group, $F(12, 276) = 2.59, p < .01, \eta_p^2 = .10$].

A detailed analysis of the interaction of Response Type x Condition x Time x Group was conducted using Tukey's Unequal N HSD post-hoc test (see Table 6). This test revealed that in the 80 GO/20 No-GO condition, the TLD-A group showed greater negative amplitude for rare No-GO stimuli from 480-560 ms ($p < .001$). By contrast, the SLI and TLD-Y groups did not show the N2 effect in this condition ($p > .05$). This finding for N2-P2 responses contrasts with those of the N2 analysis described above in which GO/No-GO response differences in the TLD-A group emerged earlier at 440-480 ms and TLD-Y children showed GO/No-GO differences throughout the N2 time interval, from 400-560 ms. The current finding indicates that when GO/No-GO differences for the

N2 are considered independent of preexisting response type differences during the P2 region, the TLD-Y group, as well as the SLI group, showed no N2 effects.

In the baseline condition, the TLD-A group showed significantly greater negativity to GO stimuli from 440-520 ms ($p < .05$). By contrast, the SLI and TLD-Y groups showed no differences between GO and No-GO responses ($p > .05$). These N2-P2 results are the reverse findings of those from the N2 analysis described above and indicate that when N2 responses are considered independent of P2 responses, only TLD-A children showed GO/No-GO differences between equiprobable stimuli.

Table 6. Results of Tukey's Unequal N post-hoc test for analysis of the N2-P2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Linguistic experiment.

	80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
TLD-A	-	-	**	***	-	^	**	-	^	***	***	***
SLI	-	-	-	-	-	-	-	-	-	-	***	***
TLD-Y	-	-	-	-	-	-	-	-	-	-	*	*

Significance of effects: *** $p < .0001$; ** $p < .001$; * $p < .01$; ^ $p < .05$; - $p > .05$

In the 20 GO/80 No-GO condition, the TLD-A group exhibited greater negative amplitude for rare GO relative to No-GO stimuli throughout the N2 time interval ($p < .05$), as observed in the N2 analysis reported above. SLI children only showed this response type difference during the last two 40 ms time intervals of the N2, from 480-560 ms. In the earlier N2 analysis in which the P2 was not subtracted out, SLI children only showed this effect in the last time interval (520-560 ms). TLD-Y children exhibited this

same pattern of greater negativity to rare GO stimuli ($p < .01$). In the previous analysis, they had shown no GO/No-GO differences in this condition.

Excluding the main effect of Time, which was not of interest here, no other main effects or interactions in the current analysis were significant ($p > .05$), as indicated in Table 7. A comparison of the results in Table 6 alongside those for the N2 analysis presented earlier in Table 5 reveals close similarities in the pattern of N2 effects within and across groups, in spite of the aforementioned differences. The TLD-A group demonstrated robust, adult-like N2 effects, characterized by greater amplitude for rare GO and No-GO responses. SLI and TLD-Y children only showed this effect in the second half of the N2 region. Notably, though, the adult-like pattern of N2 effects is apparent in at least one time interval in both the SLI and TLD-Y groups. Although these findings are not statistically significant, they suggest that the adult-like N2 patterns are emerging in these groups and that their N2 effects are quantitatively, but not qualitatively, different from those of the TLD-A group.

Table 7. Results of the repeated measures ANOVA for N2-P2 responses using mean amplitude values at frontal sites in the Linguistic experiment.

Effect	df	F
Group (G)	2, 46	1.86
Response Type (R)	1, 46	3.34
Condition (C)	2, 92	3.85 *
Time (T)	3, 138	139.41 ***
R x G	2, 46	< 1
C x G	4, 92	< 1
T x G	6, 138	< 1
R x C	2, 92	16.64 ***
R x C x G	4, 92	2.11
R x T	3, 138	< 1
R x T x G	6, 138	< 1
C x T	6, 276	11.95 ***
C x T x G	12, 276	< 1
R x C x T	6, 276	15.10 ***
R x C x T x G	12, 276	2.59 **

Significance of effects: *** $p < .0001$; ** $p < .01$; * $p < .05$

The finding of GO/No-GO differences between equiprobable stimuli in the TLD-A group has been reported in adults (Nieuwenhuis et al., 2003). Studies that found enhanced negativity to No-GO stimuli attributed this finding to a bias toward the GO response in speeded response tasks. Here, though, the bias appears to be toward the No-GO response, assuming the enhanced negativity indicates the need to inhibit a dominant response.

Before interpreting the observed N2 and P2 effects, several considerations are warranted. In general, greater negative amplitude was found for the response type that included fewer trials. In the 80 GO/20 No-GO condition, which consisted of 320 and 80 trials, respectively, the rare No-GO response showed greater amplitude and in the 20 GO/80 No-GO condition, which included 80 and 320 trials, respectively, the rare GO response showed greater amplitude. These findings may have been influenced by disparate signal-to-noise ratios for the GO versus No-GO responses due to differences in the number of trials per response type. The response type with fewer trials is likely to have noisier waveforms, possibly causing small intervals in the waveforms to have greater maximum amplitude as compared with the corresponding intervals of clean waveforms. This is a negligible concern in the current study because a mean amplitude measure rather than a peak amplitude measure was used. Mean amplitude measures are not biased by higher noise levels due to lower trial numbers and are also more objective than selecting a peak in a broad time range.

3.2.5 *N2 Equal n Analysis*

One additional factor that questions the accuracy of the observed N2 effects concerns the unequal participant numbers across the groups (TLD-A = 21; SLI = 12; TLD-Y = 14). The robust, adult-like N2 effects in the TLD-A group, as compared with the inconsistent and seemingly immature N2 patterns in the TLD-Y and SLI groups, may be due to the greater number of participants in the TLD-A group. To ensure that this factor did not underlie the observed effects, an analysis was performed in which the TLD-A and SLI groups were closely matched on the following variables: age (± 7 months; 1 pair: ± 10 months); gender; handedness; and non-verbal intelligence, based on TONI-3 raw scores (± 5 points). The results of this analysis were highly similar to those of the N2 analysis that included unequal participant numbers across the groups (see Appendix J).

3.2.6 *P3 Analysis*

The grand average waveforms for each group were inspected to identify the time interval that included the P3 across conditions. The time interval of 600-1200 ms was thereby selected for analysis. P3 responses in the frontal region were chosen for between-group analyses because repeated measures ANOVAs for each individual group revealed that the P3 was maximal over frontal sites. This is illustrated in Appendix I, which presents the topographical maps of P3 difference waves (No-GO - GO) from 800-1200 ms for each condition in the individual participant groups. The P3 is shown in these maps as a negativity because GO waveforms were subtracted from No-GO waveforms to maintain consistency with the difference waves for the N2 analyses. To examine whether

the P3 differed as a function of response type, condition, and time across groups, a repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (600-700, 700-800, 800-900, 900-1000, 1000-1100, 1100-1200 ms) using mean amplitude values at frontal sites. Tukey's HSD post-hoc tests were used to follow up significant interactions.

Table 8 shows the means and standard deviations for the current analysis. Overall, GO responses showed enhanced positivity, as per a main effect of Response Type, $F(1, 46) = 7.52, p < .01, \eta_p^2 = .14$. An interaction of Response Type x Condition, $F(2, 92) = 10.31, p < .0001, \eta_p^2 = .18$, arose from significant differences between GO and No-GO responses in the 20 GO/80 No-GO and 50 GO/50 No-GO conditions ($p < .001$). This effect varied across the groups, as indicated by a significant interaction of Response Type x Condition x Group, $F(4, 92) = 2.76, p < .05, \eta_p^2 = .11$. Tukey's Unequal N HSD post-hoc tests revealed that this effect was due to significant GO/No-GO differences exhibited by the TLD-A group in the 20 GO/80 No-GO condition ($p < .05$) and by the SLI group in the 50 GO/50 No-GO condition ($p < .001$). The TLD-Y group did not exhibit any significant GO/No-GO differences in any of the conditions ($p > .05$).

Significant GO/No-GO differences were observed during the time intervals of 900-1000 ms and 1000-1100 ms ($p < .0001$), [Response Type x Time, $F(5, 230) = 5.81, p < .01, \eta_p^2 = .11, \epsilon = .34$]. In addition, the interaction of Condition x Time was significant, $F(10, 460) = 5.32, p < .001, \eta_p^2 = .10, \epsilon = .39$. In the 80 GO/20 No-GO condition, a significant difference was also found between the second and third time intervals, 700-800 ms and 800-900 ms. The impact of condition on GO/No-GO responses varied over

time, as per a significant interaction of Response Type x Condition x Time, $F(10, 460) = 13.52$, $p < .000001$, $\eta_p^2 = .23$, $\varepsilon = .36$. Specifically, GO/No-GO differences were observed from 900-1200 ms in the 20 GO/80 No-GO condition and from 900-1100 ms in the baseline condition ($p < .01$). No other main effects or interactions were significant ($p > .05$), as indicated in Table 9.

Table 8. Mean amplitudes of P3 (1000-1100 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Linguistic experiment (*SD* = standard deviation).

		TLD-A		SLI		TLD-Y	
		Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>
Frontal	80 GO	24.49	29.44	21.47	28.20	14.04	13.73
	50 GO	22.65	26.34	27.37	23.90	16.95	18.28
	20 GO	27.22	29.77	26.85	31.58	21.77	23.02
	80 No-GO	14.02	15.01	9.49	14.83	15.06	11.11
	50 No-GO	15.07	15.95	10.46	11.58	14.43	15.05
	20 No-GO	21.92	23.60	21.32	17.88	25.21	21.55
Fronto-Central	80 GO	10.68	10.21	9.00	10.03	6.00	7.00
	50 GO	9.66	8.82	11.70	11.51	8.09	10.57
	20 GO	13.77	13.55	10.61	10.27	11.87	13.63
	80 No-GO	8.09	9.21	4.00	4.24	7.95	8.63
	50 No-GO	7.77	6.90	4.52	5.62	6.77	4.61
	20 No-GO	10.13	10.64	8.89	7.23	13.17	7.27
Central	80 GO	6.69	5.18	5.33	5.91	4.92	6.35
	50 GO	5.56	4.57	4.38	4.10	7.23	10.25
	20 GO	6.69	5.18	5.35	8.53	9.87	11.58
	80 No-GO	7.41	7.40	3.90	4.01	7.18	4.85
	50 No-GO	7.32	4.71	5.24	4.71	7.41	4.95
	20 No-GO	8.35	7.81	8.63	6.15	11.41	7.78

Summary of P3 Analysis.

To summarize, enhanced positivity for GO responses was found during the time interval of 900-1100 ms of the P3 time region. This effect varied by condition on account of GO/No-GO differences exhibited by the TLD-A group in the 20 GO/80 No-GO

condition and by the SLI group in the 50 GO/50 No-GO condition. The TLD-Y group did not show differential P3 responses to GO and No-GO stimuli.

Table 9. Results of the repeated measures ANOVA for the P3 (600-1200 ms) using mean amplitude values at frontal sites in the Linguistic experiment.

Effect	df	F
Group (G)	2, 46	< 1
Response Type (R)	1, 46	7.52 **
Condition (C)	2, 92	< 1
Time (T)	5, 230	17.96 ***
R x G	2, 46	1.10
C x G	4, 92	< 1
T x G	10, 230	< 1
R x C	2, 92	10.31 ***
R x C x G	4, 92	2.76 *
R x T	5, 230	5.81 ***
R x T x G	10, 230	1.11
C x T	10, 460	5.32 ***
C x T x G	20, 460	< 1
R x C x T	10, 460	13.52 ***
R x C x T x G	20, 460	< 1
Significance of effects: *** $p < .00001$; ** $p < .01$; * $p < .05$		

3.2.7 N1 Analysis

An analysis was conducted to examine whether group differences were exhibited for the exogenous N1 component. Based on inspection of the grand averages for each of the groups, it was determined that the N1 appeared during the same approximate time interval of 160-200 ms in each of the groups. Mean amplitudes were computed for this time window. A repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO) and Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO).

No differences between GO and No-GO responses and no relationship between response type and condition were anticipated because the N1 is considered independent

of the cognitive control mechanism (Bokura et al., 2001). Contrary to this prediction, GO/No-GO responses differed by condition, $F(2, 92) = 4.37, p < .05, \eta_p^2 = .09$, although this was not a large effect. This interaction was characterized by greater negative amplitude for No-GO responses in the 80 GO/20 No-GO and baseline conditions and greater negative amplitude for GO responses in the 20 GO/80 No-GO condition. Tukey's HSD post-hoc test indicated that within conditions, GO and No-GO responses were not significantly different ($p > .05$).

Although the N1 is sensitive to age, as demonstrated by later latencies and larger amplitudes in children than adults (e.g., Rueda et al., 2004), no group differences were predicted considering the relatively small age differences across the groups. No other main effects or interactions in this analysis were significant ($p > .05$).

3.3 Correlational Analyses

Pearson correlations were computed between the mean RT for GO responses and mean amplitudes of the N2 in response to GO stimuli in each condition. As presented in Table 10, an analysis of the groups combined revealed moderate negative correlations between RT in each condition and N2 mean amplitudes. TLD-A children showed moderate to large negative correlations between RT in each condition and N2 mean amplitudes, whereas SLI and TLD-Y children showed no significant correlations among these variables ($p > .01$).

Table 10. Correlations between reaction time (RT) and mean amplitudes of the N2 to GO stimuli per condition in the Linguistic experiment (* = significant at $p < .01$).

Measures	ALL GROUPS	TLD-A	SLI	TLD-Y
RT 80 GO N2 GO 80	-.39*	-.62 *	-.25	-.21
RT 50 GO N2 GO 50	-.42*	-.66 *	-.11	-.39
RT 20 GO N2 GO 20	-.38*	-.68 *	-.37	-.11

Additional correlations were computed between false-alarm rates and the No-GO minus GO waveforms for correct responses in each condition, as shown in Table 11. No significant correlations were found ($p > .05$).

Further correlations examined whether there were relationships between the participants' receptive, expressive, and composite standardized language test scores on the CELF-4 and the mean RT to GO stimuli in each condition, as well as between the aforementioned CELF-4 test scores and mean amplitudes of the N2 difference waves in each condition (see Table 12). No significant correlations were found ($p > .01$).

Table 11. Correlations between false-alarm rates and mean amplitudes of N2 difference waves (No-GO - GO) per condition in the Linguistic experiment.

Measures	ALL GROUPS	TLD-A	SLI	TLD-Y
80 No-GO False-Alarms N2 80 No-GO - 20 GO	.25	.08	.04	.50
50 No-GO False-Alarms N2 50 No-GO - 50 GO	-.15	-.34	.41	.06
20 No-GO False-Alarms N2 20 No-GO - 80 GO	-.11	-.37	-.10	.19

Table 12. Correlations between standardized language test scores, mean amplitudes of N2 difference waves (No-GO - GO), and reaction time (RT) to GO stimuli per condition in the Linguistic experiment.

Measures		ALL GROUPS	TLD-A	SLI	TLD-Y
RLS	N2 80 No-GO - 20 GO	.11	.17	.31	-.12
	N2 50 No-GO - 50 GO	.06	.10	.04	-.21
	N2 20 No-GO - 80 GO	-.25	.08	-.50	-.44
	RT 80 GO	.02	-.08	-.20	.04
	RT 50 GO	-.04	-.10	-.44	-.02
	RT 20 GO	.11	.07	-.31	.11
ELS	N2 80 No-GO - 20 GO	.13	-.32	.26	.15
	N2 50 No-GO - 50 GO	.13	-.08	-.17	.05
	N2 20 No-GO - 80 GO	-.14	-.11	-.04	.04
	RT 80 GO	-.10	-.34	.20	-.20
	RT 50 GO	-.19	-.33	-.03	-.55
	RT 20 GO	-.17	-.47	-.27	-.38
CLS	N2 80 No-GO - 20 GO	.15	-.02	.41	-.14
	N2 50 No-GO - 50 GO	.15	.05	-.10	-.08
	N2 20 No-GO - 80 GO	-.17	-.00	-.32	-.08
	RT 80 GO	-.04	-.21	-.01	.00
	RT 50 GO	-.15	-.33	-.27	-.26
	RT 20 GO	-.07	-.32	-.41	-.06

RLS = Receptive Language Score, ELS = Expressive Language Score, and CLS = Core Language (total language) Score of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4).

Correlations were calculated between mean amplitudes of the N2 (400-560 ms) and P3 (1000-1100 ms) difference waves in each condition to determine whether the N2 and P3 are associated, as suggested by previous studies (e.g., Jonkman et al., 2003). Additionally, correlations between false-alarm rates and P3 difference waves in each condition were computed to determine if the P3 is related to a measure of behavioral inhibition. As shown in Table 13, none of these correlations were significant ($p > .05$).

Table 13. Correlations between mean amplitudes of N2 and P3 difference waves (No-GO - GO) and between false-alarm rates and P3 difference waves per condition in the Linguistic experiment.

Measures		ALL GROUPS	TLD-A	SLI	TLD-Y
N2 80 No-GO - 20 GO	P3 80 No-GO - 20 GO	-.29	-.29	-.08	-.41
N2 50 No-GO - 50 GO	P3 50 No-GO - 50 GO	-.14	-.42	.36	-.14
N2 20 No-GO - 80 GO	P3 20 No-GO - 80 GO	.13	-.18	.56	.16
80 No-GO False-Alarms	P3 80 No-GO - 20 GO	.04	-.06	.31	-.12
50 No-GO False-Alarms	P3 50 No-GO - 50 GO	.03	.24	.47	-.48
20 No-GO False-Alarms	P3 20 No-GO - 80 GO	.14	-.10	.04	.12

3.4 Discussion

The aim of the Linguistic experiment was to examine whether children with SLI show deficient cognitive control skills relative to typically developing children in performing a GO/No-GO task involving pictures of common items. Stimulus probability was manipulated to invoke competing response tendencies to GO and No-GO stimuli.

3.4.1 Behavioral Data.

As predicted, hit rates in all of the groups were near ceiling level (> 96%) and the manipulation of stimulus probability resulted in higher false-alarm rates in the 80 GO/20 No-GO condition relative to the baseline condition. False-alarm rates were lower than 1% in the 20 GO/80 No-GO condition. TLD-Y children were expected to demonstrate slightly higher false-alarm rates than TLD-A children. This prediction was founded on evidence from studies with similar tasks, which showed that inhibitory control over motor responses increases with age (Band, van der Molen, Overtom, & Verbaten, 2000; Falkenstein, Hoormann, & Hohnsbein, 2002; Levy, 1980; Tamm et al., 2002). Accordingly, TLD-Y children showed a marginally significant effect of higher false-alarm rates than TLD-A children across conditions. Relative to the TLD-A group, the SLI group exhibited comparable false-alarm rates, indicating that they were able to control inappropriate motor responses to rare and equiprobable stimuli at age-appropriate levels. This finding is consistent with evidence that SLI children demonstrated normal performance in inhibiting motor responses to irrelevant stimuli in a GO/No-GO task (Noterdaeme et al., 2001).

Previous evidence (Nieuwenhuis et al., 2003) suggested that RT to GO stimuli would increase across conditions with an increase in the frequency of No-GO trials and this was observed. A marginally significant effect of longer RT was exhibited by the TLD-Y relative to the TLD-A group, as expected in view of the well-documented developmental pattern of decreased response execution timing over childhood (Cerella & Hale, 1994; Kail, 1991). The finding of longer RT and higher false-alarm rates in the TLD-Y children raises the question of whether false-alarms arose from slower response times for decision making. Notably though, the TLD-Y group showed high hit rates and the highest mean RT among the three conditions in the TLD-Y group was 558.30 ms ($SD = 55.98$), which is considerably lower than the allotted response interval of 1600 ms. Thus, the false-alarms committed by the TLD-Y group do not seem to reflect insufficient time to determine how to respond to the stimuli.

Contrary to the prediction that SLI children would exhibit significantly longer RT than the TLD-A group, the SLI and TLD-A groups demonstrated comparable RT. This finding contrasts with evidence that children with SLI commonly perform 10-30% more slowly than their same-age peers (Kail, 1994; Miller et al., 2001; Windsor et al., 1999). The relative ease of the current task may account for this finding.

3.4.2 ERP Data.

N2 Results.

The N2 peak was maximal at 400 ms and returned to baseline at 560 ms. Previous studies of typically developing children have reported an N2 occurring considerably earlier, within approximately 200-350 ms post-stimulus onset (e.g., Jonkman et al., 2003;

Johnstone et al., 2005). The later onset of the N2 here is likely attributable to the use of a categorization task, which presumably required more extensive stimulus processing than in typical GO/No-GO paradigms.

In each group, an adult-like N2 topography showing maximum negativity at frontal sites and distributed across fronto-central locations was observed. Most GO/No-GO investigations have likewise observed frontal N2 topography. Contrastingly, Ciesielski et al. (2004) found that the No-GO N2 effect in 6-12 year-old children was more prominent over parietal sites, whereas adults showed a frontal distribution of this effect. The posterior topography of the child N2 effect was attributed to involvement of the striatum during early stages in the development of inhibitory skills. According to this view, the frontal distribution of the N2 effect in the current study reflects maturation of inhibitory control.

It was posited that the N2 would index the detection of conflict among competing response tendencies by increasing in amplitude on trials requiring a rare response. According to the conflict monitoring theory, the N2 is elicited in response to conflict between response alternatives and is not contingent on the nature of the response. Consistent with this proposal, the TLD-A group exhibited adult-like N2 effects of greater amplitude in response to rare GO and No-GO stimuli from 440-560 ms at frontal sites. In the baseline condition, in which trial probability was balanced (50 GO/50 No-GO), the TLD-A group showed no differences between GO and No-GO responses in the frontal region. Generally, greater No-GO than GO amplitude in response to equiprobable stimuli is found and has been attributed to the emphasis on executing responses “as quickly as possible,” which was included in the instructions of the current study (Nieuwenhuis et al., 2003). This contradictory result will be elaborated upon below.

SLI children were expected to demonstrate attenuated N2 amplitudes in response to rare relative to frequent stimuli in comparison with typically developing children of the same age. Instead, the SLI group showed no significant N2 effects in either the 80 GO/20 No-GO or 20 GO/80 No-GO condition. Of note, though, the similar pattern of N2 effects for these conditions in the TLD-A and SLI groups suggests that the SLI children's N2 effects were attenuated rather than absent.

The SLI group demonstrated greater responses to No-GO stimuli from 520-560 ms in the baseline condition at frontal sites. This effect during the last time window of the N2 analysis may reflect GO/No-GO differences related to the ensuing P3. Similar to the TLD-A group, TLD-Y children exhibited greater positive amplitude for rare responses at frontal sites in the 80 GO/20 No-GO condition; however, they showed no effect in the 20 GO/80 No-GO condition. In the baseline condition, greater amplitude for No-GO responses from 400-440 ms in this group may have been a carryover of activity during the preceding P2 and greater positive amplitude from 520-560 ms may have been the onset of the P3 component.

A follow-up analysis in which 11 TLD-A and 11 SLI participants were matched based on age, gender, handedness, and non-verbal intelligence revealed remarkably similar findings for the N2. This result indicates that the seemingly immature N2 pattern exhibited by the SLI children was not due to the lower number of participants in the SLI group relative to the TLD-A group.

P2 Results.

To elucidate the contradictory findings for the N2 in the SLI and TLD-Y groups, the P2 was examined to determine if it influenced the subsequent N2 pattern of effects. The amplitude of the P2, which spanned from 240-300 ms, was greater for No-GO stimuli across conditions. Because the P2 effect is enhanced in response to infrequent targets (Luck et al., 1994), this finding was expected for the 80 GO/20 No-GO condition but not for the 20 GO/80 No-GO and baseline conditions, in which No-GO stimuli were not rare. The enhancement of the P2 in response to frequent, equiprobable, and rare No-GO stimuli is consistent with the functional interpretation of the P2 as reflecting stimulus classification (Luck et al., 1994, for visual stimuli; Garcia-Larrea, Lukaszewicz, & Mauguiere, 1992, for auditory stimuli).

Another interpretation of the P2 is that when it is large, it reflects greater efficiency in stimulus processing. This efficiency is thought to result from the inhibition of irrelevant stimulus information, which clears the way for relevant stimulus features to be further processed (Oades, 1998, for auditory stimuli). Evidence that the P2 increases with age in typically developing children and adolescents (Johnstone et al., 2001) supports this view. Due to the relatively narrow age range of the children in the current study, no overall between-group difference was predicted for the P2 and this was confirmed.

P2 differences between GO and No-GO stimuli were observed for the baseline condition in the SLI and TLD-Y groups. This finding indicates that the unexpected GO/No-GO differences for the N2 analysis in this condition may have arisen due to a lingering response type effect during the P2 time interval. To examine the influence of

cognitive control on the N2 independent of any preceding response type differences belonging to the P2, the waveforms for the P2 time interval were subtracted from those for the N2 time interval (N2-P2).

N2-P2 Results.

Results of the N2-P2 analysis revealed adult-like N2 effects in TLD-A children in response to rare stimuli; greater amplitude for GO and No-GO infrequent stimuli was demonstrated. The SLI and TLD-Y children showed no significant differences between GO and No-GO stimuli in the 80 GO/20 No-GO condition. Notably though, they demonstrated the adult-like pattern of enhanced amplitude to rare No-GO stimuli, although the effects were small and did not reach statistical significance. This suggests that the SLI and TLD-Y children exhibited immature N2 effects that were quantitatively rather than qualitatively different from those of the TLD-A group. The finding of attenuated N2-P2 amplitudes in the SLI group supports the notion that these children have poor skills in detecting conflict between competing response tendencies.

All of the groups demonstrated enhanced amplitude to rare GO responses in the 20 GO/80 No-GO condition. Latency differences in the onset of this effect were exhibited across the groups. The TLD-A group showed an adult-like N2 effect throughout the N2 time interval of 400-560 ms. In the SLI and TLD-Y groups, this effect began later, at 480 ms, and persisted to 560 ms. This finding indicates that SLI children are delayed in detecting conflict between competing response tendencies and that the speed at which they detect conflict resembles that of typically developing children who are on average three years younger.

The results of the N2-P2 analysis in the baseline condition are less straightforward. TLD-A children demonstrated greater amplitude for GO stimuli from 440-520 ms, whereas SLI and TLD-Y children showed no differences between GO and No-GO stimuli throughout the N2 time region. Previous studies (e.g., Nieuwenhuis et al., 2003) have reported greater amplitude for *No-GO* stimuli when stimulus frequency was balanced and this has been interpreted as reflecting a bias toward the GO response in speeded response tasks. The current finding may indicate that TLD-A children experienced a bias toward the No-GO response. The explanation for this discrepancy might lie in the nature of the feedback provided. In the current study, participants were told that for each trial they would lose two points for “doing the wrong thing” regardless of whether a GO or No-GO stimulus was presented (i.e., not responding to a GO stimulus or pressing the button in response to a No-GO stimulus). Following each block, accuracy scores were provided. This scoring system, in contrast to the presentation of error rates in the study by Nieuwenhuis et al. (2003), may have shifted the participants’ bias from the natural tendency to GO in speeded response tasks toward No-GO responses.

P3 Results.

Following the N2, a positive component identified as the P3 peaked between 900-1100 ms post-stimulus onset. The visual P3 commonly appears earlier in GO/No-GO paradigms, peaking between 300-500 ms following stimulus onset. The inclusion of a categorization task in the GO/No-GO paradigm of this study may account for the relatively late occurrence of the P3, as noted above with regard to the N2.

An enhanced P3 on No-GO as compared with GO trials has been exhibited by adults (Bokura et al., 2001; Bruin et al., 2001; Bekker et al., 2004; Donkers & van Boxtel, 2004; Smith et al., 2007) and normally developing 7-12 year-old children (Dimoska et al., 2003; Johnstone et al., 2005, 2007; Jonkman, 2006). In the current study, the P3 was generally enhanced for GO relative to No-GO responses in the frontal region. This effect was impacted by condition; GO/No-GO differences were exhibited by the TLD-A group in the 20 GO/80 No-GO condition and by the SLI group in the 50 GO/50 No-GO condition. Consistent with this finding, the influence of stimulus probability on P3 amplitude has been well documented. Specifically, events presented at lower probability levels engender a larger P3 (e.g., Bokura et al., 2001). Accordingly, the finding of enhanced GO P3s to rare GO stimuli in the 20 GO/80 No-GO condition is unsurprising. This result, though, casts doubt on the interpretation of the P3 as an inhibition component because it is unlikely that the rare motor responses in this condition required inhibition. Likewise, the absence of a No-GO P3 effect in the 80 GO/20 No-GO condition challenges the interpretation of the P3 as an inhibition component.

The SLI group's enhanced GO P3 effect in the baseline condition contrasts with evidence of No-GO > GO P3 amplitude for stimuli presented with equal frequency (Eimer, 1993). The latter finding has been used to support the notion that the P3 reflects inhibition of a motor response, rather than merely reflecting differences in stimulus frequency. If the inhibition proposal is true, why would *GO* P3s to equiprobable stimuli in the current study be enhanced? Jonkman et al. (2003) reported a similar finding as the present study for a visual cued-continuous performance task (CPT) in which the presentation of GO and No-GO stimuli was equiprobable. Whereas young adults (mean

age = 20.2 years) showed fronto-centrally maximal No-GO > GO amplitudes, children (mean age = 9.4 years) showed minor GO > No-GO amplitude. The absence of the fronto-central No-GO P3 effect in children was interpreted as a suggestion that they are developmentally delayed in response inhibition. Similarly, Johnstone et al. (2005) reported that in an auditory paradigm (70% GO, 30% No-GO), young adults (mean age = 20.7 years) showed No-GO > GO P3 amplitude whereas children (mean age = 10.8 years) exhibited the opposite GO > No-GO P3 pattern, which was not significant. The convergence of data from these two studies, one which included a visual paradigm and the other which included an auditory paradigm, was interpreted as evidence that the P3 component related to inhibition is not specific to a modality (Johnstone et al., 2005).

Although the aforementioned reports in the literature of GO > No-GO P3 effects in children provide a precedent for the current findings, they fail to explain why GO P3 responses have been found enhanced to equiprobable GO and No-GO stimuli. Furthermore, it remains unclear how to reconcile this finding with evidence that in response to equiprobable GO and No-GO stimuli, the *No-GO* P3 is larger (Eimer, 1993) or GO and No-GO responses are undifferentiated (Lavric, Pizzgalli, & Forstmeier, 2004).

The observed GO > No-GO P3 effect for equiprobable stimuli is also at odds with the notion that the GO/No-GO P3 is primarily attributable to differences in stimulus probability or contextual novelty, as is common for P3 effects with frontal distributions (Yamaguchi & Knight, 1991). According to this view, why would a GO > No-GO P3 effect be observed for equiprobable stimuli? Moreover, why would the No-GO P3 effect be absent in the 80 GO/20 No-GO condition? The P3 results of the current study thus suggest that stimulus frequency is not the only key determinant of P3 effects.

An alternative explanation of the P3 is that it represents the closure of an inhibitory process. This proposal was raised by Falkenstein et al. (1999), who contended that the latency of the P3 in GO/No-GO tasks typically occurs much later than the behavioral response and thus appears to be too late to reflect an inhibition mechanism. The late occurrence of the P3 in the current study is consistent with this argument. It is unclear how this proposal can be applied to the current results, though, given that GO/No-GO P3 responses varied by condition in a manner that is inconsistent with the inhibitory account. For example, rare stimuli in the 80 GO/20 No-GO condition would be expected to require inhibition, yet no P3 effects (potentially indicating closure of this process) were observed in this condition.

It has also been suggested that the No-GO P3 relates to the outcome of the inhibition process, reflecting performance evaluation in the post-response phase (Roche, Garavan, Foxe, & O'Mara, 2005). This proposal is buttressed by reports of P3 effects for successful but not failed inhibition trials in a stop-signal paradigm (de Jong, Coles, Logan, & Gratton, 1990; Dimoska et al., 2003, & Overtom et al., 2002). In GO/No-GO tasks, including the one used in the current experiment, failed inhibition trials are typically excluded from ERP analyses and therefore, this hypothesis requires further examination in future studies.

One approach in elucidating the functional interpretation of the P3 involves identifying its topographical features. Numerous studies have reported that the P3 in response to No-GO stimuli has an anterior topographic distribution, referred to as *No-GO anteriorization*; No-GO relative to GO responses show larger amplitudes at fronto-central sites (de Jong et al., 1990; Eimer, 1993; Falkenstein et al., 1999, 2002; Fallgatter & Strik,

1999; Pfefferbaum et al., 1985; Roberts et al., 1994; Simson et al. 1977; van Boxtel et al., 2001). Commonly, GO stimuli elicit a P3 that is parietally maximal (e.g., Bokura et al.; Fallgatter & Strik, 1999; Kopp et al., 1996; Smith et al. 2004). In the current experiment, GO and No-GO P3 were maximal frontally and no parietal effects were observed. It is likely that the frontal and parietal P3 effects in the GO/No-GO paradigm represent different processes.

The frontal topography of the P3 observed in this experiment is common following the anterior No-GO N2 and corresponds with what is reported for the P3a (Folstein & Van Petten, 2008). The P3a, a subcomponent of the P300, is frontally maximal and its general functional interpretation is that it indexes the orienting of attention to environmental events that are significant or unexpected. This component contrasts with the second subcomponent of the P300, the parietally maximal P3b, which reflects the updating of working memory (e.g., Dien, Spencer, & Donchin, 2004; Donchin, 1981; Friedman, Cycowitz, & Gaeta, 2001).

The possibility that the P3 and N2 reflect overlapping cognitive control processes raises the question of why GO/No-GO differences were absent or attenuated in the SLI relative to the TLD-A group for the N2 but not for the P3. Following the proposal that the No-GO P3 represents evaluation of the outcome of the inhibition process, it seems plausible that whereas conflict detection is impaired in SLI, post-response assessment of GO/No-GO performance is intact.

To summarize, the GO > No-GO P3 effects in the current study are consistent with previous studies that included children of similar ages. Although the developmental studies cited above suggest that the absence of the No-GO > GO P3 effect reflects an

immaturity, the processes reflected by the P3 remain unclear. The current findings do not support the interpretation of the P3 as an inhibition component, nor do they suggest that stimulus probability is the primary determinant of P3 effects. Instead, the results of the current study are consistent with the hypothesis that the P3 effect indexes post-response evaluation of performance related to inhibitory control.

N1 Results.

The N1, which peaked between 160-200 ms, was not expected to differ for GO and No-GO stimuli because it is presumably independent of the cognitive control system (e.g., Bokura et al., 2001) and this prediction was confirmed. Unexpectedly, GO/No-GO responses varied by condition overall, although the response types did not differ statistically within conditions. This finding indicates that the brains of 8-12 year-old children detected changes in conditions of probability between GO and No-GO stimuli as early as 160-200 ms. Although this occurred during the time range of the N1 component, it is not necessarily a modulation of this component.

In spite of evidence that the latency and amplitude of the N1 are sensitive to age (e.g., Rueda et al., 2004), no group differences in latency or amplitude were expected because of the relatively small age differences across the groups and none were observed. The anterior visual N1 has been attributed to response preparation processes based on evidence that the component can be eliminated by not requiring a motor response or reduced by stressing speed in a reaction time task (Vogel & Luck, 2000). The undifferentiated N1 amplitude across the groups may thus suggest similar response preparation among the TLD and SLI children. Evidence that the N1 indexes selective

attention to basic stimulus features (e.g., Vogel et al., 2000) suggests that the similarity of N1 latency and amplitude in the SLI and TLD children reflects similar early attentional skills.

3.4.3 Correlational Analyses

False-alarm rates and the amplitude of N2 difference waves were expected to negatively correlate based on evidence of No-GO N2 attenuation in participants with high false-alarm rates (Falkenstein et al., 1999). No significant correlations between these measures were found. The discordance of these behavioral and electrophysiological results questions whether the N2 reflects inhibitory processes involved in the commission of false-alarms. The lack of significant correlations might be due to the exclusion of unsuccessfully inhibited No-GO trials from the ERP data, which would have been more likely to bear an association with false-alarm rates.

Whereas SLI and TLD-Y children showed no significant correlations between RT and N2 mean amplitudes, TLD-A children showed moderate to large negative correlations in each condition. These significant findings suggest that ERP amplitudes are driven by cognitive functions that may facilitate processing speed (see Rueda et al., 2004). Adopting this view, these operations appear to be underdeveloped in 8-9 year-old typically developing and 10-12 year-old SLI children relative to 10-12 year-old typically developing children. In addition, the relationship between RT and N2 mean amplitudes bears insight into the processes reflected by GO N2 amplitude. Above, it was noted that as the frequency of No-GO trials decreased across conditions, thereby increasing inhibitory demands, RT decreased. Shorter RTs thus appear to be associated with high

levels of inhibition and the negative correlation between RT and N2 amplitudes implies that high inhibitory demands are electrophysiologically represented by higher GO N2 amplitudes.

Correlations computed to investigate whether N2 difference waves and RT to GO stimuli were associated with language performance revealed no significant findings. Further examination of specific receptive and expressive language abilities and how they may be associated with RT, as well as with the cognitive control mechanism, is warranted.

Additional correlations examined the contested notion that the N2 and P3 measure similar inhibitory processes. No significant correlations were found between N2 and P3 difference waves or between false-alarm rates and P3 difference waves. These results contrast with evidence reported by Jonkman et al. (2003) that 9 year-old children (but not adults) showed strong correlations between No-GO N2 and P3 amplitudes. In the present study, N2 effects may partially reflect inhibitory processes but the absence of No-GO P3 differences in the 80 GO/20 No-GO condition, in which inhibitory demands were presumably high, challenges interpretation of the P3 as an inhibition component. The current findings, therefore, do not support the proposal that the N2 and P3 reflect identical inhibitory processes. The specific functional interpretation of the P3 thus requires further investigation.

Chapter 4

Non-Linguistic Experiment: Results

4.1 Behavioral Results

Mean hit rates and RT to GO stimuli and false-alarm rates to No-GO stimuli with their corresponding standard deviations for each of the participant groups are presented in Table 14. Hit rates in all of the groups were at or near ceiling level (>94%) for each of the conditions and were therefore not entered into statistical analyses. False-alarm rates for the 20 GO/80 No-GO condition were likewise near ceiling level (< 2.02%) and were therefore excluded from statistical analyses.

Table 14. Mean hit rate, RT, and false-alarm rate (standard deviation) per group and condition in the Non-linguistic experiment.

	<u>80 GO/20 No-GO</u>			<u>50 GO/50 No-GO</u>			<u>20 GO/80 No-GO</u>		
	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)	Hit Rate (%)	RT (ms)	False-Alarm Rate (%)
TLD-A	99.34 (.01)	465.20 (40.84)	25.91 (.16)	98.81 (.02)	495.10 (46.67)	5.55 (.04)	98.13 (.03)	536.32 (46.84)	1.12 ($< .01$)
SLI	99.04 (.02)	475.30 (57.98)	25.25 (.15)	98.33 (.02)	516.37 (70.40)	4.90 (.03)	96.15 (.04)	574.52 (75.34)	1.34 ($< .01$)
TLD-Y	98.18 (.02)	500.16 (79.81)	35.16 (.17)	95.70 (.08)	534.66 (73.35)	6.44 (.04)	93.98 (.11)	584.72 (83.81)	2.01 (.01)

Tukey's (1977) method for identifying non-representative outliers, as described above for the Linguistic experiment, was applied to false-alarm rates and identified two outliers in the 50 GO/50 No-GO condition in the SLI group. The values for these participants were excluded from the following analysis.

A repeated measures ANOVA for false-alarm rates with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factor, Condition (80 GO/20 No-GO, 50 GO/50 No-GO), was performed. Results showed a main effect of Condition, $F(1, 45) = 116.15, p < .00001, \eta_p^2 = .72$. This effect arose from significantly higher false-alarm rates in the 80 GO/20 No-GO condition as compared with the baseline (50 GO/50 No-GO) condition in each of the groups. The main effect of Group, $F(2, 45) = 1.75, p > .05, \eta_p^2 = .07$, and the interaction of Group x Condition, $F(2, 45) = 1.87, p > .05, \eta_p^2 = .08$, were not significant.

Using Tukey's method to identify outliers for RTs, one outlier in the TLD-A group for the 80 GO/20 No-GO condition was excluded from the following analysis. A 3 x 3 (Group: TLD-A, SLI, TLD-Y x Condition: 80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) repeated measures ANOVA with RT scores revealed a main effect of Condition, $F(2, 94) = 88.91, p < .0001, \eta_p^2 = .65, \epsilon = .84$. As in the Linguistic experiment, this effect arose from significant differences among all of the three conditions (Tukey's HSD post-hoc test, $p < .001$). Although a clear pattern of increasing RTs from the TLD-A to the SLI and then to the TLD-Y groups was apparent, the main effect of Group, $F(2, 47) = 2.37, p = .10, \eta_p^2 = .09$, and the interaction of Group x Condition, $F(4, 94) = .82, p > .05, \eta_p^2 = .03$, were not significant. Appendix G presents the individual participants' mean reaction times for each condition.

Pearson correlations between false-alarm rates and RT to GO stimuli for each condition in each of the groups were examined to assess whether the participants demonstrated a speed/accuracy trade-off. No significant correlations were found ($p > .05$).

4.2 ERP Results

4.2.1 N2 Within-Group Analyses

Table 15 provides the mean amplitudes and their corresponding standard deviations for the N2 time interval (400-560 ms) of GO and No-GO waveforms at frontal, fronto-central, and central sites in each of the conditions. Following are each group's results for a repeated measures ANOVA with the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Region (frontal, fronto-central, and central). Reports of significant interactions are accompanied by Tukey's HSD post-hoc test results.

Table 15. Mean amplitudes of N2 (400-560 ms) GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Non-linguistic experiment (*SD* = standard deviation).

		TLD-A		SLI		TLD-Y	
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
Frontal	80 GO	3.75	6.07	2.47	4.53	3.35	7.42
	50 GO	3.17	6.37	3.81	3.54	2.23	8.28
	20 GO	.31	5.91	-.56	5.16	.76	9.00
	80 No-GO	1.04	4.83	-2.76	4.21	.47	7.94
	50 No-GO	2.68	6.82	.79	3.93	-1.32	6.25
	20 No-GO	.96	7.84	-3.26	4.19	1.66	6.43
Fronto-Central	80 GO	3.16	5.01	.95	2.86	3.45	5.03
	50 GO	2.84	5.27	2.48	5.70	2.83	6.00
	20 GO	.97	6.01	-2.64	5.34	2.58	6.69
	80 No-GO	.59	4.37	-3.91	7.63	.84	5.40
	50 No-GO	2.03	6.00	-.35	5.61	-.56	5.47
	20 No-GO	1.34	7.04	-4.06	3.97	2.69	4.78
Central	80 GO	7.81	4.92	6.79	4.89	6.25	5.24
	50 GO	8.53	5.10	7.98	8.48	5.56	5.15
	20 GO	7.95	6.56	5.42	4.84	5.05	6.11
	80 No-GO	4.89	4.25	1.31	4.72	4.09	5.48
	50 No-GO	5.92	5.48	4.13	6.57	2.59	4.75
	20 No-GO	6.31	6.41	2.93	7.19	4.66	5.20

TLD-A Children.

Results of the repeated measures analysis described above showed a main effect of Region, $F(2, 40) = 16.69$, $p < .001$, $\eta_p^2 = .45$, $\epsilon = .60$, characterized by significantly greater positive amplitude in the central region than in the frontal and fronto-central regions ($p < .001$). The main effect of Response Type was marginally significant, $F(1, 20) = 3.72$, $p = .068$, $\eta_p^2 = .16$, due to greater amplitude for No-GO responses. The main effect of Condition, $F(2, 40) = 1.38$, $p > .05$, $\eta_p^2 = .06$, and the interactions of Region x Condition, $F(4, 80) = 1.79$, $p > .05$, $\eta_p^2 = .17$, $\epsilon = .62$, Region x Response Type, $F(2, 40) = 3.50$, $p = .07$, $\eta_p^2 = .15$, $\epsilon = .60$, and Response Type x Condition, $F(2, 40) = .13$, $p > .05$, $\eta_p^2 < .01$, were not significant. The interaction of Region x Response Type x Condition was significant, $F(4, 80) = 8.10$, $p < .0001$, $\eta_p^2 = .29$, $\epsilon = .61$. This finding was due to Response Type differences in the frontal region for the 80 GO/20 No-GO condition ($p < .001$) and in the central region for the 50 GO/50 No-GO and 20 GO/80 No-GO conditions ($p < .001$) but not in the fronto-central region ($p > .05$).

Figure 5 illustrates the interaction of Region x Response Type x Condition. The figure shows that enhanced negativity for rare GO responses in the 20 GO/80 No-GO condition, which was found in the Linguistic experiment, was not observed here. No-GO responses in this condition showed greater amplitude than expected and were statistically undifferentiated from GO responses. Furthermore, the classical N2 effect was not apparent in the fronto-central region, in contrast to the results of the Linguistic experiment; instead, a pattern of greater amplitude for No-GO responses in all conditions was exhibited in this region, as well as in the central region. The N2 pattern of responses in the frontal region most closely resembled adult-like effects.

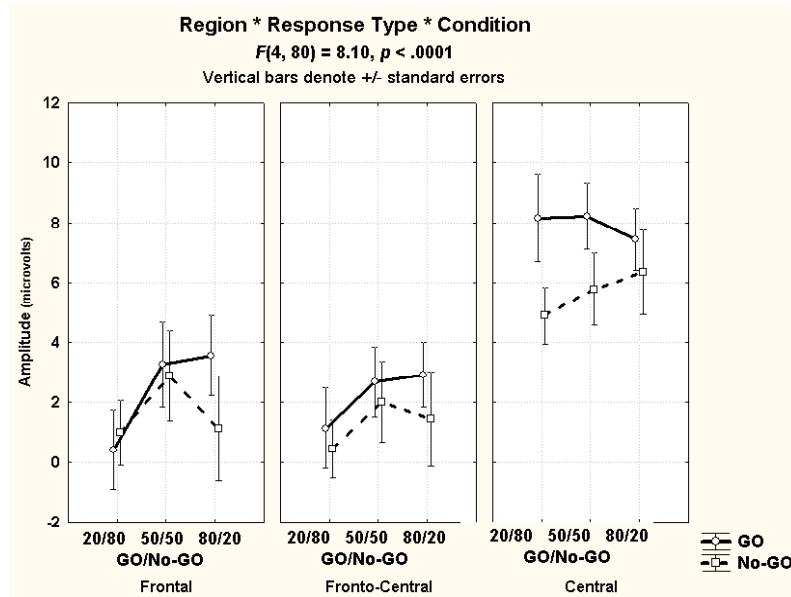


Figure 5. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in TLD-A children in the Non-linguistic experiment.

SLI Children.

A repeated measures ANOVA for the SLI group revealed three significant main effects: The main effect of Region, $F(2, 22) = 9.84, p < .01, \eta_p^2 = .47, \epsilon = .63$, reflected greater positive amplitude in the central region relative to the frontal and fronto-central regions ($p < .01$). Overall, enhanced negativity was found for No-GO relative to GO responses, $F(1, 11) = 32.91, p < .001, \eta_p^2 = .75$. A significant main effect of Condition, $F(2, 22) = 6.63, p < .01, \eta_p^2 = .38$, arose because responses in the 50 GO/50 No-GO condition had greater positive amplitude than responses in the 80 GO/20 No-GO and 20 GO/80 No-GO conditions. The impact of Condition on Response Type differed across regions, as indicated by a significant interaction of Region x Response Type x Condition, $F(4, 44) = 3.38, p < .05, \eta_p^2 = .23$ (see Figure 6). This interaction was due to enhanced negativity for No-GO responses in all conditions in the frontal region ($p < .05$); at the 50

GO/50 No-GO and 80 GO/20 No-GO levels in the fronto-central region ($p < .05$); and at all levels in the central region ($p < .001$). The interactions of Region x Response Type, $F(2, 22) = .43$, $p > .05$, $\eta_p^2 = .04$, $\epsilon = .60$, Region x Condition, $F(4, 44) = 1.86$, $p > .05$, $\eta_p^2 = .14$, and Response Type x Condition, $F(2, 22) = 1.52$, $p > .05$, $\eta_p^2 = .12$, were not significant.

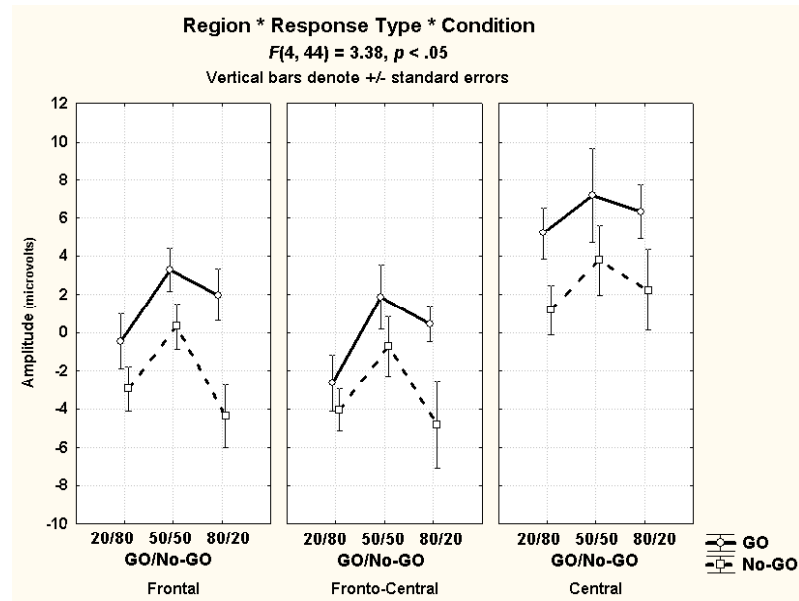


Figure 6. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in SLI children in the Non-linguistic experiment.

To summarize, the SLI group showed a pattern of more negative amplitude for No-GO than GO N2 responses across the frontal, fronto-central, and central regions. This finding contrasts with the results for the TLD-A group, which exhibited an N2 pattern that resembled adult-like effects in the frontal region.

TLD-Y Children.

The TLD-Y group showed a significant main effect of Region, $F(2, 26) = 4.77$, $p < .05$, $\eta_p^2 = .52$, arising from greater positive amplitude in the central region as compared with the frontal ($p < .001$) and fronto-central ($p < .05$) regions, similar to the TLD-A and SLI children. The main effect of Response Type, characterized by enhanced negativity for No-GO responses, was significant, $F(1, 13) = 8.49$, $p < .05$, $\eta_p^2 = .40$. The main effect of Condition, $F(2, 26) = 1.65$, $p > .05$, $\eta_p^2 = .11$, and the interactions of Response Type x Condition, $F(2, 26) = 3.04$, $p > .05$, $\eta_p^2 = .19$, Region x Response Type, $F(2, 26) = .02$, $p > .05$, $\eta_p^2 < .01$, $\epsilon = .62$, Region x Condition, $F(4, 52) = .50$, $p > .05$, $\eta_p^2 = .04$, $\epsilon = .37$, and Region x Response Type x Condition, $F(4, 52) = .96$, $p > .05$, $\eta_p^2 = .07$, $\epsilon = .41$, were not significant.

As illustrated in Figure 7, the TLD-Y children's N2 responses in the frontal region did not show adult-like N2 effects of enhanced negativity for rare responses in the 20 GO/80 No-GO condition. Overall, a pattern of greater negativity for No-GO responses was found, as observed in the SLI group.

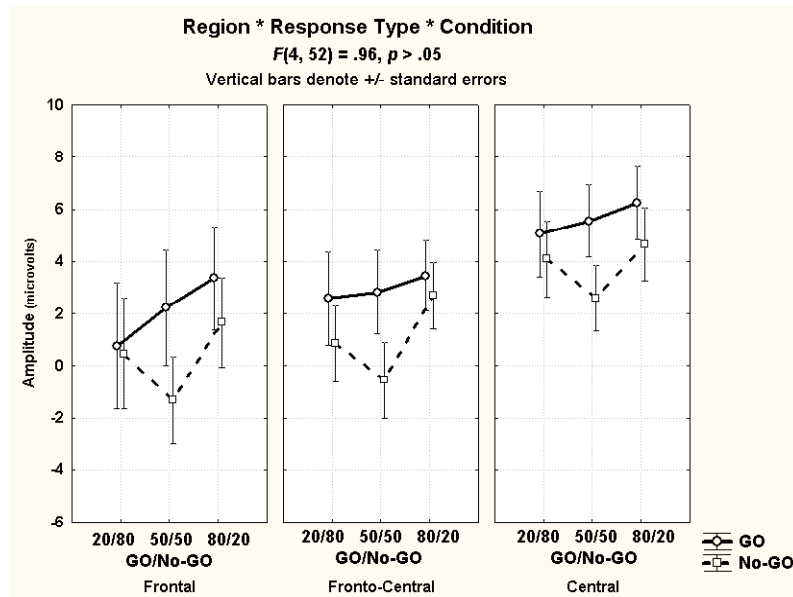


Figure 7. Influence of condition on GO/No-GO N2 responses at frontal, fronto-central, and central sites in TLD-Y children in the Non-linguistic experiment.

Summary of N2 Within-Group Analyses.

The anticipated finding of enhanced negativity for ERP responses withheld in the context of dominant responses was exhibited by TLD-A children in the 80 GO/20 No-GO condition but not in the 20 GO/80 No-GO condition in the frontal region. In addition, GO/No-GO differences were absent in the baseline condition at frontal sites in the TLD-A group. These findings differ from adult-like effects and they contrast with the TLD-A group's N2 responses in the fronto-central and central regions. The TLD-A group's N2 pattern also contrasts with those of the SLI and TLD-Y groups, who exhibited overall greater negativity for No-GO than GO responses across conditions and regions. In view of the TLD-A group's partially adult-like N2 effects in the frontal region and considering the frontal N2 effects observed in the Linguistic experiment detailed above, the frontal region was chosen for subsequent analyses. Topographical maps illustrating N2

difference waves (No-GO - GO) for each condition in the individual participant groups are presented in Appendix L.

4.2.2. N2 Between-Group Analyses

To allow comparison of cognitive conflict detection among the TLD-A, SLI, and TLD-Y groups, as reflected by the N2, a repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (400-440, 440-480, 480-520, 520-560 ms). Significant interactions were followed up by Tukey's HSD post-hoc test. The main effect of Time and interactions involving this variable that were not relevant to the hypotheses of interest are not reported below.

A significant main effect of Response Type, $F(1, 44) = 13.05, p < .001, \eta_p^2 = .23$, characterized by more negative amplitude for No-GO responses, was found. Responses in the 20 GO/80 No-GO condition were significantly less positive in amplitude relative to the 50 GO/50 No-GO condition ($p < .05$), as per a significant main effect of Condition, $F(2, 88) = 4.26, p < .05, \eta_p^2 = .09$.

Condition influenced the N2 effect (GO vs. No-GO) in the 50 GO/50 No-GO ($p < .05$) and 80 GO/20 No-GO ($p < .001$) conditions, resulting in a significant interaction of Response Type x Condition, $F(2, 88) = 4.25, p < .05, \eta_p^2 = .09$. The impact of condition on GO/No-GO responses varied over time, as indicated by a significant interaction of Response Type x Condition x Time, $F(6, 264) = 4.93, p < .05, \eta_p^2 = .07, \epsilon = .40$. Tukey's HSD post-hoc test was used to examine this interaction and the results of this test are

provided in Table 16. No-GO responses were more negative in amplitude than GO responses throughout the N2 region in the 80 GO/20 No-GO condition ($p < .01$). The same finding was observed in the baseline condition ($p < .05$), whereas GO and No-GO responses did not differ in the 20 GO/80 No-GO condition ($p > .05$).

Table 16. Results of Tukey's HSD post-hoc test for the N2 effect (GO vs. No-GO) using mean amplitude values at frontal sites in the Non-linguistic experiment.

80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
**	****	****	****	***	*	*	***	-	-	-	-
Significance of effects: **** $p < .0001$; *** $p < .001$; ** $p < .01$; * $p < .05$; - $p > .05$											

The main effect of Group, $F(2, 44) = .52$, $p > .05$, $\eta_p^2 = .02$, and the following interactions were not significant: Response Type x Group, $F(2, 44) = 1.94$, $p > .05$, $\eta_p^2 = .08$; Condition x Group, $F(4, 88) = 1.81$, $p > .05$, $\eta_p^2 = .08$; Time x Group, $F(6, 132) = .39$, $p > .05$, $\eta_p^2 = .02$; Response Type x Condition x Group, $F(4, 88) = 1.11$, $p > .05$, $\eta_p^2 = .05$; Response Type x Time, $F(3, 132) = .08$, $p > .05$, $\eta_p^2 < .01$, $\epsilon = .41$; Response Type x Time x Group, $F(6, 132) = .39$, $p > .05$, $\eta_p^2 = .02$; Condition x Time x Group, $F(12, 264) = .91$, $p > .05$, $\eta_p^2 = .04$; and Response Type x Condition x Time x Group, $F(12, 264) = 1.24$, $p > .05$, $\eta_p^2 = .05$. Notably, the N2 responses during the last two time segments, from 480-520 ms and from 520-560 ms, showed the expected effects in all three conditions in the TLD-A group only, although this group's GO/No-GO effects for the 20 GO/80 No-GO condition did not reach statistical significance in pairwise post-hoc comparisons ($p > .05$). The grand average waveforms of each group at frontal sites are provided in Appendix M.

Summary of N2 Between-Group Analysis.

In general, No-GO responses were greater in amplitude than GO responses across most conditions and time intervals in all of the groups. Close examination of the N2 responses from 480-560 ms, however, revealed that the TLD-A group exhibited the adult-like pattern of effects in this condition, although this was not borne out statistically in the 20 GO/80 No-GO condition. Contrary to the expectation that TLD-A, SLI, and TLD-Y children would demonstrate differing patterns of N2 effects, the three groups exhibited statistically similar N2 responses.

The preponderance of greater amplitude for both rare and frequent No-GO responses in the analysis detailed above calls into question whether N2 effects were offset by preceding negativity during the P2 time interval. To explore this possibility, the following analysis was performed.

4.2.3 P2 Analysis

Because the P2 is enhanced in response to infrequent targets (Luck et al., 1994), responses to rare, as compared with frequent, GO and No-GO stimuli were expected to be larger and it was predicted that condition might influence GO/No-GO differences. No group differences for this early component were anticipated.

Through visual inspection of the grand averages, the P2 time interval was identified as spanning from 240-300 ms. Mean amplitudes were computed for GO and No-GO waveforms during this time segment. A repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO) and Condition (80 GO/20 No-GO, 50

GO/50 No-GO, 20 GO/80 No-GO). Tukey's HSD post-hoc tests were used to investigate significant interactions.

GO responses were more positive in amplitude than No-GO responses, as per a significant main effect of Response Type, $F(1, 44) = 20.90, p < .0001, \eta_p^2 = .32$. The main effect of Condition was also significant, $F(2, 88) = 3.96, p < .05, \eta_p^2 = .08, \varepsilon = .41$, due to greater positive amplitude in the 50 GO/50 No-GO condition relative to the 20 GO/80 No-GO condition ($p < .05$) but no differences between these two conditions and the 80 GO/20 No-GO condition were found ($p > .05$). A significant interaction of Response Type x Group, $F(2, 44) = 5.07, p < .05, \eta_p^2 = .19$, arose due to a significant difference between GO and No-GO responses (Tukey's Unequal N HSD post-hoc test, $p < .001$) in the SLI group only. The main effect of Group, $F(2, 44) = 1.91, p > .05, \eta_p^2 = .08$, as well as the interactions of Condition x Group, $F(4, 88) = 1.30, p > .05, \eta_p^2 = .06$; Response Type x Condition, $F(2, 88) = .32, p > .05, \eta_p^2 < .01$; and Response Type x Condition x Group, $F(4, 88) = 1.39, p > .05, \eta_p^2 < .06$, were not significant.

Summary of P2 Analysis.

The unexpected finding of overall greater negative amplitude for No-GO than GO N2 responses was followed up by examining whether GO/No-GO differences for the N2 were influenced by P2 responses. The P2 differed for GO and No-GO stimuli, as in the Linguistic experiment and consistent with the predictions of the current study.

The absence of an interaction between condition and response type indicates that GO/No-GO P2 differences were not modulated by conditions of probability, in contrast to the significant influence of condition on the N2 in both the Linguistic and Non-

linguistic experiments. This finding suggests that the processes underlying the observed GO/No-GO differences for the P2 and N2 are at least partially dissociable. Accordingly, response type differences during the N2 time interval should be considered independently of preceding P2 response type differences. Moreover, the finding that the SLI but not the typically developing children showed overall GO/No-GO differences for the P2 may account for the lack of group effects in the N2 analysis detailed above and warrants examination. These considerations were addressed in the following analysis, which is identical to the N2-P2 analysis in the Linguistic experiment detailed above.

4.2.4 N2-P2 Analysis

Mean amplitudes for the P2 (240-300 ms) were subtracted from the mean amplitudes for the four 40 ms time intervals of the N2 (400-440, 440-480, 480-520, 520-560 ms). This enabled examination of whether each of the groups exhibited an N2 effect beyond any foregoing GO/No-GO differences during the P2 time interval. A repeated measures ANOVA was computed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (400-440, 440-480, 480-520, 520-560 ms). Significant interactions were followed up by Tukey's HSD post-hoc test.

The results of the repeated measures ANOVA are provided in Table 17. GO and No-GO responses varied as a function of condition, $F(2, 88) = 6.79, p < .01, \eta_p^2 = .13$. Specifically, GO and No-GO responses differed in the 80 GO/20 No-GO condition only ($p < .001$). There was a significant interaction of Condition x Time, $F(6, 264) = 3.49, p <$

.01, $\eta_p^2 = .07$, $\varepsilon = .40$, and this interaction was modulated by Response Type, $F(6, 264) = 4.93$, $p < .01$, $\eta_p^2 = .10$, $\varepsilon = .36$. Tukey's post-hoc test was used to identify the time intervals in which GO and No-GO responses differed within each condition. The results of this test are presented in Table 18. As shown, responses to rare No-GO stimuli were more negative in amplitude from 440-560 ms in the 80 GO/20 No-GO condition, as characteristic of the N2. Non-differential GO/No-GO N2 responses were found in the 50 GO/50 No-GO condition. In the 20 GO/80 No-GO condition, responses to rare GO stimuli were more negative in amplitude during the 520-560 ms time interval. No other main effects or interactions were significant. Notably, the general pattern of these N2-P2 results indicates that the N2 showed its characteristic sensitivity to conflict when considered in isolation of the P2.

Table 17. Results of the repeated measures ANOVA for the N2-P2 effect (400-560 ms) using mean amplitude values at frontal sites in the Non-linguistic experiment.

Effect	df	F
Group (G)	2, 44	< 1
Response Type (R)	1, 44	3.60 (*)
Condition (C)	2, 88	3.09 (*)
Time (T)	3, 132	23.52 ***
R x G	2, 44	< 1
C x G	4, 88	1.22
T x G	6, 132	< 1
R x C	2, 88	6.79 *
R x C x G	4, 88	1.65
R x T	3, 132	< 1
R x T x G	6, 132	< 1
C x T	6, 264	3.49 *
C x T x G	12, 264	< 1
R x C x T	6, 264	4.93 **
R x C x T x G	12, 264	1.24
Significance of effects: *** $p < .00001$; ** $p < .0001$; * $p < .01$; (*) $p = .06$		

Table 18. Results of Tukey's HSD post-hoc test for analysis of the N2-P2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in the Non-linguistic experiment.

80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
-	*	**	**	-	-	-	-	-	-	-	*

Significance of effects: ** $p < .0001$; * $p < .001$; - $p > .05$

4.2.5 N2-P2 Equal *n* Analysis

Paralleling the Linguistic experiment, a follow-up analysis was conducted to determine whether the observed N2 effects were accurate in view of the unequal participant numbers across the groups (TLD-A = 21; SLI = 12; TLD-Y = 16). N2-P2, rather than N2, mean amplitude values were used in the current analysis because the results detailed above indicated that N2-P2 values were more representative of the N2 effects for this experiment. The results of this analysis were similar to those of the N2 analysis for unequal participant numbers across the groups. The expected N2 effects were observed in at least two time intervals in the 80 GO/20 No-GO and 20 GO/80 No-GO conditions but no response type differences were found throughout the baseline condition. Although the anticipated N2 effects apparently emerged later in the SLI group, no group differences were statistically significant in this analysis (see Appendix N).

4.2.6 P3 Analysis

Based on inspection of each group's grand average waveforms, the time interval of 600-1200 ms was selected for analysis of the P3 because it included the component across conditions. Individual analyses of each group's data revealed that the P3 was

maximal over frontal sites and therefore, P3 responses in this region were selected for further analysis. This is illustrated in Appendix O, which presents the topographical maps of P3 difference waves (No-GO – GO) from 800-1200 ms for each condition in the individual participant groups. To determine whether the P3 differed as a function of response type, condition, and time across groups, a repeated measures ANOVA was performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO), Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO), and Time (600-700, 700-800, 800-900, 900-1000, 1000-1100, 1100-1200 ms) using mean amplitude values at frontal sites. Significant interactions were followed up by Tukey's HSD post-hoc tests.

The means and standard deviations for the current analysis are presented in Table 19. As observed in the Linguistic experiment, GO responses showed enhanced positivity, as per a main effect of Response Type, $F(1, 44) = 5.36, p < .05, \eta_p^2 = .11$. GO/No-GO differences were impacted by condition, as demonstrated by a significant interaction of Response Type x Condition, $F(2, 88) = 7.49, p < .001, \eta_p^2 = .15$. This effect arose from significant differences between GO and No-GO responses in the 20 GO/80 No-GO ($p < .001$) and 50 GO/50 No-GO ($p < .05$) conditions. Within each condition, amplitude varied over time [$F(10, 440) = 3.24, p < .05, \eta_p^2 = .07, \epsilon = .35$] during the following consecutive time intervals: From 600-700 ms to 700-800 ms; from 800-900 ms to 900-1000 ms; and from 1000-1100 ms to 1100-1200 ms ($p < .05$). In addition to the aforementioned effects for the baseline condition, amplitude varied from 900-1000 ms to 1000-1100 ms in this condition ($p < .05$).

Table 19. Mean amplitudes of the P3 (1000-1100 ms) for GO and No-GO waveforms at frontal, fronto-central, and central sites as a function of condition in the Non-linguistic experiment (*SD* = standard deviation).

		TLD-A		SLI		TLD-Y	
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
Frontal	80 GO	17.34	25.96	23.46	29.66	17.56	18.66
	50 GO	19.95	25.49	26.56	33.65	21.48	19.03
	20 GO	25.56	21.89	31.31	30.11	22.77	22.38
	80 No-GO	12.78	18.11	14.21	15.41	15.06	11.11
	50 No-GO	16.62	21.59	15.83	21.02	14.43	15.05
	20 No-GO	24.04	29.13	19.51	18.58	25.21	21.55
Fronto-Central	80 GO	6.95	9.93	8.34	12.91	7.43	8.81
	50 GO	6.37	10.27	8.94	15.98	10.48	9.97
	20 GO	10.31	10.20	10.97	15.54	6.75	11.24
	80 No-GO	5.15	8.36	5.10	6.87	7.83	4.71
	50 No-GO	6.38	9.60	6.37	8.41	8.21	6.75
	20 No-GO	8.46	12.96	4.77	11.27	12.16	9.56
Central	80 GO	3.20	6.08	3.79	6.75	5.80	9.51
	50 GO	2.29	6.48	3.74	8.53	7.97	8.39
	20 GO	4.89	6.68	5.35	8.53	7.10	11.61
	80 No-GO	4.70	4.73	3.90	4.01	7.37	5.52
	50 No-GO	5.50	5.89	5.24	4.71	7.76	5.48
	20 No-GO	5.61	7.76	2.69	7.25	11.09	8.52

Lastly, the impact of condition on GO/No-GO responses varied over time, as indicated by a significant interaction of Response Type x Condition x Time, $F(10, 440) = 14.55$, $p < .000001$, $\eta_p^2 = .25$, $\varepsilon = .35$. This effect was due to significant amplitude differences between GO and No-GO responses during the following time intervals: In the 80 GO/20 No-GO condition, No-GO was more positive than GO from 1000-1100 ms ($p < .05$); in the 50 GO/50 No-GO condition, GO was more positive than No-GO from 900-1000 ms and from 1000-1100 ms ($p < .001$); and in the 20 GO/80 No-GO condition, GO was more positive than No-GO from 900-1000 ms, 1000-1100 ms, and from 1100-1200 ms ($p < .001$). No other relevant main effects or interactions in the current analysis were significant ($p > .05$), as reported in Table 20.

Table 20. Results of the repeated measures ANOVA for the P3 component (600-1200 ms) using mean amplitude values at frontal sites in the Non-linguistic experiment.

Effect	df	F
Group (G)	2, 44	< 1
Response Type (R)	1, 44	5.36 *
Condition (C)	2, 88	< 1
Time (T)	5, 220	12.27 **
R x G	2, 44	1.04
C x G	4, 88	< 1
T x G	10, 220	< 1
R x C	2, 88	7.49 **
R x C x G	4, 88	1.87
R x T	5, 220	2.99
R x T x G	10, 220	< 1
C x T	10, 440	3.24 *
C x T x G	20, 440	1.54
R x C x T	10, 440	14.55 ***
R x C x T x G	20, 440	1.10
Significance of effects: *** $p < .00001$; ** $p < .001$; * $p < .05$		

Summary of P3 Analysis.

In summary, P3 responses showed enhanced positivity for either GO or No-GO stimuli from 900-1100 ms in each of the conditions, as observed in the Linguistic experiment. The latency of this effect differed across conditions, beginning and ending between 1000-1100 ms in the 80 GO/20 No-GO condition, spanning 900-1100 ms in the baseline condition, and spanning 900-1200 ms in the 20 GO/80 No-GO condition. No significant between-group differences for any P3 effects were found.

4.2.7 N1 Analysis

The P2 analysis detailed above indicated that the SLI group, but not the groups of typically developing children, responded differently to GO and No-GO stimuli. This finding for the exogenous P2 component was unpredicted. To examine whether the

preceding exogenous component, the N1, also differed among the groups, the following analysis was conducted. Inspection of the grand averages revealed that the N1 appeared during the approximate time interval of 160-200 ms in each of the groups. Mean amplitudes were computed for this time window. A repeated measures ANOVA was then performed with the between-group factor, Group (TLD-A, SLI, TLD-Y), and the within-group factors, Response Type (GO, No-GO) and Condition (80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) at frontal sites.

The N1 was not expected to differ between GO and No-GO responses and no association between GO/No-GO responses and condition was anticipated. All main effects and interactions were non-significant ($p > .05$). To summarize, the exogenous N1 component did not differ between GO and No-GO responses and across groups.

4.3 Correlational Analyses

To determine if RT and N2 amplitude in the current experiment were associated, Pearson correlations were computed between the mean RT for GO responses and mean amplitudes of the N2 in response to GO stimuli in each condition. No significant correlations were found among these variables ($p > .01$), as shown in Table 21.

Table 21. Correlations between reaction time (RT) and mean amplitudes of the N2 to GO stimuli per condition in the Non-linguistic experiment.

Measures	ALL GROUPS	TLD-A	SLI	TLD-Y
RT 80 GO N2 GO 80	.03	-.07	.25	.03
RT 50 GO N2 GO 50	-.08	-.34	.48	-.03
RT 20 GO N2 GO 20	-.02	-.36	.58	-.06

Correlations that were computed between false-alarm rates and the No-GO minus GO waveforms for correct responses in each condition also showed no significant findings ($p > .05$), as indicated in Table 22.

Additional correlations tested whether there were relationships between the participants' receptive, expressive, and composite standardized language test scores on the CELF-4 and the mean RT to GO stimuli and between the aforementioned CELF-4 scores and mean amplitudes of the N2 difference waves in each condition. No significant correlations were found ($p > .01$), as indicated in Table 23.

To determine if the N2 and P3 are associated, as posited by previous studies (Jonkman et al., 2003), correlations were calculated between mean amplitudes of the N2 (400-560 ms) and P3 (1000-1100 ms) difference waves in each condition. Correlations were also computed between false-alarm rates and P3 difference waves in each condition to evaluate whether the P3 is related to a measure of behavioral inhibition. In the 80 GO/20 No-GO condition, all of the groups combined exhibited a moderate positive correlation between N2 and P3 difference waves ($r = .49$) and the TLD-Y group individually exhibited a strong positive correlation between N2 and P3 difference waves ($r = .74$). In addition, the SLI group showed a strong negative correlation ($r = -.81$) between false-alarm rates and P3 differences waves in the 80 GO/20 No-GO condition. No other correlations were significant ($p > .01$). These results are presented in Table 24.

Table 22. Correlations between false-alarm rates and mean amplitudes of N2 difference waves (No-GO - GO) per condition in the Non-linguistic experiment.

Measures		ALL GROUPS	TLD-A	SLI	TLD-Y
80 No-GO False-Alarms	N2 80 No-GO - 20 GO	-.02	.16	-.13	-.16
50 No-GO False-Alarms	N2 50 No-GO - 50 GO	-.09	.10	-.62	-.23
20 No-GO False-Alarms	N2 20 No-GO - 80 GO	-.08	-.22	-.20	.12

Table 23. Correlations between standardized language test scores and mean amplitudes of N2 difference waves (No-GO - GO) and reaction time (RT) to GO stimuli per condition in the Non-linguistic experiment.

Measures		ALL GROUPS	TLD-A	SLI	TLD-Y
RLS	N2 80 No-GO - 20 GO	.31	.39	-.27	.28
	N2 50 No-GO - 50 GO	.01	.16	-.43	-.12
	N2 20 No-GO - 80 GO	.11	.11	-.33	-.16
	RT 80 GO	.00	-.22	-.06	-.22
	RT 50 GO	-.09	-.29	-.25	-.08
	RT 20 GO	-.07	-.23	-.25	.11
ELS	N2 80 No-GO - 20 GO	.17	-.15	-.15	.15
	N2 50 No-GO - 50 GO	-.01	.04	-.43	-.55
	N2 20 No-GO - 80 GO	.08	.02	-.26	-.36
	RT 80 GO	-.11	-.25	.22	-.40
	RT 50 GO	-.14	-.15	.18	-.40
	RT 20 GO	-.19	-.19	.13	-.27
CLS	N2 80 No-GO - 20 GO	.25	.15	-.21	.16
	N2 50 No-GO - 50 GO	.03	.20	-.54	-.37
	N2 20 No-GO - 80 GO	.07	.13	-.41	-.41
	RT 80 GO	-.02	.04	.07	-.16
	RT 50 GO	-.12	-.35	-.03	-.09
	RT 20 GO	-.16	-.37	-.06	.03

RLS = Receptive Language Score, ELS = Expressive Language Score, and CLS = Core Language (total language) Score of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4).

Table 24. Correlations between mean amplitudes of N2 and P3 difference waves (No-GO - GO) and between false-alarm rates and P3 difference waves per condition in the Non-linguistic experiment.

Measures		ALL GROUPS	TLD-A	SLI	TLD-Y
N2 80 No-GO - 20 GO	P3 80 No-GO - 20 GO	.12	.38	.03	-.17
N2 50 No-GO - 50 GO	P3 50 No-GO - 50 GO	-.04	-.27	.03	.21
N2 20 No-GO - 80 GO	P3 20 No-GO - 80 GO	.49*	.18	.52	.74*
80 No-GO False-Alarms	P3 80 No-GO - 20 GO	.26	.45	.61	-.22
50 No-GO False-Alarms	P3 50 No-GO - 50 GO	.00	.24	.09	-.56
20 No-GO False-Alarms	P3 20 No-GO - 80 GO	-.18	.06	-.81*	-.10

4.4 Discussion

The purpose of the Non-linguistic experiment was to determine if children with SLI show poor cognitive control skills relative to typically developing children in performing a GO/No-GO task with non-linguistic stimuli. Geometric shapes contrasted by vertical and horizontal lines were presented at various probability levels to elicit competing response tendencies to GO and No-GO stimuli.

4.4.1 Behavioral Data.

All of the groups demonstrated hit rates that were near ceiling level (> 94%) and the manipulation of stimulus probability resulted in higher false-alarm rates in the 80 GO/20 No-GO condition relative to the baseline condition, as predicted. False-alarm rates were lower than approximately 1% in the 20 GO/80 No-GO condition. No group differences in false-alarm rates were found, contrary to the prediction that TLD-Y children would exhibit slightly higher false-alarm rates than TLD-A children, considering developmental differences in inhibitory control over motor responses (Band et al., 2000; Falkenstein et al., 2002; Levy, 1980; Tamm et al., 2002). The SLI children's ability to control motor responses age-appropriately is consistent with previous evidence from a GO/No-GO task reported by Noterdaeme et al. (2001).

In response to GO stimuli, RT increased across conditions with an increase in the frequency of No-GO trials, as reported by Nieuwenhuis et al. (2003). No group differences in RT were observed, in spite of two common findings: Younger children typically demonstrate longer RTs than older children and SLI children commonly perform 10-30% more slowly than their same-age peers (Kail, 1994; Miller et al., 2001;

Windsor et al., 1999). The lack of significant group differences in RT here may be due to the relative simplicity of the current task.

4.4.2 ERP Data.

N2 Results.

As observed in the Linguistic experiment, the N2 was maximal at 400 ms and returned to baseline at 560 ms. This N2 time interval is relatively late as compared with reports of N2 latency between 200-350 ms following stimulus onset in other studies of children (e.g., Jonkman et al., 2003; Johnstone et al., 2005). The use of a categorization task in the current experiment likely resulted in more extensive stimulus processing relative to other GO/No-GO tasks and may therefore account for this difference in timing. Between-group analyses were limited to ERP data in the frontal region, where adult-like patterns were generally exhibited, and because robust N2 effects were manifested in this region in the Linguistic experiment.

Previous research indicates that the N2 reflects the detection of conflict among competing response tendencies by increasing in amplitude on trials that necessitate a rare response (Nieuwenhuis et al., 2003). Greater N2 amplitude in response to rare GO and No-GO stimuli would support the conflict monitoring theory, which posits that the N2 effect is not contingent on the type of response.

Results showed greater amplitude for No-GO responses throughout the N2 time region in the 80 GO/20 No-GO and baseline conditions, but undifferentiated N2 responses in the 20 GO/80 No-GO condition. The preponderance of greater amplitude for No-GO responses suggests a bias toward the tendency to GO. Similarly, Ciesielski et al.

(2004) observed larger No-GO than GO N2 responses in adults, irrespective of stimulus probability, whereas 6-12 year-old children showed larger N2 responses to rare than to frequent stimuli. These results were interpreted as suggesting that No-GO N2 amplitudes in adults were mainly determined by the “inhibitory content” of stimuli, whereas children’s N2 responses were primarily impacted by stimulus probability. Greater No-GO than GO responses in the 80 GO/20 No-GO and baseline conditions of this experiment might thus reflect the presumably higher inhibitory demands of these conditions relative to the 20 GO/80 No-GO condition.

To adopt the above interpretation, the influence of condition on N2 responses to linguistic versus non-linguistic stimuli in the present study requires explanation. In the Linguistic experiment, N2 responses showed greater amplitude for rare GO and No-GO stimuli in contrast to the preponderance of greater amplitude for No-GO responses in the Non-linguistic experiment. This difference across experiments might be due to the greater degree of perceptual overlap between the GO and No-GO non-linguistic relative to the linguistic stimuli. Nieuwenhuis, Yeung, and Cohen (2004) reported that the degree of perceptual overlap between GO and No-GO stimuli impacts the degree of conflict generated, as expressed by the amplitude of the N2. When GO and No-GO stimuli share many perceptual features, as applies to the geometric shapes of the Non-linguistic experiment, the typical bias toward executing a response may become heightened. This is because GO responses are more likely to be erroneously activated on No-GO trials, thereby invoking more response conflict on No-GO trials, as demonstrated by greater No-GO than GO amplitude. This is a reasonable explanation for why larger No-GO than GO amplitude was observed in the 80 GO/20 No-GO and baseline conditions of the Non-

linguistic experiment. The absence of larger GO than No-GO responses in the 20 GO/80 No-GO condition of this experiment suggests that erroneous activation of No-GO responses did not pose the same degree of response competition as that of GO responses in the 80 GO/20 No-GO condition.

It was posited that the SLI group would show attenuated N2 amplitude differences between GO and No-GO stimuli relative to typically developing children of the same age based on the premise that SLI children are impaired in conflict detection. This prediction, however, was not borne out. The groups' N2 effects were statistically similar. The P2 component was therefore examined to determine if responses during its time region masked group effects in the ensuing N2.

P2 Results.

The P2 was maximal between 200-340 ms and its amplitude was more negative in response to No-GO stimuli across conditions. Furthermore, condition did not impact the amplitude of the P2, in spite of prior evidence that the P2 is enhanced for infrequent targets (Luck et al., 1994). The enhancement of the P2 in response to No-GO stimuli in all of the conditions is consistent with the functional interpretation of the P2 as reflecting stimulus classification (Luck et al., 1994, for visual stimuli; Garcia et al., 1992, for auditory stimuli) and mirrors the results of the Linguistic experiment.

No developmental differences between the TLD-Y and older children's P2 responses were observed, as predicted in view of the relatively narrow age range of the participants. Post-hoc tests revealed that a significant overall difference between GO and No-GO responses was exhibited by the SLI group only. This finding raised the question

of whether the SLI children's N2 effects were differentially impacted by P2 responses relative to typically developing children. To address this possibility, the waveforms for the P2 time interval were subtracted from those for the N2 time interval, providing a measure of cognitive control isolated from preceding P2 effects.

N2-P2 Results.

Larger N2-P2 responses to rare stimuli in the 80 GO/20 No-GO condition were observed, as found for the N2. In this analysis, however, no differences between GO and No-GO stimuli were demonstrated in the baseline condition and larger responses to rare GO stimuli were observed in the last time interval of 520-560 ms in the 20 GO/80 No-GO condition. As compared with the N2 results described above, these findings resemble the N2 adult-like pattern of results demonstrated by the TLD-A group in the Linguistic experiment and thus appear to better represent N2 effects related to cognitive control.

The absence of GO/No-GO differences in the baseline condition contrasts with the general finding of greater No-GO than GO amplitude in response to equiprobable stimuli (e.g., Eimer, 1993) and has also been reported by Donkers et al. (2004). Assuming that larger No-GO than GO responses to equiprobable stimuli reflect a bias toward the GO response due to instructions to respond as quickly as possible, the current results suggest that no bias was present in this condition. This may be due to the provision of accuracy scores that penalized participants equally for executing a response on No-GO trials and for failing to respond on GO trials, in contrast to other studies that only provided error rates (e.g., Nieuwenhuis et al., 2003). This form of feedback, which

participants were apprised of prior to the experiment, may have eliminated the natural bias toward the GO response.

The lack of group differences in the N2-P2 results suggests that TLD-A, SLI, and TLD-Y children process conflict invoked by non-linguistic stimuli comparably. This conclusion runs counter to the prediction that SLI children would exhibit attenuated N2 amplitude differences between GO and No-GO stimuli due to poor conflict detection and that developmental differences between TLD-Y and TLD-A children would be demonstrated. Furthermore, this finding is surprising because in the Linguistic experiment, SLI children demonstrated immature conflict detection and this skill is a domain-general ability that should have ramifications for both linguistic and non-linguistic stimuli. Perhaps the Non-linguistic experiment was not sufficiently sensitive to detect group differences in cognitive control skills. Moreover, because the linguistic stimuli presumably required access to semantic representations of pictures in order to categorize the stimuli, the process of conflict detection may have been more adversely impacted by the speed of processing in the Linguistic experiment. Considering that SLI children process information more slowly than their same-age peers (Kail, 1994; Miller et al., 2001; Windsor et al., 1999), as inferred from slower task performance, the time-sensitive nature of processing linguistic stimuli may have exacerbated their poor processing of linguistic relative to non-linguistic stimuli.

To ensure that the lack of group effects in the aforementioned analysis was not an outcome of poorly matched groups, a follow-up analysis in which 10 TLD-A and 10 SLI participants were matched based on age, gender, handedness, and non-verbal intelligence

was performed. The results of this analysis closely resembled those of the N2-P2 analysis for unequal *ns*.

P3 Results.

The P3 component peaked within the time region of 900-1100 ms post-stimulus onset. The late occurrence of this component, relative to the common visual P3 between 300-500 ms following stimulus onset, might be due to the inclusion of a categorization task in the current study, as noted above in relation to the N2.

The literature reports that the amplitude of the P3 is greater on No-GO relative to GO trials in adults (Bokura et al., 2001; Bruin et al., 2001; Bekker et al., 2004; Donkers et al., 2004; Smith et al., 2007) and normally developing 7-12 year-old children (Dimoska et al., 2003; Johnstone et al., 2005, 2007; Jonkman, 2006). In the present experiment, the P3 was enhanced for GO relative to No-GO responses in the 20 GO/80 No-GO and baseline conditions at frontal sites. The enhanced responses for rare GO stimuli are consistent with a key characteristic of the P3b; larger responses to low- relative to high-frequent stimuli are invoked in the classical oddball task. The larger GO > No-GO responses for equiprobable stimuli, however, differentiate the P3 observed in the current study from the P3b.

As detailed above in relation to the Linguistic experiment, the functional significance of the P3 in GO/No-GO tasks remains highly disputed. Larger No-GO P3 responses to rare and equiprobable stimuli suggest that the P3 represents inhibition of a motor response (e.g., Eimer, 1993). This proposal is discordant with the current results because GO stimuli, which do not require motor inhibition, elicited greater P3 responses

in the 20 GO/80 No-GO condition. Furthermore, no response type differences were exhibited in the 80 GO/20 No-GO condition, which presumably invoked high inhibitory demands. Similar findings of GO > No-GO P3 effects in children, but not adults, have been reported (Jonkman et al., 2003; Johnstone et al., 2005) and the absence of adult-like No-GO > GO P3 effects has been inferred as evidence of a maturational delay in response inhibition. This interpretation can be evaluated by testing adults on the paradigm of the current study.

Considering the late latency of the P3, it seems plausible that this component represents post-response evaluation of performance (Roche et al., 2005). If so, the lack of group differences for the P3 suggests that SLI and typically developing children evaluate GO/No-GO performance comparably. The latency of the P3 is also consistent with Falkenstein et al.'s (1999) suggestion that the P3 reflects the conclusion of an inhibitory process. This proposal, however, does not account for the absence of GO/No-GO P3 differences in the 80 GO/20 No-GO condition, which likely entailed high inhibitory demands.

Commonly, No-GO P3 responses have an anterior topographic distribution (de Jong et al., 1990; Eimer, 1993; Falkenstein et al., 1999, 2002; Fallgatter & Strik, 1999; Pfefferbaum et al., 1985; Roberts et al., 1994; Simson et al. 1977; van Boxtel et al., 2001) and GO P3 responses are maximal at parietal sites (e.g., Bokura et al.; Fallgatter & Strik, 1999; Kopp et al., 1996; Smith et al. 2004). Only the former effect was observed in the current study. Both GO and No-GO P3 responses were maximal frontally and showed no parietal effects. The anteriorization of the P3 observed in this experiment is common following the frontal No-GO N2 and is consistent with the characteristics of the P3a,

which reflects the orienting of attention to significant or unpredicted environmental events (Folstein et al., 2008). The similar topographical distribution of the N2 and P3 implies that both of these components have neural generators in frontal regions. Whereas the N2 indexes conflict detection, the P3 may reflect evaluation of this function.

To recap, larger GO > No-GO P3 effects were observed in the 20 GO/80 No-GO and baseline conditions and no effects were observed in the 80 GO/20 No-GO condition. Neither stimulus probability nor the inhibitory explanation of the P3 can fully account for the current results. Instead, the P3 may represent evaluation of conflict detection following trial performance. Lastly, group differences in the impact of condition on GO/No-GO responses were observed in the Linguistic but not the Non-linguistic experiment, possibly due to the time-sensitive nature of linguistic processing.

N1 Results.

No differences between GO and No-GO responses were predicted for the N1 considering that this component is presumably not modulated by the cognitive control system (e.g., Bokura et al., 2001). A marginally significant difference between GO and No-GO responses, however, was observed. This effect varied slightly across the groups due to response type differences in the SLI group only. The divergence of GO/No-Go waveforms during the N1 signals differential activation in response to GO and No-GO stimuli during early sensory processing, by approximately 160-200 ms. The SLI group may have found the No-GO stimuli more novel, or attention grabbing, resulting in greater amplitude differences between the response types relative to typically developing children.

There are only a few studies that have reported on the visual N1 component in the GO/No-GO paradigm. In contrast to the current findings, Bokura et al. (2001) found no differences in N1 amplitude, latency, or generator source between GO and No-GO responses to visual stimuli in adults. Contrastingly, Johnstone et al. (2005) observed a larger fronto-central N1 response to auditory No-GO than GO stimuli in children, similar to the results of this experiment.

Although the N1 has a developmental pattern of larger amplitudes in children than adults (e.g., Rueda et al., 2004), no group differences in amplitude were expected in view of the relatively similar ages of the participants in each group and this was confirmed. As in the Linguistic experiment, the TLD-Y group showed greater overall amplitude than the TLD-A and SLI groups, but here, the difference was not statistically significant.

4.4.3 *Correlational Analyses*

Based on the purported association between false-alarm rates and the N2 (Falkenstein et al., 1999), these measures were expected to negatively correlate. No correlations were observed between these two measures in any of the conditions. This might be due to the exclusion of unsuccessfully inhibited No-GO trials from the ERP data, which would have been more likely to bear an association with false-alarm rates. Alternatively, the lack of a significant correlation between false-alarm rates and the N2 may dispute the notion that the N2 indexes the behavioral inhibition that is associated with commission errors.

No significant correlations between RT and N2 mean amplitudes were found in any of the groups, whereas TLD-A children showed moderate to large negative

correlations in each condition in the Linguistic experiment. The findings for the current experiment challenge the proposal that ERP amplitudes are driven by cognitive functions that may facilitate processing speed (see Rueda et al., 2004).

In the analysis of whether N2 difference waves and RT to GO stimuli are associated with language performance in children, no significant correlations were found. Future studies should examine specific receptive and expressive language abilities and how they may be associated with electrophysiological measures of cognitive control.

Lastly, correlations computed to assess whether the N2 and P3 measure similar inhibitory processes revealed interesting findings. N2 and P3 difference waves showed a positive correlation for the 80 GO/20 No-GO condition in all of the groups combined and in the TLD-Y group individually. Additionally, P3 difference waves and false-alarm rates showed a strong negative correlation in the 80 GO/20 No-GO condition in the SLI group. These findings appear to support a relationship between the N2 and P3 components, contrary to the lack of significant correlations for these measures in the Linguistic experiment. The current results are consistent with evidence reported by Jonkman et al. (2003) that 9 year-old children (but not adults) showed strong correlations between No-GO N2 and P3 amplitudes. Significant correlations between N2 and P3 difference waves and between false-alarms and P3 difference waves in the present study suggest that these components are at least partially driven by overlapping neural mechanisms. Further research examining the relative characteristics of the N2 and P3 is required to reconcile the discrepant findings between the Linguistic and Non-linguistic results and more generally, to clarify the specific functional interpretation of the P3.

Chapter 5

General Discussion

5.1 *Introduction*

The foundation of this study rests upon evidence that children with SLI are deficient in tasks that involve executive function (e.g., Bishop et al., 2005; Im-Bolter et al., 2006; Norbury, 2005), a set of higher-order supervisory skills involved in controlling thought and behavior. To date, investigations in this area have inadequately disentangled the numerous skills subsumed under executive function and have thus offered limited insight into the nature of SLI. The current study examined a specific domain of executive function that is included under the term *cognitive control* and explored its implications for information processing abilities in children with SLI.

5.2 *Cognitive Control*

As emphasized in the present investigation, cognitive control is especially important in tasks that involve conflict (Miller, 2000). Conflict arises when neural pathways associated with two or more incompatible representations or processes are concurrently activated. Because conflict often results in performance decrements, it is essential that conflict be detected so that control processes may be recruited. In both experimental and everyday tasks, conflict is ubiquitous. In the Eriksen flanker task (Eriksen & Eriksen, 1974), for example, a right-facing arrow that is centrally situated on a computer screen may activate the tendency to respond with the right hand while left-facing arrows surrounding the central arrow activate the tendency to execute a response with the left hand. The Stroop (1935) task requires participants to override the dominant tendency to read a word in order to perform the less habitual and therefore more difficult

task of naming the color in which the word is written. In everyday tasks, conflict may be generated by competing semantic representations of a word with multiple meanings (e.g., *repair* and *prepare* for the word *fix*, as in *Fix her a cup of coffee.*) and by environmental distractions that vie for an individual's attention, for example.

A compelling question is how does the human brain “know” when conflict is present? It has been proposed that the attentional mechanism directly monitors for conflict, a process referred to as *conflict monitoring*. Botvinick and his colleagues (e.g., Botvinick et al., 2001) advanced a two-part proposal to explain this process: 1) Specific brain systems detect conflict in information processing, particularly response competition and 2) the detection of conflict prompts adjustments in attention or control to strategically prevent conflict in subsequent performance. Empirical support for this evaluate-regulate hypothesis has been garnered from advanced neuroimaging methods (Botvinick et al., 1999; van Veen et al., 2001). In turn, the conflict monitoring hypothesis has spawned numerous investigations that have identified an electrophysiological correlate of ACC activity, the N2. These studies provided the groundwork for the current investigation, which capitalized on the N2 as an index of conflict detection in tasks that demand response override.

Traditionally, the N2 has been related to the inhibition of motor responses rather than to response conflict. Inhibition in this context refers to the internally generated, active suppression of dominant responses (e.g., Logan, 1994). The term inhibition, however, has various meanings across disciplines, including synaptic, circuit, and systems neuroscience, as well as in psychology. Commonly, the concept of inhibition is invoked as a process of exerting cognitive control over responses, emotions, memories,

and irrelevant stimuli. The wide appeal of inhibitory theories is that they can account for the classical cognitive deficits that are observed in neuropsychological patients who have experienced damage to the frontal lobes, such as the failure to inhibit distracting information and inappropriate responses.

In spite of the long history of theorizing about inhibition and the confidence of the scientific community in its purported neural basis, there are considerable challenges to the idea that an active inhibitory function engages in cognitive control. MacLeod et al. (2003) and Aron (2007) devote their arguments on inhibition theories to the notion of inhibition as applied to memory, attention, and other cognitive operations rather than to the motor sense of inhibition. The latter case of an active inhibition mechanism controlling physical responses is generally uncontested; the controversy surrounds whether this mechanism can be applied to other areas of cognition. The present study coupled the GO/No-GO task with the collection of ERPs to examine the N2 as an index of conflict detection. Indisputably, the GO/No-GO task involves both conflict and motor inhibition. Accordingly, one might ask why the current study is framed from the perspective of the conflict monitoring hypothesis rather than from inhibition accounts. The following section considers both accounts and the relative suitability of each one to the design and results of the current study.

5.3 Inhibition Versus Conflict Monitoring

It would be misleading to pit inhibition accounts against the conflict monitoring hypothesis in explaining GO/No-GO performance without mentioning that these approaches are not mutually exclusive. In fact, the conflict monitoring hypothesis

postulates both inhibition and conflict detection as mechanisms implicated in cognitive control (Botvinick et al., 2001). Simulation studies by Botvinick and his colleagues modeled conflict as the “simultaneous activation of mutually inhibiting units.” When incompatible units are concurrently activated in this model, the activity in the inhibitory group peaks higher than the activity in compatible units. Conflict detection could be accomplished by merely monitoring the level of inhibitory activity. Links between inhibitory units and a central structure that monitors conflict, the ACC, could enable conflict detection. This neural network model needs to be tested empirically because model-based assumptions might be erroneous. Moreover, inhibition of this type might apply to motor responses but not to other areas of cognition, such as the suppression of semantic representations. Importantly, though, neural inhibition is not theoretically incongruous with the conflict monitoring hypothesis. The debate between inhibition accounts and the conflict monitoring hypothesis is thus an issue of which one can better account for GO/No-GO performance. The recurrent theme here is that inhibition of dominant GO responses does not sufficiently explain the present findings. More sophisticated models might be developed in the future to incorporate both inhibition and conflict monitoring into a theory of cognitive control.

One general problem with invoking the notion of inhibitory mechanisms in cognitive psychology (as contrasted with the neural sciences) is that inhibition has historically been inferred through observation of overt behavior. Investigators commonly describe a negative deviation from baseline as evidence of inhibition although such a performance decrement is merely evidence of a cost. It is possible that the cost is due to interference caused by irrelevant information, which might implicate inhibition

processes, but this is only an inference. Ascribing interference effects to inhibition and then defining inhibition as interference in behavioral performance is a circularity problem (MacLeod et al., 2003). This reason stands behind the avoidance of terms such as *inhibitory effects* or *inhibitory deficits* in describing GO/No-GO behavioral performance in this study.

The problem with citing inhibitory accounts in describing electrophysiological effects extends beyond the issue of accurate terminology. There is neuroimaging evidence supporting and refuting the role of inhibition in GO/No-GO performance. Evidence supporting inhibition accounts has been derived from neuroscientific studies that revealed a specific No-GO potential in lateral frontal brain areas of monkeys (Sasaki, Gemba, & Tsujimoto, 1989). The magnetic counterpart of this potential has been found in the dorsolateral frontal cortex of man (Sasaki, Gemba, Nambu, & Matsuzaki, 1993). Strong ERP evidence that the N2 reflects response inhibition is the sensitivity of the No-GO N2 to speed pressure (Jodo et al., 1992). Further support for the inhibition hypothesis is that the N2 is enhanced for No-GO stimuli when GO and No-GO trials are equiprobable (Eimer, 1993), thus ruling out stimulus frequency as the sole basis for the effect. In the current study, though, this was not consistently found in typically developing children. In some cases, a GO > No-GO N2 effect was observed or N2 responses to both stimulus types were identical.

Additional support for the inhibition hypothesis stems from observed correlations between the size of the N2 and a behavioral measure of inhibition efficiency (van Boxtel et al., 2001). Specifically, an inverse relationship between N2 amplitude and false-alarms has been reported (Falkenstein et al., 1999). In the present study, the TLD-A group alone

showed a moderate negative correlation between N2 difference waves and false-alarm rates in the baseline condition of the Linguistic experiment. The lack of correlations between these measures in the other conditions and in the SLI and TLD-Y groups questions the notion that the N2 reflects response inhibition. On the surface, Falkenstein et al.'s finding that good inhibitors demonstrated larger N2 responses suggests that good behavioral performance is correlated with a large degree of response conflict. This is counterintuitive and poses as a problem for the conflict monitoring hypothesis. Nieuwenhuis and his colleagues (2003) explained that given the correlational basis of this finding, an additional variable may underlie the association between N2 amplitude and false-alarms. For example, the ability to monitor efficiently may have increased the N2 signal and decreased false-alarms, represented by a negative correlation between these measures.

If the N2 effect represents response inhibition, lateral frontal brain areas would be expected to comprise the scalp distribution of the effect (Band & van Boxtel, 1999). Localization studies, though, have indicated that the topographical distribution of the N2 effect is consistent with a dipole source in the region of the ACC, which is responsible for conflict monitoring (Nieuwenhuis et al., 2003). Furthermore, inverse dipole modeling has revealed that the N2 is co-localized in the ACC with a component that manifests response conflict on error trials, the ERN (Carter et al., 1998; Nieuwenhuis et al., 2003). As noted earlier, the ERN is a negative deflection with a fronto-central scalp distribution (Dehaene et al., 1994; Falkenstein et al., 1991) and it peaks 50-150 ms following the commission of an error or the omission of a correct response (Scheffers et al., 1996). The common source of the N2 and ERN in the ACC thus furthers the proposal that the N2

reflects the evaluative function of cognitive control. In the current study, the N2 effect was most robust at frontal sites and was also present at fronto-central electrodes, consistent with the conflict monitoring hypothesis. Due to the low spatial resolution of ERP data, though, the source of cognitive control generators could not be identified. To explore whether an ERN occurred and to compare its features with those of the N2, response-locked averages were examined. Statistical analyses of these averages could not be performed for two reasons. Firstly, the averages comprised a low number of trials due to the low commission and omission error rates, resulting in a poor signal to noise ratio. Secondly, the N2 response, which occurred relatively late, overlapped with the behavioral response, thereby precluding observation of the ERN.

Both the inhibition and conflict monitoring accounts can explain why No-GO N2 amplitude in the current study decreased as the frequency of No-GO trials increased, as previously reported (Nieuwenhuis et al., 2003). The inhibition hypothesis, however, fails to account for the enhancement of the N2 in response to rare GO stimuli, since GO trials did not require behavioral inhibition. It is possible that inhibition was required to suppress the dominant No-GO tendency on rare GO trials, but this interpretation involves cognitive forms of inhibition that rely on weak empirical evidence as compared with evidence for inhibition of planned movements on No-GO trials. The conflict monitoring hypothesis can readily explain that enhanced N2 responses to rare GO and No-GO stimuli results from the conflict generated when a low-frequency response is required. To summarize thus far, the conflict monitoring hypothesis can fully account for the current results, whereas inhibition accounts offer only a partial explanation of the N2 effects observed.

There are additional concerns that weaken the stance of inhibition accounts in cognitive control. From the perspective of computational efficiency, it seems improbable that the PFC would actively suppress numerous cortical and subcortical foci when it could more simply amplify task-relevant information (Hillyard & Anllo-Vento, 1998; Miller et al., 2001; Miller & D'Esposito, 2005). Egner and Hirsch (2005) reported an fMRI study which demonstrated that cognitive control mechanisms optimized performance in a selective attention task by amplifying cortical responses to task-relevant information in human visual cortex, rather than by inhibiting task-irrelevant features. Aron (2007), however, pointed out that these results are inconclusive because fMRI may not detect differences in hemodynamic responses in a cortical region even when a different method, such as transcranial magnetic stimulation (TMS), has identified a high level of neural inhibition in the same region.

Another reason for opposition against the concept of inhibition is that it has limited explanatory benefit when based on the effects of frontal lobe lesions on performance. The often cited analogy by Gregory (1961), adapted by Nieuwenhuis and Yeung (2005), is that if haphazard blotches of color appeared on your monitor due to a short circuit in your desktop computer, you would not assume that the damaged part typically functions as a “color inhibition” mechanism. It would be more logical to infer that the damaged mechanism was previously able to perform computations that executed meaningful patterns of color to the monitor. Likewise, damage to the PFC that is manifested by impulsivity, distractibility, and perseveration does not indicate that the PFC formerly served as an inhibition mechanism. It may be more accurate to consider the PFC the cortical region that orchestrates thought and action according to internal goals.

If the concept of inhibition that is widely applied to various forms of cognition is invalidated or at least considered insufficiently instructive, a host of psychological inhibition and interference effects reported in the literature require a substitute explanation. Working memory is one candidate that has been proposed to this end. Using executive function tasks in a network with simulated frontal lobe damage, Kimberg and Farah (1993) demonstrated that merely weakening the associations of items held in working memory increased interference costs. Similarly, perseveration in a simple network model can result from weak working memory representations (Morton & Munakata, 2002). Accordingly, poor ability to ignore irrelevant information may be partially rooted in difficulty maintaining task instructions in working memory. Thus, specific results that have been interpreted according to inhibition accounts can also be interpreted without invoking the concept of inhibition. MacLeod et al. (2003) provide a comprehensive review of studies citing inhibition and interference effects in the psychological literature and offer a candidate replacement for an inhibitory mechanism: “a combination of routine memory retrieval coupled with choosing between two (or more) routes when there is conflict” (p. 205). In view of this compelling evidence in favor of working memory in cognitive control, further research on the influence of working memory in tasks thought to involve inhibition is presented below.

5.4 The Relationship Between Working Memory and Inhibition

Several theories of inhibitory control underscore the importance of working memory capacity in inhibiting prepotent responses. According to one approach, which has been posited specifically for senescence (Hasher & Zacks, 1988), inefficient

inhibitory mechanisms allow task-irrelevant information to gain access to working memory. Consequently, the working memory system becomes overburdened by irrelevant information, thereby increasing vulnerability to interference and the likelihood that inappropriate responses will be executed.

Other models view working memory as a source of inhibitory control (e.g., Conway & Engle, 1996; Roberts, Hager, & Heron, 1994). To successfully inhibit a predominant response, an individual must retain in working memory the task instructions to refrain from executing a response to inappropriate, prepotent stimuli. Accordingly, Baddeley's model of working memory posits that successful execution of a task necessitates the maintenance of task-relevant information, including how to correctly respond, throughout task execution (Baddeley, 1986). Roberts et al. (1994) further suggested that inhibition might be a by-product of working memory processes that are activated and maintained. According to this view, the ability to inhibit is influenced by the degree to which a response is prepotent, the working memory requirements of the task, and the availability of working memory resources. This perspective is supported by evidence that individuals with high working memory capacity perform superiorly to individuals with low working memory capacity on tasks that seemingly require inhibitory control. Among these tasks are the negative priming task (Engle, Conway, Tuholski, & Shisler, 1995), the cocktail party phenomenon (Conway, Cowan, & Bunting, 2001), and a paired-associates task (Rosen & Engle, 1998).

The interdependence of cognitive control and memory abilities is supported by neurobiological evidence that motor tasks that presumably require executive control and memory retrieval recruit overlapping neural systems (Levy & Anderson, 2002). In view

of this interdependence, children with ADHD, a disorder characterized by poor inhibitory control, would be expected to show deficient working memory. Indeed, this has been suggested on the basis of poor performance on tasks that demand working memory, including the digit span, Tower of Hanoi, mental arithmetic, and the imitation of hand movement sequences (Kemp & Kirk, 1993; Mariani & Barkley, 1997; Pennington, Groisser, & Welsh, 1993; Pennington & Ozonoff, 1996).

Evidence of working memory engagement in tasks that require inhibitory control warrants consideration of the influence of working memory abilities on the cognitive control skills of children with SLI. This issue is of particular import in light of working memory deficits in the SLI population (Ellis Weismer et al., 1999; Gathercole et al., 1990; Marton et al., 2003; Marton et al., 2007). The measure of memory skills included in the current study was the Recalling Sentences subtest of the CELF-4, which assesses the ability to repeat sentences increasing in length and complexity. SLI children performed significantly lower than same-age typically developing and younger typically developing children matched group-wise on language abilities. Although this subtest measures immediate verbal memory rather than working memory, there is presumably considerable overlap between the mechanisms engaged in both types of memory skills. Working memory might therefore be deficient in the SLI children and this impairment would likely interact with the cognitive control abilities of this group. The finding of poor memory abilities in the SLI group is thus consistent with the attenuated N2 effects demonstrated by these children. Of note, though, the high hit rates and low false-alarm rates in all of the participant groups suggest intact ability in recalling the task instructions

in working memory. Future studies on SLI should be designed to examine both cognitive control and working memory skills, as well as the relationship between these abilities.

5.5 The Role of Attention in Cognitive Control

The brain regions implicated in cognitive control, primarily including the dorsolateral and ventromedial PFC and the ACC, comprise a network of attention referred to as the *executive network*, which is responsible for processing information or responding when some form of control is required (Posner, 1988), as in the GO/No-GO task. This invites a critical and intriguing question: What is the relationship between attention and conflict detection?

One well-recognized perspective on attention is that limitations in attention during information processing may be rooted in conflict between processing pathways (e.g., Allport, 1987; Cohen, Dunbar, & McClelland, 1990). According to this viewpoint, attention is a conflict prevention mechanism. The purpose of attention in this context is to ensure processing of task-relevant sources of information in the face of competition from other sources. Conflict is a “natural signal” that attentional control is required (Cohen, Aston-Jones, & Gilzenrat, 2004). If attention to appropriate representations, such as task rules, in the PFC is inadequate, cascading effects on conflict detection and allocation of control might ensue. Thus, attention and conflict monitoring interact. The ability to detect conflict and subsequently deploy control, however, does not require explicit intention on the part of the individual who encounters conflict. Does this mean that conflict detection is automatic rather than controlled?

The dichotomy between processing that requires attention, or controlled processing, and automatic processing is not an absolute distinction. In a review of studies on attention, Kahneman and Treisman (1984) concluded that some degree of attention is required for all processes. The automaticity of a process varies depending on the context in which the process occurs. The question here is thus, how much attention does conflict detection demand? The term *cognitive control* is perhaps misleading because *control* in the field of psychology commonly denotes processes that demand conscious effort in contrast to automatic processes (Schneider & Shiffrin, 1977). Conflict detection does not require such controlled processes as awareness or intention in participants (Botvinick et al., 2001). To adapt Egner's (2008) analogy, the current use of *control* is comparable to the self-regulating of a thermostat. This is not to say that the GO/No-GO task itself does not demand attention; clearly, attention is required to perform the task. Conflict detection and the reactive adjustment in attention or control, though, operate with some degree of automaticity.

In view of the relationship between the mechanisms implicated in attention and conflict detection, poor conflict monitoring may reflect attentional limitations. In spite of this relationship, though, there is evidence that the systems engaged in attention to targets and inhibition (presumably an aspect of cognitive control) may partially operate independently (Logan, 1994). This proposition is supported by the finding that young children develop proficiency in detecting GO stimuli prior to developing proficiency in inhibiting responses to No-GO stimuli (Fiducia & O'Leary, 1990; Williams, Ponesse, Schachar, & Logan, 1999). Consistent with this notion, a series of studies by Tipper et al. (1989) suggested similar attentional mechanisms in second graders and adults but

relatively immature inhibitory mechanisms in the second graders. Nonetheless, the potential role of attentional deficits as either a causal or correlational variable implicated in cognitive control warrants consideration. Poor conflict monitoring, as reflected by attenuated N2 effects in children with SLI, may reflect deficient attention. This possibility is buttressed by evidence of attentional deficits in the SLI population (Hallahan et al., 1980; Krupski, 1986; Nichols et al., 1995; Noterdaeme et al., 2001; Shafer et al., 2005; Shafer et al., 2007). Notably, though, the N1 and P2 exogenous components that signal early attention to stimulus features were not deviant in the SLI group. It may be that the attentional deficits in SLI emerge at later stages of processing, once multiple stimulus or response representations are activated.

The relative influence of attention and cognitive control on behavior is difficult to disentangle. Poor behavioral performance might be due to insufficient selective attention to appropriate information or to insufficient suppression of inappropriate information. As compared with behavioral methods, the ERP method provides a more objective approach toward identifying putative cognitive functions through analysis of neural activity. The ERP method, however, has low spatial resolution, whereas fMRI is better suited for determining which PFC subregions are responsible for specific cognitive control functions. Nonetheless, even advanced neuroimaging techniques are limited in this regard because regions within the PFC are richly interconnected and the degree to which these regions can be functionally differentiated is controversial (Ridderinkhof, Wildenberg, Segalowitz, & Carter, 2004). Our knowledge of the functional relationship between attention mediated by the executive network and conflict monitoring orchestrated by the ACC thus requires further refinement. Paradigms that examine various forms of attention

and conflict detection should be employed in future behavioral and neuroscientific studies to inform our understanding of how these operations are interrelated.

5.6 The Development of Cognitive Control

A group of younger, typically developing children was included in the current study to determine if SLI children's cognitive control skills are delayed rather than deviant. The inclusion of younger children also provided developmental information about conflict detection skills across the ages of 8 to 12 years in typically developing children. Developmental data in this area is critical because the protracted development of the PFC (see Dempster et al., 1999, for a review), which houses the cognitive control system, might make functions orchestrated by this system particularly vulnerable to developmental delays. Knowledge about the normal development of cognitive control provides a benchmark by which deviant performance may be evaluated.

5.6.1 Immature Conflict Detection in SLI

Overall, the ERP results of the current study suggest that children with SLI fall along the typical developmental trajectory in acquiring cognitive control skills and are delayed in this regard. The precise amount of time by which SLI children are delayed in showing age-appropriate cognitive control N2 effects was not determined; it can only be stated that the N2 patterns of SLI children resembled those of children who were on average three years younger. The finding that SLI children are delayed in cognitive control development does not suggest that they have a selective delay in this ability. Instead, children with SLI may have generalized neurological immaturity that is evident

for any function executed by late-developing structures. Evidence of immaturity in other areas, such as auditory processing (Bishop & McArthur, 2004) and motor abilities (Bishop & Edmundson, 1987), supports this idea.

The fact that 10-12 year-old SLI children showed a maturational lag in cognitive control development does not indicate that they will catch up to their peers in demonstrating age-appropriate cognitive control N2 effects. This should be explored in future studies that are longitudinal and that include children with SLI who are above age 12.

Attenuated N2 effects in the SLI children may have been an outcome of longer, albeit statistically non-significant, RT relative to typically developing children of the same age. This idea is supported by the negative correlations between RT and N2 amplitude demonstrated by TLD-A children in all of the conditions in the Linguistic experiment, which suggests an association between the speed of processing and N2 amplitude. Investigations of motor inhibition and response execution over the lifespan, however, suggest that these abilities have different developmental trajectories (Band et al., 2000; Becker, Isaac, & Hynd, 1987; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Schachar & Logan, 1990; Williams et al., 1999). For example, the rate at which prepotent responses are inhibited in the stop-signal task increases during childhood and slows slightly during adulthood. By contrast, response execution improves over childhood but shows a marked slowing throughout adulthood. Investigations using other tasks that require motor inhibition and response execution, such as the GO/No-GO paradigm, have borne similar results (Band et al., 2000; Falkenstein, Hoormann, & Hohnsbein, 2000; Levy, 1980). Thus, while it is possible that response speed and N2

amplitude reflect overlapping brain processes, developmental research suggests that response execution and motor inhibition are dissociable.

SLI and younger typically developing children demonstrated similar immature N2 effects in response to linguistic, rare, GO stimuli relative to TLD-A children. This finding suggests that SLI children show a maturational lag in detecting conflict between competing response tendencies. The fact that SLI children did not demonstrate significantly longer RT than typically developing children of the same age refutes the notion that this finding represents a generic delay in processing speed rather than one that is specific to conflict detection. It is possible, though, that a lag in conflict detection in SLI children is exacerbated by a general processing delay.

5.6.2 Immature Conflict Detection in Younger Relative to Older Children

The finding of immature N2 responses in the younger typically developing children of this study is consistent with evidence of the protracted developmental course of executive function from early childhood until adulthood (see Zelazo & Müller, 2002, for a review). From among numerous executive function processes (e.g., selective attention, stimulus expectation, etc.), the development of response inhibition has been afforded the most attention. Most investigations of inhibition have reported poorer inhibitory skills in younger relative to older children (e.g., Ridderinkhof et al., 1999). Although many of these investigations drew conclusions from behavioral tasks with low construct validity, they are nonetheless informative insofar as performance in these studies entailed cognitive control processes.

Among children ages 5-12, younger children (approximately 5-8 years of age) have shown poorer inhibitory control than older children (Ridderinkhof et al., 1999). Whereas most developmental studies that employed inhibition paradigms concluded that younger children have reduced suppression, others have suggested that younger children are less efficient at maintaining appropriate mappings between each stimulus and response type (Ridderinkhof, van der Molen, Band, & Bashore, 1997; Bub, Masson, & Lalonde, 2006). Bub et al. (2006) applied this interpretation to the Stroop task and noted that this deficiency might be rooted in poor ability to shift attention weights from a more common, habitual task set to a less dominant, appropriate one. Although this interpretation may partially explain the current developmental findings, the high accuracy for hit rates in the younger, typically developing children in this study casts doubt on this explanation.

Developmental studies of the N2 in GO/No-GO tasks and in the Eriksen flanker task (Eriksen et al., 1979) have reported that amplitude and latency generally decrease with age (Davis et al., 2003; Johnstone et al., 2005; Jonkman et al., 2003; Jonkman, 2006; Lewis et al., 2006; Rueda et al., 2004). This is consistent with the typical developmental pattern of larger amplitudes and commonly later latencies in the ERPs of children relative to adults (Courchesne, 1983; Friedman, Putnam, & Sutton, 1989; Holcomb, Coffey, & Neville, 1992; Howard & Polich, 1985; Segalowitz, Unsal, & Dywan, 1992). The biological factors that presumably underlie these developmental differences include greater thickness of cortical tissue, high synaptic density, and incomplete myelination in children (Huttenlocher, 1990; Luria, 1973; Sowell, Thompson, Holmes, Batth, Jernigan, & Toga, 1999). The lower signal to noise ratio of responses and higher resting activity in

children have also been cited as causes for these developmental differences (Gaillard, Grandin, & Xu, 2001).

Generally, an increase in ERP amplitude is associated with greater allocation of attention to a process. As applied to the conflict monitoring account of the GO/No-GO N2, the decrease in N2 amplitude with age may signify that older children and adults require less attention to conflict to respond appropriately. It is also possible that stronger stimulus and response representations in older individuals result in less overlap among competing processing pathways and therefore less conflict. According to this interpretation, the similar overall GO/No-GO N2 amplitude between the typically developing 8-10 and 10-12 year-olds suggests that both groups dedicated a similar degree of attention to the task. Nevertheless, the younger children were less proficient at conflict monitoring, as indicated by the absence or attenuation of N2 effects.

The developmental differences between the 8-10 and 10-12 year-old typically developing children indicate that conflict monitoring is not yet stable until at least age 10. This is consistent with behavioral evidence from a flanker task used to assess response conflict monitoring, which demonstrated that children's conflict scores reached adult levels by age 10 (Ridderinkhof et al., 1997). Rueda et al. (2004) reported that conflict scores were already stable after age 7, a finding that contrasts with the current results. Evidence of stability in conflict paradigms by age 10 or earlier supports the involvement of conflict monitoring beyond response inhibition in these tasks. If response inhibition were the primary ability involved, mature performance would not be evident by age 10 because the neural network engaged in response inhibition does not mature until late adolescence (Bunge et al., 2002; Kanemura, Aihara, Aoki, Araki, & Nakazawa, 2003;

Sowell et al., 1999). These developmental differences between conflict monitoring and inhibition may arise because conflict monitoring is contingent on distinct brain structures, particularly the ACC, whereas response inhibition requires the engagement of and communication between areas of a complex frontal-parietal network, as demonstrated by source localization studies of adults (Garavan, Ross, & Stein, 1999; Watanabe et al., 2002).

No topographic developmental differences were anticipated considering the narrow age range of the children included in this study. Previous investigations of the GO/No-GO N2 found medial negativity that was largest at fronto-central sites along with posterior activation above medial parietal cortex in 9-10 year-old children (Jonkman, 2006). Ciesielski et al. (2004) observed posterior but no frontal GO/No-GO N2 effects in 6-12 year-old children. In the current study, a similar frontal and fronto-central, but not parietal, scalp distribution for N2 effects was demonstrated by 8-12 year-old children. The disparate results among these studies may be attributable to the degree of executive control required across studies. In tasks that demanded a relatively high degree of executive control, posterior areas may have been recruited to supplement available resources and thereby maintain appropriate performance (Jonkman, 2006).

To summarize, the current developmental results suggest that children with SLI lag in the acquisition of conflict monitoring skills and demonstrate qualitatively similar N2 effects as typically developing children of the same age. In addition, the findings suggest maturational growth in conflict monitoring skills over the age range of 8-12 years in typically developing children. This proposal is in accordance with neurobiological

evidence of protracted development of the PFC, which contains the ACC responsible for conflict monitoring.

5.7 Cognitive Control in Relation to Other Deficits in SLI

By providing evidence of deficient conflict detection in children with SLI, this study complements numerous others in demonstrating that the SLI population is impaired in a general cognitive skill that is not specific to language abilities (see Leonard, 1998, for a review). The current results will now be considered in relation to several common characteristics of SLI to explain how knowledge about conflict monitoring skills can inform our understanding of this disorder.

A number of deficits in SLI are amenable to the proposal that SLI is characterized by poor cognitive control, hereafter referred to as the *cognitive control hypothesis*. This notion does not claim that poor conflict monitoring is the core deficit in SLI, but that it may explain a considerable amount of extant evidence on this population. Of chief importance is the potential association between the language deficits in SLI and deficient cognitive control. The deficits in SLI are commonly subdivided into production difficulties and production plus comprehension difficulties. This division is artificial and children classified as exhibiting production deficits only may have comprehension difficulties that are not detected by the standardized tests used for classification. Nonetheless, production problems are recognized as more prevalent in SLI. For example, school-age children with SLI demonstrate word-finding problems (e.g., German, 1987; McGregor & Leonard, 1995; Rapin & Wilson, 1978; Weiner, 1974) characterized by frequent circumlocutions, exceptionally long pauses during speech, and excessive use of ambiguous words (*that, stuff*). Studies that examined naming response times found that

children with SLI performed more slowly than same-age controls and that their responses differed according to how stimuli were presented in a manner similar to controls. No evidence pointed to problems in retrieval as the basis for word-finding problems (see Leonard, 1998, for a review). It is possible that children with SLI exhibit delayed speed of word retrieval due to conflict among words that are associated in memory. Whether the relationship among the words is semantic, phonological, or grammatical, activation of more than one lexical candidate might engender conflict. Inadequate detection of this conflict would likely hamper conflict resolution, thereby delaying word retrieval.

It does not seem that poor conflict monitoring could account for other common production deficits in SLI, most notably, poor morphosyntax (Leonard, 1998), which seems disproportionately impaired. Late lexical acquisition, limitations in verb production, and phonological deficits are also not readily explicable by the cognitive control hypothesis. This does not pose as a challenge to the current proposal because the cognitive control hypothesis does not preclude the concomitance of poor conflict monitoring and unrelated problems.

Comprehension deficits in SLI might be due in part to poor detection of multiple sources of interference. In reading, for example, inadequate detection of conflict among semantic representations of a polysemous word might result in adopting the inappropriate meaning of the word. Consequently, a misleading text representation might be formed, leading to impaired comprehension. There are numerous other sources of text-based interference that might generate cognitive conflict and therefore pose as problematic in children with SLI. Irrelevant background information or inappropriate interpretations of figurative expressions are examples. In addition, texts that refer to two or more related

topics in succession might invoke conflict. When more than one character is mentioned, anaphors that are vague or less explicit, such as *he* rather than a proper noun, might present conflict that impairs reading comprehension. These sources of conflict might be generated in discourse as well. Even if children with SLI ultimately adopt appropriate representations, processing might be slowed as conflict is detected and resolved. In an incremental task such as reading or discourse, adverse cumulative effects are probable.

The relationship between comprehension and the ability to detect and resolve on-line interference is supported by evidence that good comprehenders show more resistance to textual interference as compared with poor comprehenders (see Dempster et al., 1999, for a review). Poor readers commonly read more slowly when presented with irrelevant information, whereas good readers read at the same pace with and without distraction (Willows, 1974). Furthermore, evidence of an association between poor language processing and poor inhibition suggests that comprehension deficits in SLI may be related to executive control processes, such as conflict monitoring.

Considering the abundant possible sources of conflict during reading and discourse, future research should examine whether children with SLI show poor conflict detection during these tasks. This is one way by which the broad and poorly defined information processing deficits in SLI might be illuminated.

Deficient conflict detection also offers an attractive explanation for working memory problems in SLI. If competition among sources of information in working memory is not detected adequately and in a timely manner, irrelevant information that should be eliminated may overburden the working memory system, causing it to function less efficiently. The cognitive control hypothesis can also explain the interference and

inhibition effects exhibited by children with SLI during processing of verbal (Bishop et al., 2005; Ellis Weismer et al., 1999; Lorschach et al., 1996; Marton & Schwartz, 2003; Norbury, 2005) and non-verbal (Bishop et al., 2005; Im-Bolter et al., 2006) material as an outcome of poor conflict detection.

In summary, the cognitive control hypothesis provides an appealing account of specific linguistic and general cognitive deficits in SLI. Future studies should focus on probing the potential associations between conflict monitoring and language abilities in this population. One possibility is that delayed acquisition of cognitive control skills predisposes the SLI child to language deficits that may or may not resolve once the cognitive control system matures. Alternatively, cognitive control immaturity and language deficits may bear a non-causal relationship, both being distinct manifestations of a neurodevelopmental disorder rooted in one or multiple causes.

5.8 Evidence for SLI as a Domain-General Disorder

Although there are conflicting theories on the nature of SLI, there is a general consensus that SLI arises from a genetic deficit (Bishop, 1997b; Bishop, North, & Donlan, 1995; Leonard, 1998). Whereas early theories reserved the term SLI for children thought to exhibit language deficits only, more current research indicates that SLI is not exclusive to language deficits. This corresponds with the domain-general perspective of development, which claims that because genes do not target particular mechanisms, neural mechanisms are not specific to any function in the process of development (Elman et al., 1996). Specialized cognitive systems evolve over development and vary based on environmental interactions. Accordingly, a genetic impairment that affects basic

cognitive abilities would likely give rise to a range of subtle deficits, not to impairment of one discrete ability (Karmiloff-Smith, 1998).

If SLI stems from a general cognitive impairment, IQ scores in this population might be expected to fall below those of typically developing children. Indeed, SLI children in the current study demonstrated significantly lower IQ scores on the TONI-3 than same-age typically developing children. This finding has been found in other studies as well (e.g., Montgomery & Evans, 2009). Many researchers, though, note the equivalence of group means in non-verbal intelligence as evidence that group differences in the independent variable are not merely a reflection of differences in intellectual capacity. The lack of group differences in non-verbal intelligence in some of these investigations, however, may be due to the following. Conventionally, a criterion in the diagnosis of SLI is a within-average score on a standardized test of non-verbal intelligence. The average range is commonly identified as within one standard deviation (*SD*) from the mean (i.e., 85-115 on a test with a mean of 100 and a *SD* of 15). Notably, though, Tomblin and Zhang (1999) reported that children with IQ scores above 85 and those with IQ scores ranging from 75 to 85 show highly similar language abilities. The cutoff of 85 may therefore be inappropriately excluding children who qualify for the diagnosis of SLI. It is possible that if a slightly lower cutoff score were used, children with SLI would commonly demonstrate significantly lower IQ scores than age-matched typically developing children.

Because SLI is regarded here as a domain-general impairment that affects linguistic and non-linguistic abilities, SLI children were expected to demonstrate poor conflict detection in processing both linguistic and non-linguistic stimuli. The finding that

SLI children exhibited deficient cognitive control in the Linguistic but not the Non-linguistic experiment is surprising. If cognitive control is a general cognitive ability, why would it be impaired in a task that involves linguistic stimuli and intact in a task that involves non-linguistic stimuli? It is possible that in the Linguistic experiment, the time-sensitive nature of accessing the semantic representations of the picture stimuli combined with the task of detecting conflict between competing response options hindered successful conflict detection. Alternatively, the lack of group differences in the Non-linguistic experiment may indicate that this task was not sufficiently sensitive to detect deficient conflict monitoring. Another plausible explanation is that different levels of task difficulty may have resulted in the discrepant findings between the experiments. During debriefing, many participants noted that the Non-linguistic experiment was more difficult than the Linguistic experiment. One possible reason why the Non-linguistic task might have been more difficult than the Linguistic task is because the geometric shapes in the Non-linguistic experiment bore greater overlap in stimulus features than the pictures in the Linguistic experiment. As a result, conflict detection might have been more difficult in the Non-linguistic experiment.

Although conflict monitoring is a general cognitive operation, it is unclear if the ACC is a domain-general conflict detector that recruits domain-general control, as posited by the conflict monitoring hypothesis. In this sense, a domain-general conflict-control loop means that the ACC does not indicate the source or nature of the conflict and control that is recruited by biasing information processing is quantitative rather than qualitative. This is a significant issue because it speaks to whether control that is triggered by one type of conflict leads to the resolution of another type of conflict. For

example, if conflict between multiple semantic representations of a polysemous word is detected, will the ensuing recruitment of control generalize to subsequent conflict that is not semantic in nature? Egner (2008) reviewed the literature on this subject and concluded that control driven by conflict is domain-specific. This conclusion is supported by recent neuroimaging evidence of anatomically distinct and specialized mechanisms for resolving different types of conflict (Egner, Delano, & Hirsch, 2007; Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). Even if neural circuits for conflict resolution are dissociable, this does not guarantee that there are local conflict detectors for various types of conflict, as opposed to one global, domain-general conflict detector. If control is mediated by multiple conflict-control loops, discrepancies in the proficiency of conflict monitoring across tasks would be unsurprising. This perspective is compatible with the current results of SLI children's deficient conflict detection in the Linguistic but not the Non-linguistic experiment.

5.9 Clinical Implications

The overarching objective of the current investigation was to elucidate information processing deficits in the SLI population. These deficits are ill-defined and only limited information is known about their associated cognitive mechanisms. Consequently, our knowledge of how to provide effective therapeutic intervention to children with SLI who process information poorly remains lacking. To address this limitation, the present study examined whether conflict detection adversely affects information processing in SLI. The following section considers the implications of deficient conflict detection in SLI.

The practical significance of conflict detection is perhaps best understood by examining performance decrements that incur as a result of conflict. This issue was addressed earlier in a discussion of interference effects that may be induced by conflicting information during reading and discourse. Competing information is activated in numerous everyday tasks, thereby engendering conflict, and poor information processing in SLI may result from inappropriate detection of this conflict. Delayed conflict detection in SLI relative to typically developing children, which was observed in one condition of the Linguistic experiment, may account for the well documented generalized slowing in SLI (Kail, 1994; Miller et al., 2001; Windsor et al., 1999).

The inability of the GO/No-GO task to behaviorally differentiate the cognitive control skills of SLI and typically developing children suggests that behavioral methods may not be adequately sensitive to detect deficient cognitive control. Likewise, current standardized tests that include measures of inhibition, such as the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1998; Manly et al., 2001), may not have sufficient sensitivity to identify impaired inhibition. If a deficit in cognitive control cannot be measured in a clinical setting, how could it be the target of intervention? This question is not intended to imply that deficient cognitive control is not manifested behaviorally; it is rather that behavioral measures may not be capable of unraveling cognitive control from the broader construct of executive function. For example, poor ability to select the appropriate definition of an ambiguous word with multiple meanings may be due to deficits in one or more of the following areas: vocabulary knowledge, attention to context that is expected to bias the response, detection of conflict among competing semantic representations, or implementation of control over inappropriate

responses. Thus, it might be difficult to isolate cognitive control from other abilities. Intervention programs aimed at increasing executive control skills might yield improvement in conflict detection and should be the target of clinical studies.

Considering that the GO/No-GO N2 differentiated SLI from typically developing children, this electrophysiological response may be a useful diagnostic marker for SLI. The viability of this measure for diagnostic purposes is partially dependent on the specificity of deficient cognitive control to the SLI population. Poor cognitive control is not at all specific to SLI; it is deviant in a wide range of clinical populations (Casey, 2005). Children with ADHD, for example, show impulsivity and distractibility (Barkley, 1997). Obsessive-compulsive disorder is characterized by poor ability to stop ritualistic behaviors and to eliminate intrusive thoughts (Insel, 1988). Individuals with childhood-onset schizophrenia are apparently deficient in ignoring irrelevant information and thoughts (Asarnow, Brown, & Strandburg, 1995). The stereotypical behaviors and ruminations manifested in autism are yet another example of cognitive control deficits in a developmental disorder. Although particular areas of cognitive control differ across these populations, they presumably all share deficits in some aspect of the network engaged in cognitive control. Therefore, it seems probable that children from at least some of these populations would show deficient GO/No-GO N2 responses similar to those of SLI children. Indeed, this has been observed, but inconsistently. Several studies found smaller N2 amplitudes in ADHD children than in controls (Pliszka et al., 2000; Satterfield, Schell, & Nicholas, 1994). Smith, Johnstone, and Barry (2004), however, reported a larger No-GO than GO N2 effect in the right frontal region in ADHD relative to control children. In contrast to these findings, several studies revealed similar No-GO

N2 responses in ADHD and control children between the ages of 7-14 (Banaschewski, Brandeis, Heinrich, Albrecht, Brunner, & Rothenberger, 2004; Fallgatter et al., 2004; Spronk, Jonkman, & Kemner, 2008; Wiersema et al., 2006).

The pervasiveness of cognitive control deficits across developmental disorders does not preclude use of the N2 in the diagnosis of SLI. If future research succeeds in identifying specific features (i.e., in amplitude, latency, and topography) of the GO/No-GO N2 that are consistently exhibited by children with SLI, this ERP response would bear promise as a clinical tool. Furthermore, ERP evidence of deficient cognitive control may serve as a biological marker that could be used alongside behavioral measures to accurately diagnose SLI and to distinguish it from other developmental disorders. To this end, the GO/No-GO paradigm of the current study should be used to assess other childhood populations such as ADHD, autism, and children diagnosed with various learning disabilities.

5.10 *Future Directions*

The present study has laid the groundwork for a thorough investigation into the cognitive control skills of children with SLI. Systematic examination of the effects of deficient conflict detection on the specific language and non-language abilities in both SLI and typically developing children is needed. Because conflict detection is presumably a prerequisite for conflict resolution, evidence of deficient conflict detection in SLI provides the impetus to examine how the control end of the conflict-control loop operates. Future investigations in this area should capitalize on the wealth of fine-grained information provided by the collection of ERPs. The benefit of employing ERPs in the

assessment of cognitive control was demonstrated in the current study by the ability of this method to distinguish the conflict detection skills of SLI and typically developing children, whereas behavioral measures were relatively uninformative in this regard. Future research should focus on refining behavioral paradigms so that they are more sensitive in detecting disordered cognitive control. By converging behavioral and electrophysiological methods, our knowledge of how each method contributes to the assessment of developmental disorders may be enhanced.

As noted above, the potential for the GO/No-GO N2 to be used as a diagnostic marker requires adaptation of the current paradigm to other clinical populations that are sometimes difficult to distinguish from SLI, including children who are broadly classified as learning disabled. This line of research should also include well-matched control groups from various sectors of the normally developing population. This might help determine whether deficient cognitive control in SLI children is a qualitatively discernible pathological characteristic or whether it represents an extreme condition within the normal distribution of cognitive control skills in typically developing children.

There are several limitations in the current study that should be addressed in future research. Because the small sample size of the SLI group may have reduced statistical power, follow-up studies should include a greater number of SLI participants. Matching SLI and typically developing children on non-verbal intelligence should be considered, although restricting participant selection according to this criterion may result in a group that is not representative of the SLI population at large.

Source analysis should be conducted in future studies to determine if the observed N2 effects are generated by the ACC. The evaluative nature of the process reflected by

the N2 could be confirmed by co-localizing the N2 with the ERN, which reflects assessment of performance. To this end, it is necessary to design paradigms that evoke N2 responses that do not overlap in time with behavioral responses so that the post-response ERN is more easily measurable. The relatively complex nature of the linguistic and non-linguistic stimuli in the current study, as compared with those of typical GO/No-GO paradigms, elicited late N2 responses that overlapped with behavioral responses, thus making examination of the ERN more difficult.

To conclude, the current evidence of deficient conflict monitoring in SLI has opened a new avenue of research that may shed light on the complexities of this disorder. Considering the ubiquity of conflict in everyday tasks, poor detection of conflict may pervade information processing in SLI and should therefore undergo further research using advanced behavioral and electrophysiological methods.

Appendix A

Table A1. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores (CFD, WC-R, RS, FS, and WC-E: mean (*M*) = 10; standard deviation (*SD*) = 3; RLS, ELS, CLS, PPVT-III/4, and TONI-3: *M* = 100; *SD* = 15) for participants with typical language development matched on group mean age (TLD-A) with children with specific language impairment (SLI).

Participant #	Gender	Age	CFD	WC-R	RLS	RS	FS	WC-E	ELS	CLS	PPVT-III/4	TONI-3
A1	M	10.3	13	11	113	10	9	12	101	106	98	105
A2	M	10.10	8	6	83	12	13	9	142	99	112	117
A3	F	10.2	14	12	113	12	13	12	117	117	105	97
A4	F	12.4	8	11	96	11	13	13	114	106	103	95
A5	M	10.1	12	12	113	14	13	13	120	119	111	123
A6	F	11.10	13	13	119	12	15	15	124	126	107	135
A7	F	12.5	8	12	98	16	13	N/A	118	108	111	95
A8	M	12.6	10	13	103	14	13	12	118	121	174	119
A9	M	10.10	10	9	104	11	9	N/A	100	102	101	115
A10	M	11.0	10	12	105	11	12	16	118	111	97	95
A11	F	10.4	11	11	105	7	14	16	114	109	110	105
A12	F	11.9	9	16	116	13	15	16	128	120	123	98
A13	F	10.6	11	10	102	12	11	13	112	109	96	97
A14	F	11.2	12	9	102	11	13	11	110	109	99	110
A15	F	11.2	11	9	102	10	12	12	108	104	86	102
A16	M	10.2	10	10	99	7	13	10	99	99	98	115
A17	M	10.9	11	13	113	10	15	15	120	115	116	142
A18	F	12.6	11	10	102	11	13	13	114	111	89	101
A19	M	10.1	13	12	103	12	13	N/A	112	114	141	100
A20	M	10.11	11	11	105	8	14	11	105	108	102	104
A21	M	12.8	9	12	102	12	13	13	116	111	108	93
A22	F	11.6	11	12	109	15	12	15	124	118	114	117
<i>M</i>		11.17	10.73	11.18	104.86	11.41	12.77	13	115.18	111	109.14	108.18
<i>SD</i>		.89	1.70	1.99	7.85	2.28	1.57	2.05	9.79	7.16	18.63	13.37

Note: Receptive language subtests of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4): CFD = Concepts and Following Directions; WC-R = Word Classes-Receptive; RLS = Receptive Language Score; Expressive language subtests of the CELF-4: RS = Recalling Sentences; FS = Formulated Sentences; WC-E = Word Classes-Expressive; ELS = Expressive Language Score; CLS = Composite Language Score; PPVT-III/4 = Peabody Picture Vocabulary Test-Third/Fourth Edition; TONI-3 = Test of Nonverbal Intelligence-Third Edition.

N/A = Not applicable because participant was tested at a younger age at which this subtest is not administered.

Table A2. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores (CFD, WC-R, RS, FS, and WC-E: mean (*M*) = 10; standard deviation (*SD*) = 3; RLS, ELS, CLS, PPVT-III/4, and TONI-3: *M* = 100; *SD* = 15) for participants with specific language impairment (SLI).

Participant #	Gender	Age	CFD	WC-R	RLS	RS	FS	WC-E	ELS	CLS	PPVT-III/4	TONI-3
S1	M	10.4	4	7	76	7	1	7	71	69	89	98
S2	M	12.3	9	8	90	6	5	8	80	82	81	85
S3	M	12.0	2	4	61	3	1	4	55	52	80	95
S4	F	12.11	5	9	83	8	6	8	85	81	91	85
S5	F	12.2	3	6	70	3	10	9	85	75	95	98
S6	M	11.7	7	6	81	5	6	10	83	79	98	93
S7	F	12.11	5	5	73	9	3	8	80	75	78	93
S8	M	10.8	7	8	85	5	5	8	75	75	94	95
S9	M	12.1	7	9	94	7	5	N/A	75	78	87	91
S10	M	11.9	9	8	86	9	4	N/A	87	88	92	108
S11	F	10.4	3	4	79	6	12	6	89	79	72	93
S12	F	10.0	3	8	76	13	7	7	95	85	77	98
<i>M</i>		11.58	5.33	6.83	79.5	6.75	5.42	7.5	80	76.5	86.17	93.17
<i>SD</i>		1.01	2.42	1.80	9.08	2.80	3.23	1.65	10.31	9.21	8.32	6.71

Note: Receptive language subtests of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4): CFD = Concepts and Following Directions; WC-R = Word Classes-Receptive; RLS = Receptive Language Score; Expressive language subtests of the CELF-4: RS = Recalling Sentences; FS = Formulated Sentences; WC-E = Word Classes-Expressive; ELS = Expressive Language Score; CLS = Composite Language Score; PPVT-III/4 = Peabody Picture Vocabulary Test-Third/Fourth Edition; TONI-3 = Test of Nonverbal Intelligence-Third Edition.

N/A = Not applicable because participant was tested at a younger age at which this subtest is not administered.

Table A3. Gender; age; and language, vocabulary, and non-verbal intelligence standardized test scores (CFD, WC-R, RS, FS, and WC-E: mean (*M*) = 10; standard deviation (*SD*) = 3; RLS, ELS, CLS, PPVT-III/4, and TONI-3: *M* = 100; *SD* = 15) for 8-10 year-old participants with typical language development (TLD-Y) matched on group mean composite language scores and non-verbal intelligence with TLD-A children.

Participant #	Gender	Age	CFD	WC-R	RLS	RS	FS	WC-E	ELS	CLS	PPVT-III/4	TONI-3
Y1	F	9.9	12	12	113	9	11	14	108	108	103	107
Y2	F	8.3	8	12	96	14	9	N/A	101	98	95	92
Y3	F	9.2	9	10	96	11	4	11	93	91	99	111
Y4	F	9.4	10	14	115	16	7	N/A	118	109	109	99
Y5	M	8.10	4	11	85	8	13	13	108	96	114	85
Y6	F	8.4	7	9	88	11	12	11	108	99	107	97
Y7	F	8.3	10	19	137	12	12	N/A	105	104	106	99
Y8	F	8.4	11	12	101	9	15	N/A	116	114	100	90
Y9	M	8.0	11	14	117	10	9	N/A	103	104	139	105
Y10	M	9.9	13	17	131	13	12	17	124	123	129	118
Y11	F	8.2	15	13	119	13	13	N/A	118	121	105	104
Y12	F	8.10	13	13	117	16	9	N/A	116	100	110	110
Y13	M	8.4	12	12	110	13	17	N/A	122	120	114	122
Y14	M	8.3	12	12	115	9	14	N/A	108	124	128	83
Y15	F	8.11	13	11	110	10	8	14	95	99	98	110
Y16	M	9.4	12	10	105	13	15	16	128	120	115	118
<i>M</i>		8.74	10.75	12.56	109.69	11.69	11.25	13.71	110.69	108.13	110.69	103.13
<i>SD</i>		.58	2.72	2.56	14.18	2.47	3.40	2.29	10.14	10.85	12.29	11.76

Note: Receptive language subtests of the Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4): CFD = Concepts and Following Directions; WC-R = Word Classes-Receptive; RLS = Receptive Language Score; Expressive language subtests of the CELF-4: RS = Recalling Sentences; FS = Formulated Sentences; WC-E = Word Classes-Expressive; ELS = Expressive Language Score; CLS = Composite Language Score; PPVT-III/4 = Peabody Picture Vocabulary Test-Third/Fourth Edition; TONI-3 = Test of Nonverbal Intelligence-Third Edition.

N/A = Not applicable because participant was tested at a younger age at which this subtest is not administered.

Appendix B

Items presented as picture stimuli in the Linguistic experiment.

Fruits and Vegetables	Items that are Worn
apple	belt
beans	bracelet
carrot	button
cherry	earrings
corn	glasses
grapes	glove
kiwi	hat
lemon	helmet
lettuce	jacket
lime	jeans
mushroom	jumper
onion	necklace
orange	scarf
peach	shirt
pear	slippers
peas	sneaker
pepper	socks
plum	sweater
pumpkin	tie
radish	watch

Appendix C

Subject #:

Parent/Guardian Consent for Child Participation in an ERP Experiment

The purpose of this information is to help you decide whether you want to volunteer your child for a research study. Please read this carefully and ask the investigator about anything you don't understand.

Title of the Study: Cognitive Control in Children with and without Specific Language Impairment

Principal Investigator: Baila Tropper

Study Location: CUNY Graduate Center, 365 5th Avenue, Room 7392.03

General Information

- The purpose of this study is to examine how the brain responds while children are presented with various types of words and pictures.
- You and your child will spend 2-2.5 hours in this study.
- During the current project period, we will include approximately 75 children in our study.

Experimental Procedure

- Your child will sit in a quiet booth. He/she will listen to words presented through speakerphones and will look at pictures presented on a computer monitor.
- There will be about 25 groups of words/pictures presented, each group lasting about 4 minutes. Your child will take a short break after about every 4 minutes.
- Your child will be asked to respond to the words and pictures by pressing a button on a response box according to the instructions provided.
- While your child listens/watches and responds, his/her brain responses will be recorded from 64 tiny electrodes in a net.
- The electrodes are soaked in a mild salt water solution.
- Each electrode is wrapped in a sponge and will rest gently on your child's scalp.
- It will take about 20 minutes to apply the electrode net to your child's head. Your child will be able to stretch his/her arms and legs before we begin the experiment and during breaks.
- This procedure is safe and there is no risk of personal injury.
- You are free to withdraw your child from the experiment at any time without incurring any penalty.

Benefits of Volunteering

- There are no immediate benefits to those who participate in the experiment. There is a potential benefit to society if the study advances our understanding of child language disorders.
- You, the parent/guardian, will be reimbursed for unspecified expenses at \$10 per hour.
- Your child will be able to choose a small toy at the end of the experiment. He/she will be given this toy regardless of his/her performance and whether or not the experiment is completed.

Risks of Volunteering

- Your child may be uncomfortable with the electrodes applied to his/her head.
- There may be water dripping from the net, which could be slightly annoying.
- **Inform the researcher** if your child seems uncomfortable or wants to stop participating.

(Continued on the back.)

Confidentiality of Your Child's Records

- Your child will be assigned a number that will be used to refer to data and other information in place of using his/her name. The ERP computer records from the experiment will be stored in a computer file that contains your child's assigned number and no other identifying information.
- Your child's records will be kept in a locked file cabinet in Dr. Richard Schwartz's locked office.
- Authorized research investigators of the United States Food and Drug Administration and the Department of Health and Human Services may audit the record keeping of this research study.
- The research staff involved in this study will also have access to your child's records.
- Results of this study may be published but will **not** include any information that can identify your child.

Volunteering

- Your child should only take part in this research if he/she wants to.
- You should only volunteer your child if you want to.
- **You or your child may stop participation in the experiment at any time, for any reason.**
- **There will be no penalty if you or your child request to stop participation.** You will be reimbursed for the amount of time that you participate in the study at \$10 per hour.
- Your child may be removed from this study at any time without your consent.

Contact Information

- If you have any questions about this research, contact the Principal Investigator, **Baila Tropper, at (212) 817-8853**, visit her at the CUNY Graduate Center in Room 7410.06, or e-mail her at **BTropper@gc.cuny.edu**. You may also call the lab director, **Dr. Valerie Shafer at (212) 817-8833** or e-mail **VShafer@gc.cuny.edu**.
- If you have any questions concerning your rights as a participant, you may call **Kay Powell, IRB Administrator, The Graduate Center, CUNY, (212) 817-7525** or e-mail **KPowell@gc.cuny.edu**.
- If you want to receive a copy of a report describing the results of this study, please write your home and/or e-mail address here: _____

Optional:

☐ I agree to be contacted by the investigators of this study in the future for inquiries about possible participation in other studies.

Consent – By signing this form you agree that:

- You have fully read this form.
- You had the opportunity to ask questions about this research and have received satisfactory answers.
- You understand that you are being asked to volunteer your child to participate in research.
- You understand the risks and benefits of this research, as described on this form.
- You freely give your consent to allow your child to participate in the procedures described above.
- You will receive a copy of this form, which is yours to keep.

Print your name

Child's name

Sign your name

Date

Investigator's name

Investigator's signature

Date

Appendix D

Subject #:

Child Assent for Participation in an ERP Experiment

Title of the Study: Cognitive Control in Children with and without Specific Language Impairment

Principal Investigator: Baila Tropper

Study Location: CUNY Graduate Center, 365 5th Avenue, Room 7392.03

Experimenter: *Read this script to the child.*

SCRIPT:

“Hi! Welcome to our lab. What I’d like to do today is find out if you want to play a game while I watch. I’m trying to find out what happens in kids’ heads when they listen to different types of words and when they see different types of pictures. To do that, I want some kids to play a game. You can’t pass or fail this game; it’s scored a different way.

This is what I want to do. While you sit in this room, I’ll play some words to you through speakerphones and show you pictures on the computer screen. At the same time, you’ll wear this net over your hair. These little round pieces on the net are called electrodes. They ‘listen’ to what goes on in your head when you hear words and when you see pictures. The net doesn’t hurt at all and it comes off easily. It’s totally safe. A watery liquid might drip from the net. That might be a little annoying. You’ll wear this cape and I’ll give you tissues to make you comfortable. I’m going to give you short breaks about every 4 minutes so that you can relax. You can stretch your arms and legs during the breaks, but if you want me to take off the net during a break, we’d have to spend about another fifteen minutes putting it back on. So, let’s try to keep the net on until the game is over.

After you hear each word, your job will be to decide if you should press the button on this answer box. You’ll do the same thing when you see pictures on the computer screen. Before we start, I’ll tell you which button to press and when you should press it.

Do you see the video monitor over there? I’m going to close the door while you’re inside the game room so that it will be nice and quiet in there. I’ll watch you and hear you through that video monitor. If you need anything, just let me know.

You’ll get to choose a small toy when you’re done participating in this game. If you decide to stop in the middle, I’ll still give you a toy. I’m going to store your answers to this game on a computer and in a locked file cabinet. Only the people who are working on this study will know who the answers belong to.

Do you have any questions that you want to ask me?

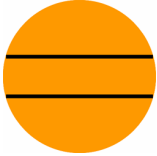
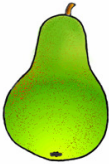
You don’t have to play this game if you don’t want to. Do you want to play this game?”

Experimenter: *Wait for child’s verbal assent. If the child assents, continue with the following.*

“If you change your mind once the game has started, you can tell me and I’ll stop the game right away. You won’t be punished in any way if you decide to stop in the middle. Are you ready?”

Appendix E

Experimental paradigm for the Linguistic and Non-linguistic experiments.

Condition	Stimulus Probability	# of Trials	Linguistic	Non-Linguistic
80 GO/ 20 No-GO	GO 80%	320		
	No-GO 20%	80		
50 GO/ 50 No-GO (Baseline)	GO 50%	200		
	No-GO 50%	200		
20 GO/ 80 No-GO	GO 20%	80		
	No-GO 80%	320		

Appendix F

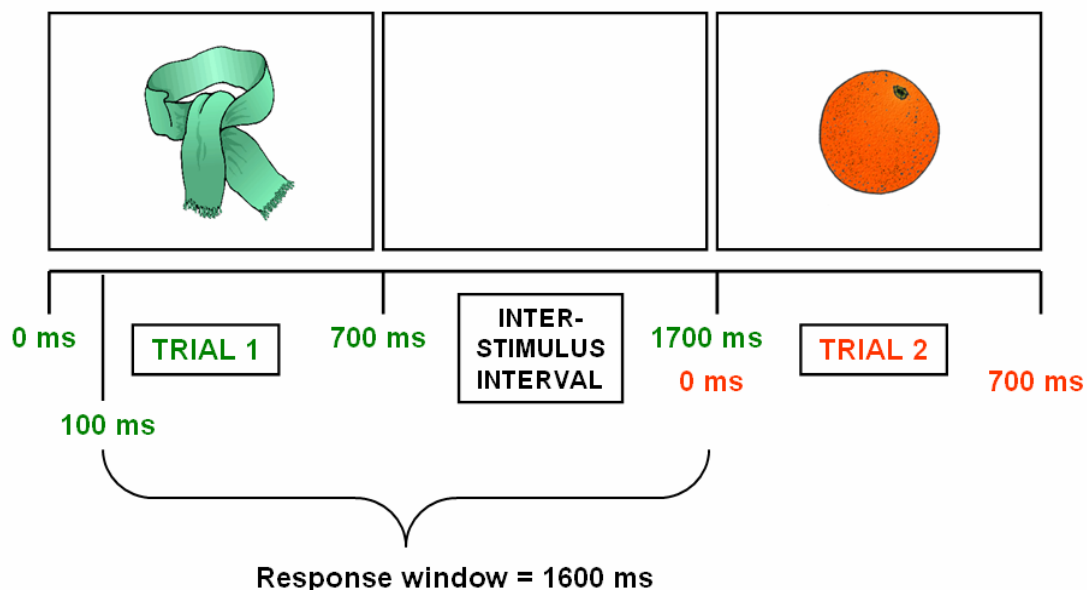


Figure F1. Diagram of experimental trial: Linguistic experiment.

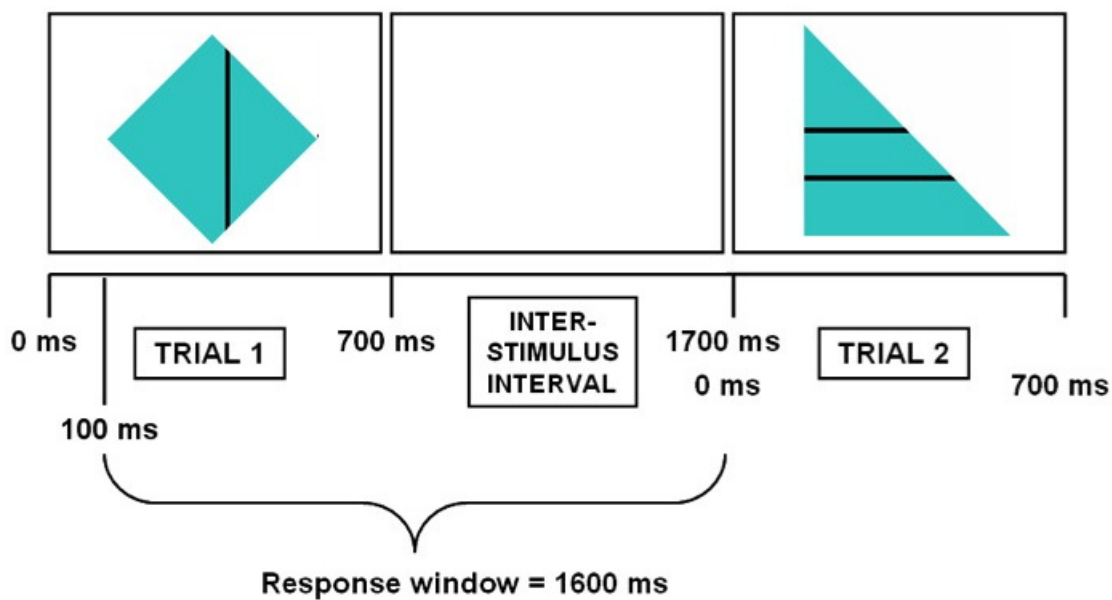


Figure F2. Diagram of experimental trial: Non-linguistic experiment.

Appendix G

Table G1. Mean reaction times of TLD-A children in each condition of the Linguistic and Non-linguistic experiments (M = mean; SD = standard deviation).

Participant #	Linguistic			Non-Linguistic		
	80/20	50/50	20/80	80/20	50/50	20/80
A1	443.06	467.51	554.84	498.38	468.77	473.78
A2	409.96	456.24	467.91	420.87	511.94	552.71
A3	438.99	493.63	549.08	462.64	518.27	603.99
A4	433.71	470.94	503.95	447.58	576.93	582.30
A5	460.72	519.63	510.53	514.73	521.32	509.96
A6	439.77	433.67	498.68	445.95	453.00	488.43
A7	415.16	459.04	504.23	401.47	459.24	496.11
A8	414.96	453.24	472.25	462.84	490.77	514.64
A9	445.39	520.66	582.53	453.68	501.32	597.84
A10	460.02	527.93	579.04	469.33	523.14	520.33
A11	360.65	421.40	463.62	440.27	448.44	521.00
A12	519.51	583.88	599.95	491.80	506.15	516.59
A13	549.42	525.82	546.67	530.78	547.14	523.94
A14	490.72	555.74	586.29	478.31	569.05	604.90
A15	459.46	506.10	533.20	512.20	535.24	606.85
A16	393.30	465.45	488.83	461.58	454.69	496.51
A17	360.11	414.19	420.79	379.87	389.12	449.39
A18	440.74	449.49	494.60	485.44	490.79	535.23
A19	402.76	435.97	485.78	395.82	451.52	550.75
A20	404.64	430.42	451.80	460.66	437.06	491.34
A21	453.43	479.36	505.90	512.95	491.25	591.49
A22	459.12	516.29	555.55	507.23	546.96	571.06
<i>M</i>	438.89	481.21	516.18	465.20	495.10	536.32
<i>SD</i>	44.89	45.62	48.19	40.84	46.67	46.84

Table G2. Mean reaction times of SLI children in each condition of the Linguistic and Non-linguistic experiments (*M* = mean; *SD* = standard deviation).

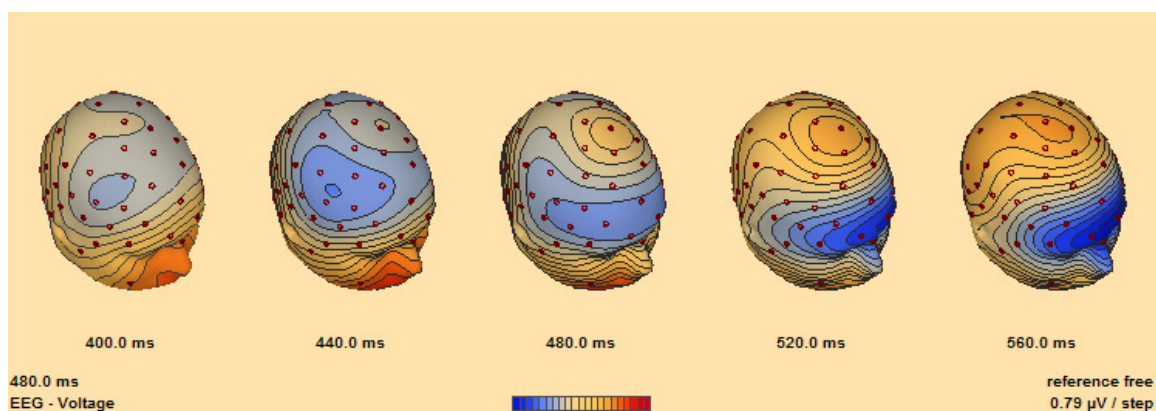
Participant #	Linguistic			Non-Linguistic		
	80/20	50/50	20/80	80/20	50/50	20/80
S1	539.33	573.65	585.35	564.26	582.46	611.78
S2	401.56	429.18	494.59	468.87	512.30	619.97
S3	399.81	493.41	564.50	391.44	447.13	526.27
S4	362.98	408.92	430.19	388.44	431.14	480.31
S5	474.66	547.60	529.30	514.71	635.92	755.10
S6	519.02	498.98	478.94	504.75	510.37	557.30
S7	431.69	452.67	468.71	478.20	521.39	536.59
S8	466.56	534.37	612.55	524.56	585.33	625.86
S9	411.49	455.07	498.53	436.89	466.97	499.44
S10	405.71	442.82	468.58	404.37	412.89	506.96
S11	514.89	516.32	576.09	522.60	499.75	598.88
S12	487.83	551.02	565.59	504.52	590.86	575.78
<i>M</i>	451.29	492.00	522.74	475.30	516.37	574.52
<i>SD</i>	56.78	53.81	57.34	57.98	70.40	75.34

Table G3. Mean reaction times of TLD-Y children in each condition of the Linguistic and Non-linguistic experiments (*M* = mean; *SD* = standard deviation).

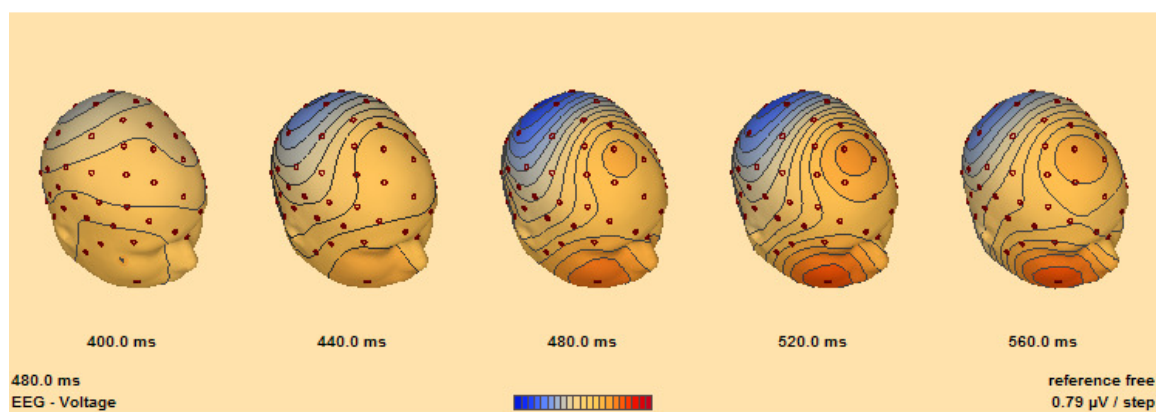
Participant #	Linguistic			Non-Linguistic		
	80/20	50/50	20/80	80/20	50/50	20/80
Y1	511.43	546.55	582.85	546.78	624.17	621.04
Y2	591.15	602.95	619.03	588.80	588.90	649.34
Y3	399.08	522.65	578.40	443.93	501.18	527.84
Y4	565.98	566.68	587.37	551.86	544.69	559.42
Y5	396.42	462.64	518.91	459.78	492.71	505.79
Y6	513.27	506.78	506.77	595.08	562.71	594.06
Y7	499.58	559.32	620.19	508.60	598.05	637.69
Y8	489.18	512.27	586.35	608.23	656.79	751.98
Y9	407.05	469.66	494.87	472.38	513.27	628.22
Y10	420.27	414.25	486.80	397.59	422.58	531.61
Y11	516.07	538.61	633.36	562.48	590.25	719.85
Y12	419.55	460.27	487.01	388.92	417.11	493.61
Y13	418.48	502.14	585.67	394.57	440.88	509.08
Y14	517.54	543.60	562.66	531.85	563.47	572.58
Y15	511.95	558.04	616.87	566.41	578.08	613.43
Y16	403.64	411.91	465.61	385.26	459.76	440.03
<i>M</i>	473.79	511.15	558.30	500.16	534.66	584.72
<i>SD</i>	63.83	54.91	55.98	79.81	73.35	83.81

Appendix H

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

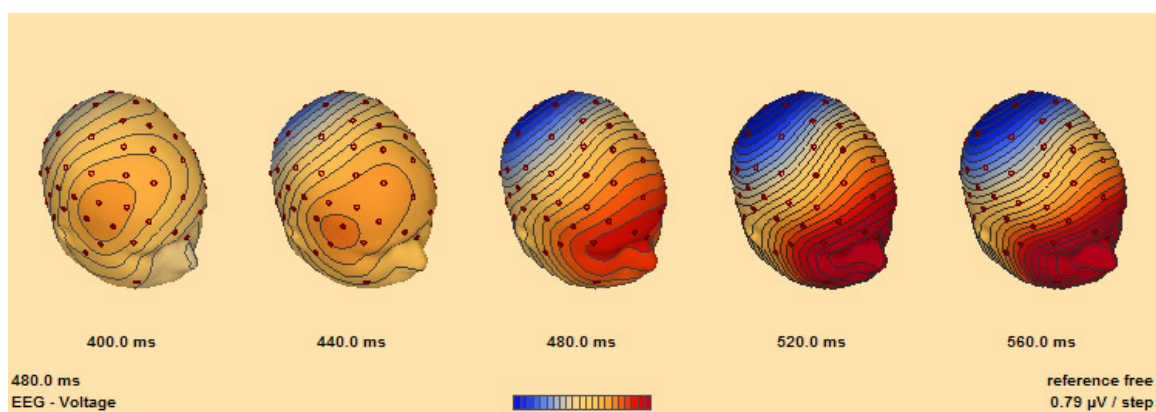
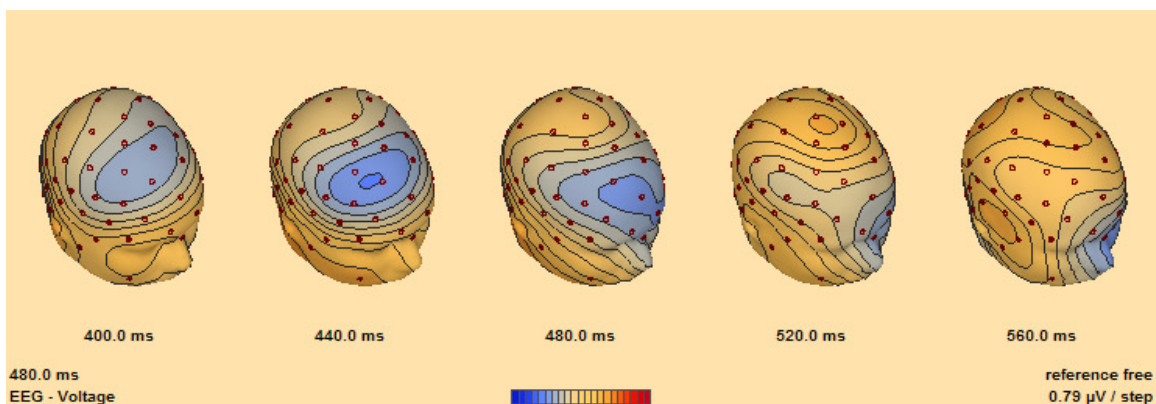
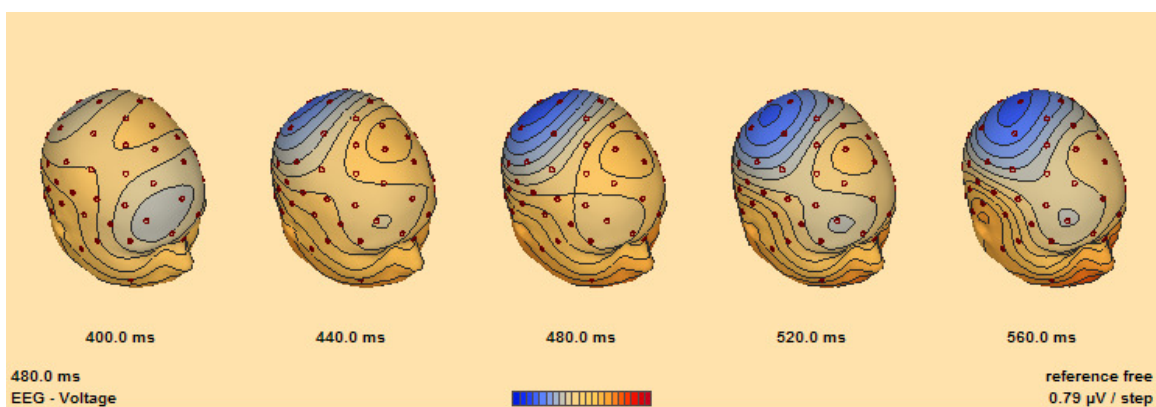


Figure H1. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-A children in the Linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

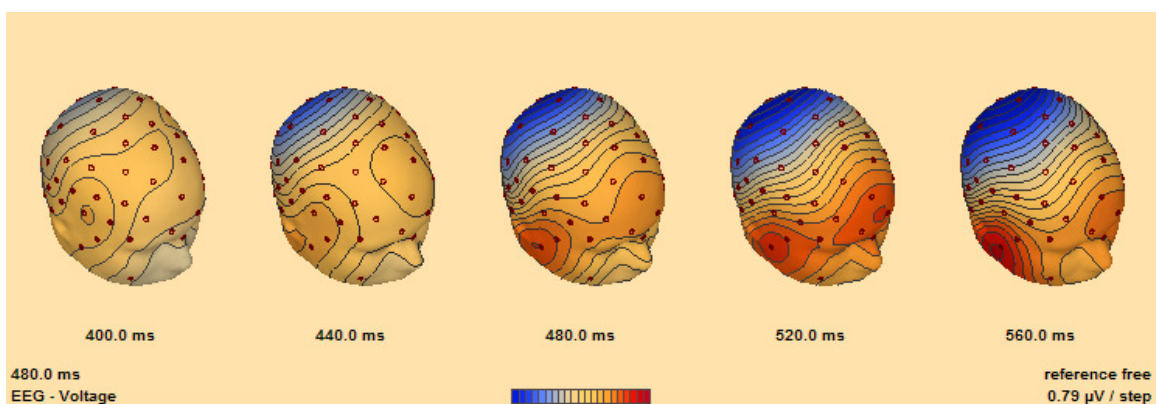
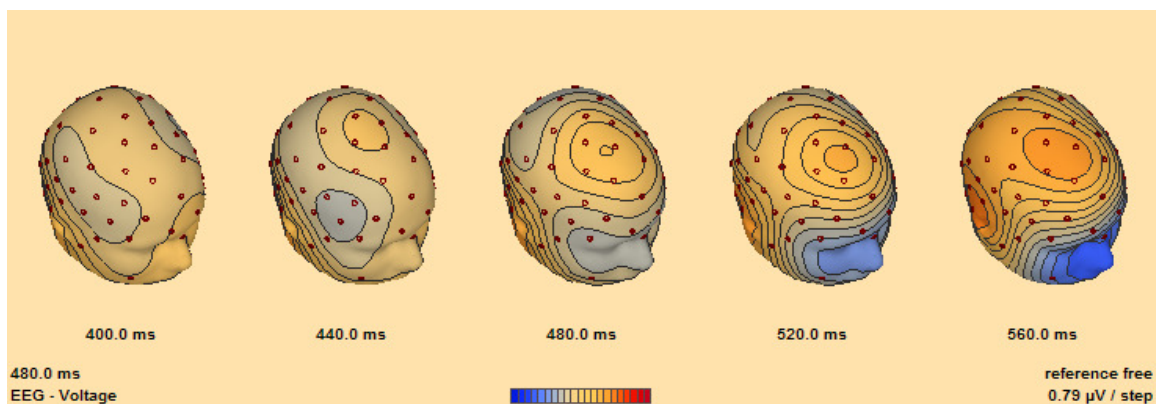
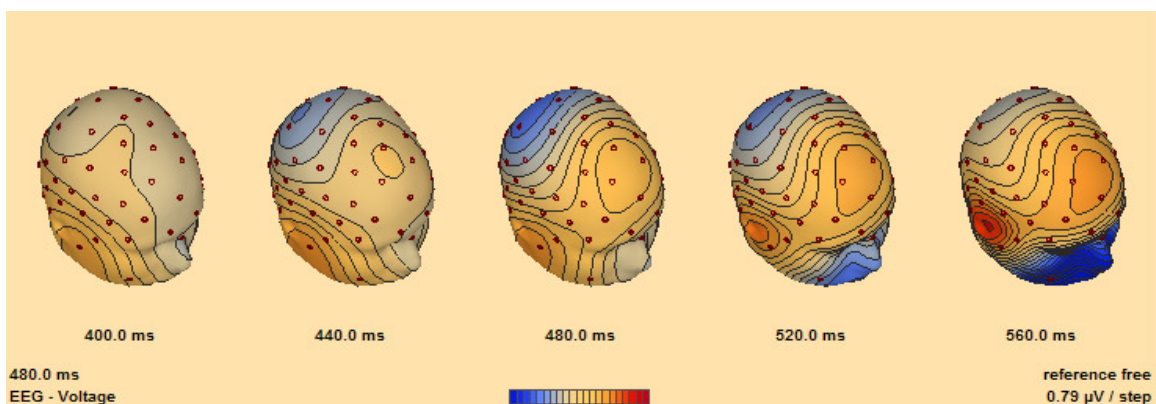


Figure H2. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in SLI children in the Linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

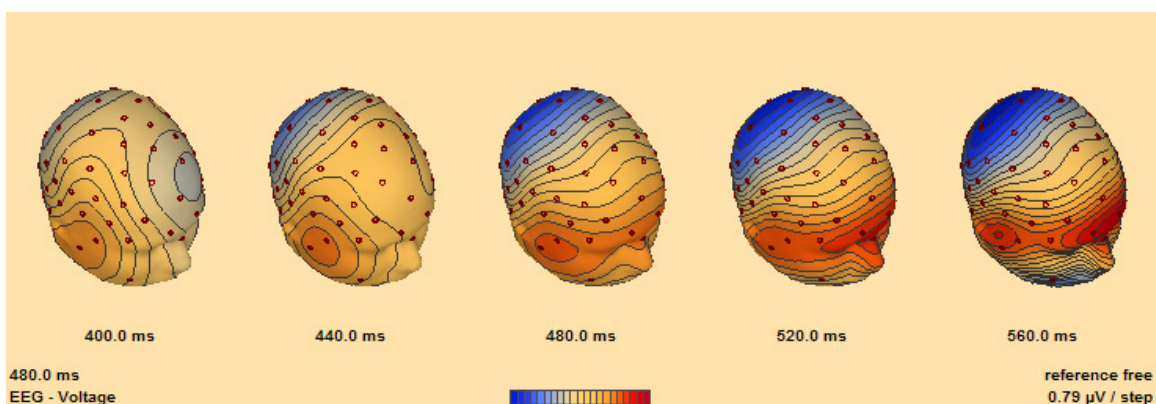


Figure H3. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-Y children in the Linguistic experiment (red - positive; blue - negative).

Appendix I

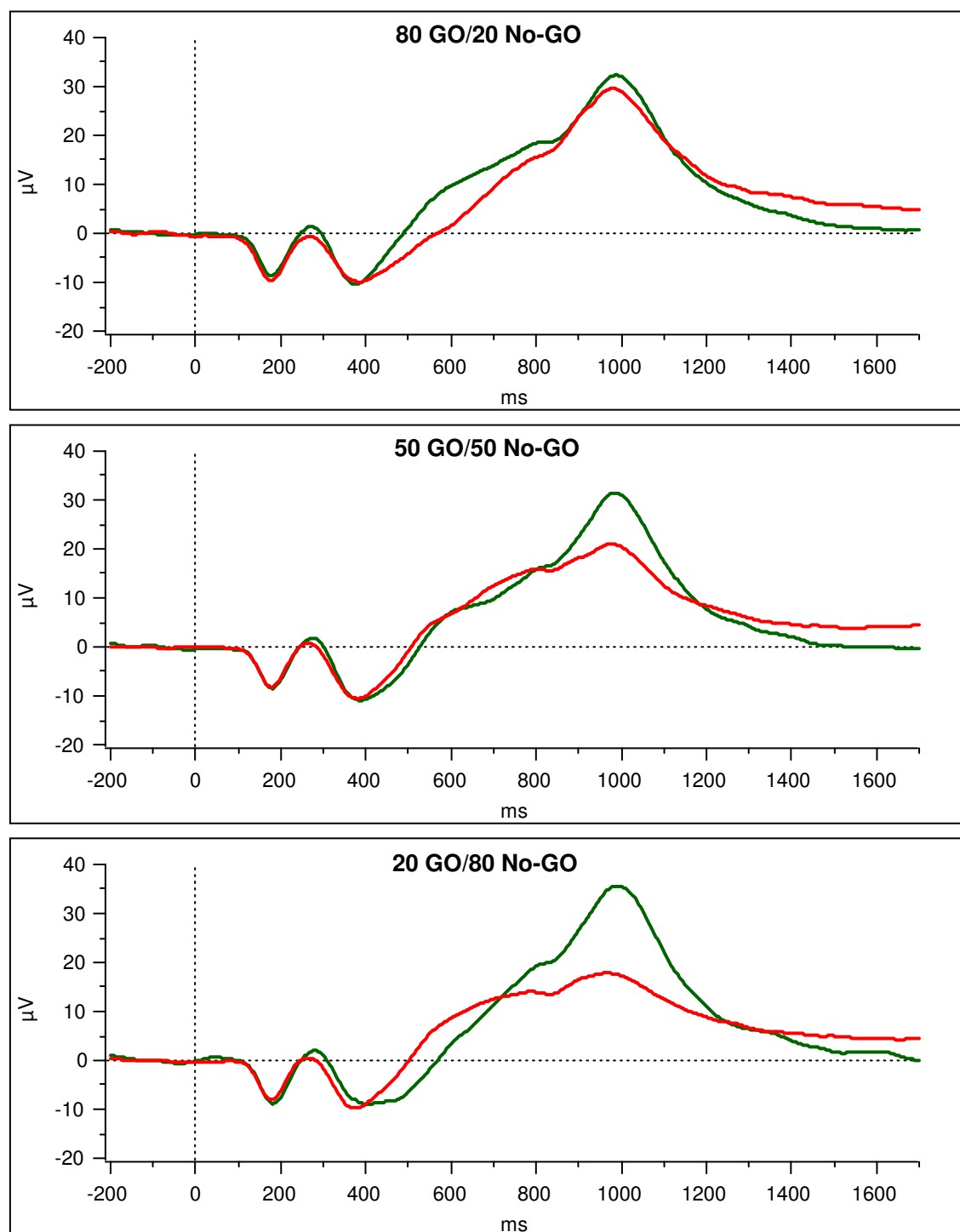


Figure I1. Grand average waveforms of TLD-A children ($n = 21$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment (green - GO; red - No-GO).

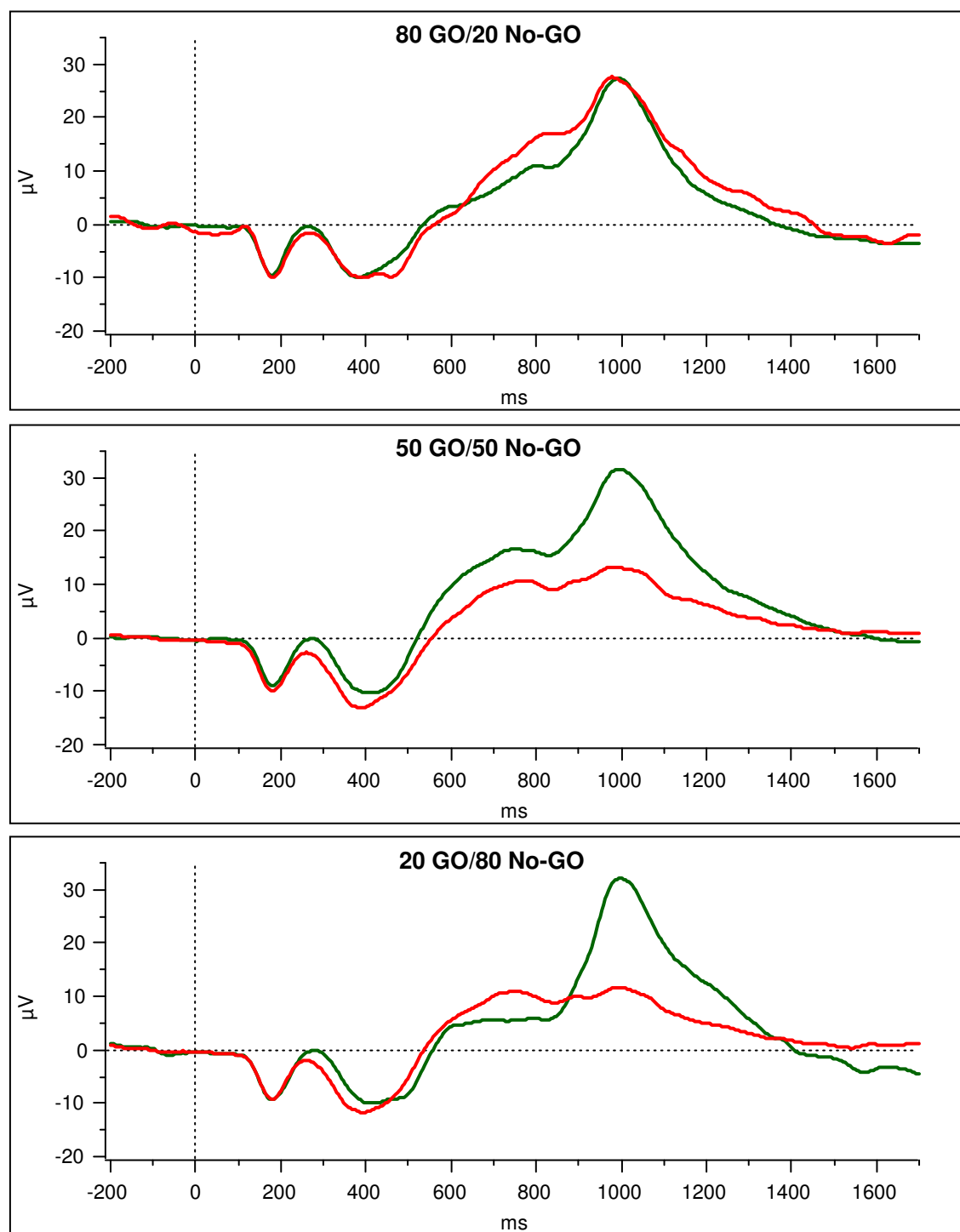


Figure I2. Grand average waveforms of SLI children ($n = 12$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment (green - GO; red - No-GO).

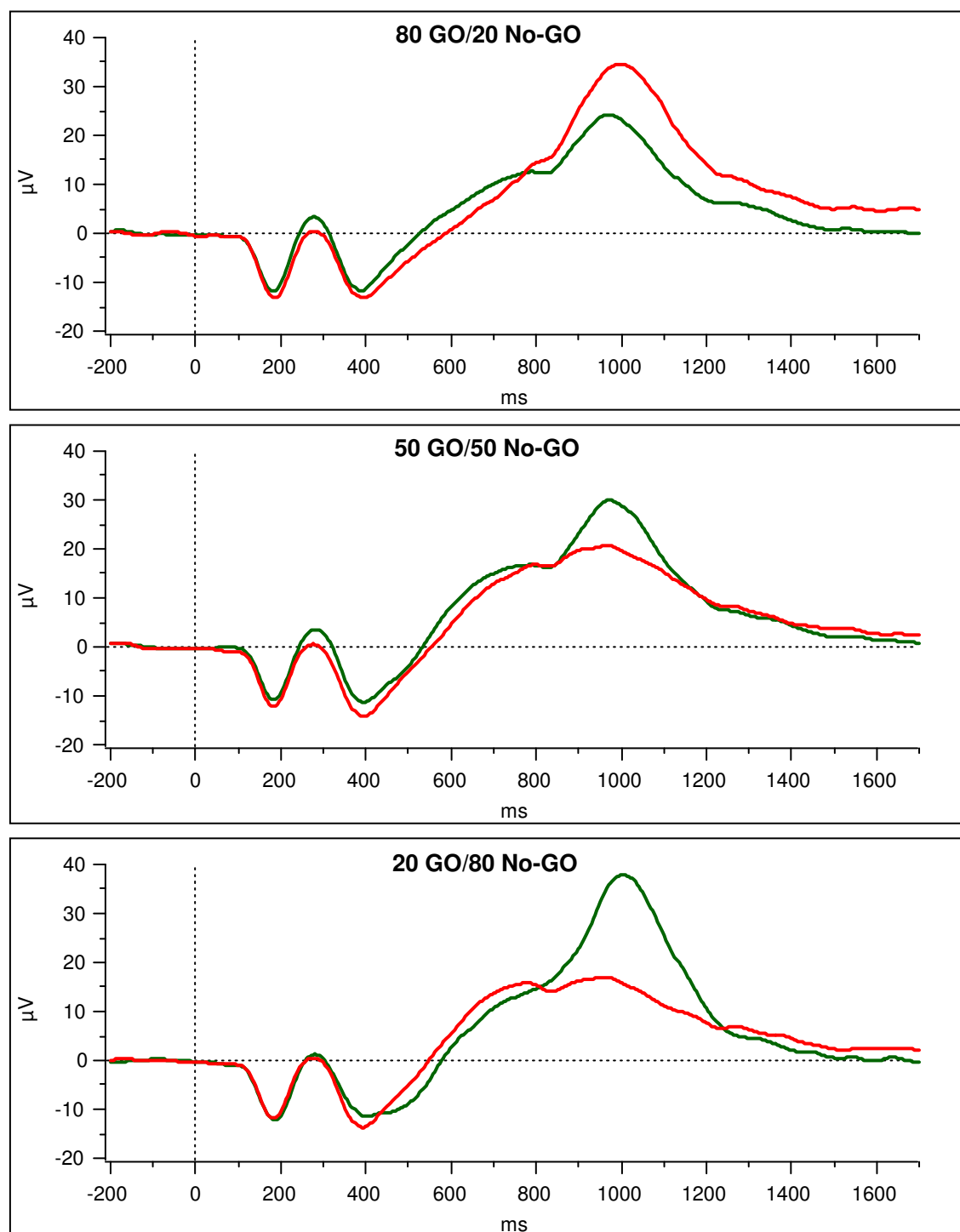


Figure I3. Grand average waveforms of TLD-Y children ($n = 16$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Linguistic experiment (green - GO; red - No-GO).

Appendix J

N2 Equal *n* Analysis in the Linguistic Experiment

To ensure that the observed N2 effects in the Linguistic experiment were not due to the imbalanced participant *n* across groups (TLD-A = 21; SLI = 12; TLD-Y = 16), the following analysis was performed. The TLD-A and SLI groups were matched on age (± 7 months; 1 pair: ± 10 months); gender; handedness; and non-verbal intelligence, based on TONI-3 raw scores (± 5 points). One of the 12 SLI children could not be matched with a TLD-A child according to the above criteria and was therefore excluded from the analysis. The data for the remaining 11 pairs were entered into a repeated measures ANOVA that examined whether the groups showed different effects of condition on mean amplitudes of the N2 for GO/No-GO responses over time. This 2 (Group: TLD-A, SLI) $\times$ 2 (Response Type: GO/No-GO) $\times$ 3 (Condition: 80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) $\times$ 4 (Time: 400-440, 440-480, 480-520, 520-560 ms) analysis was identical to the one performed for the three groups of participants, differing only in the number of participants included. Tukey's HSD post-hoc test was used to follow up significant interactions.

The results of the current analysis are strikingly similar to those of the ANOVA performed for the unequal participant groups. As expected, a significant interaction of Response Type $\times$ Condition, $F(2, 40) = 14.09$, $p < .0001$, $\eta_p^2 = .41$, indicated that condition influenced N2 responses to GO versus No-GO stimuli. N2 amplitude was greater in response to rare stimuli in the 80 GO/20 No-GO and 20 GO/80 No-GO conditions ($p < .05$) and no response type effect was evident for GO/No-GO responses in the baseline condition ($p < .05$). The effect of condition on GO/No-GO responses was

modulated by time, [Response Type x Condition x Time, $F(6, 120) = 13.20, p < .0001$, $\eta_p^2 = .40, \varepsilon = .52$], and the TLD-A and SLI groups manifested this interaction differently, [Response Type x Condition x Time x Group, $F(6, 120) = 3.72, p < .05, \eta_p^2 = .16$].

Tukey's HSD post-hoc test was used to examine the influence of condition on N2 responses to GO and No-GO stimuli over time in each of the groups. The results of this test are presented in Table J1. A comparison of this table with its counterpart from the same analysis performed for the three participant groups with unequal *ns* reveals close similarities. The TLD-A group showed adult-like N2 effects, characterized by greater amplitude for responses to rare stimuli, regardless of their association with the GO or No-GO response, and no N2 differences in the baseline condition. By contrast, the SLI children showed no response type effect in the 80 GO/20 No-GO condition ($p > .05$); greater amplitude for the No-GO response during the last two time intervals (480-520 and 520-560 ms) in the baseline condition ($p < .05$) but not in the first two time intervals (400-440 ms and 440-480 ms; $p > .05$); and greater amplitude for the rare GO response in the 20 GO/80 No-GO condition in the last two time intervals (480-520 ms and 520-560 ms; $p < .05$) but not in the first two time intervals (480-520 ms and 520-560 ms, $p > .05$).

Table J1. Results of Tukey's post-hoc test for the N2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in TLD-A ($n = 11$) and SLI ($n = 11$) children matched on age, gender, handedness, and non-verbal intelligence in the Linguistic experiment.

	80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
TLD-A	-	***	***	***	-	-	-	-	*	***	***	***
SLI	-	-	-	-	-	-	*	***	-	-	**	*

Significance of effects: *** $p < .001$; ** $p < .01$; * $p < .05$; - $p > .05$

The interaction of Response Type x Condition x Group was significant, $F(2, 40) = 4.79$, $p < .05$, $\eta_p^2 = .19$, demonstrating that between-group differences in the N2 were not solely attributable to the time variable. No other relevant main effects or interactions were significant ($p > .05$), as indicated in Table J2.

Table J2. Results of the ANOVA for the N2 (400-560 ms) using mean amplitude values at frontal sites in TLD-A ($n = 11$) and SLI ($n = 11$) children matched on age, gender, handedness, and non-verbal intelligence in the Linguistic experiment.

Effect	Df	F
Group (G)	1, 20	< 1
Response Type (R)	1, 20	< 1
Condition (C)	2, 40	1.80
Time (T)	3, 60	59.67 ***
R x G	1, 20	< 1
C x G	2, 40	< 1
T x G	3, 60	1.05
R x C	2, 40	14.09 ***
R x C x G	2, 40	4.79 *
R x T	3, 60	< 1
R x T x G	3, 60	< 1
C x T	6, 120	5.42 ***
C x T x G	6, 120	< 1
R x C x T	6, 120	13.20 ***
R x C x T x G	6, 120	3.72 **

Significance of effects: *** $p < .0001$; ** $p < .01$; * $p < .05$

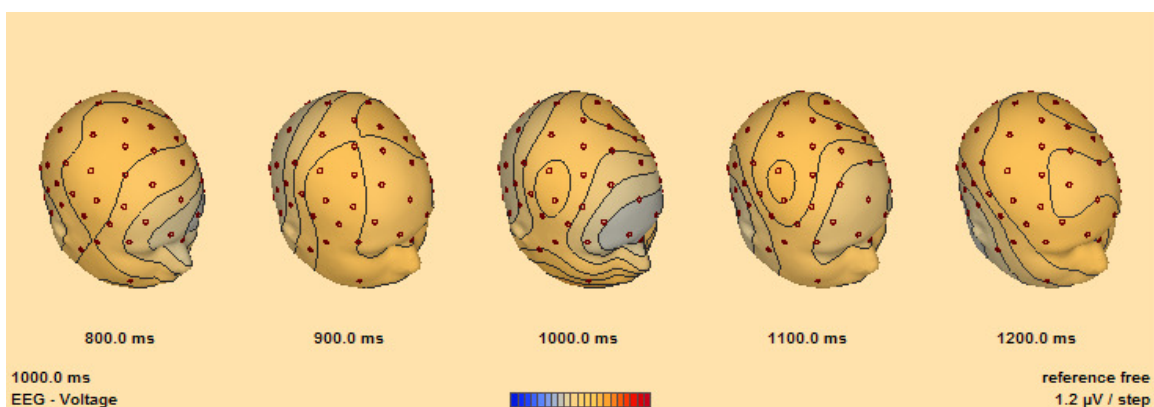
Summary of N2 Equal n Analysis

An analysis of N2 responses of an equal number of TLD-A and SLI children matched on age, gender, handedness, and non-verbal intelligence revealed highly similar results as those of the N2 analysis that included unequal participant numbers across groups. TLD-A children showed adult-like N2 effects for rare GO and No-GO stimuli and no effects for equiprobable stimuli. Contrastingly, SLI children showed No-GO > GO responses from 520-560 ms in response to equiprobable and rare GO stimuli. Only

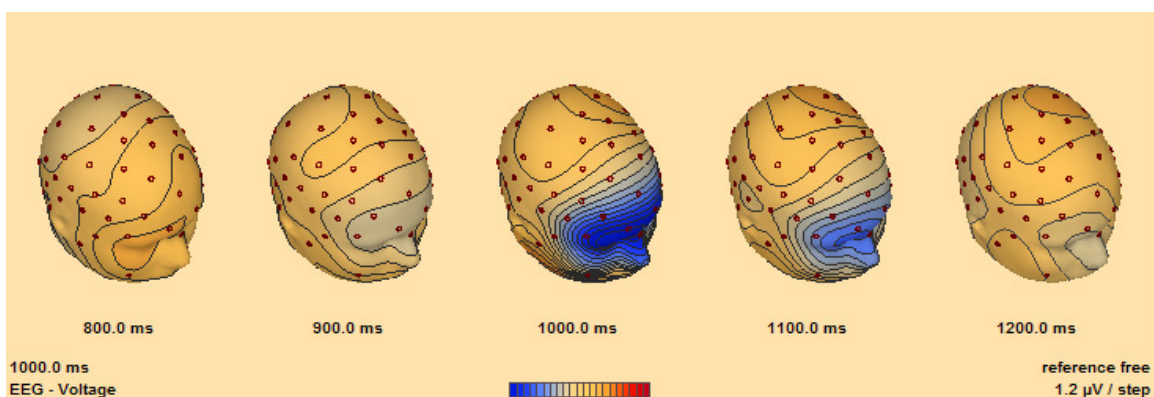
the latency of the N2 effects differed between the two analyses; in the current analysis, TLD-A children exhibited N2 effects beginning approximately 40 ms earlier (400-440 ms) in the 20 GO/80 No-GO condition and SLI children demonstrated N2 effects beginning 40 ms earlier (480-520 ms) in the 20 GO/80 No-GO and baseline conditions.

Appendix K

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

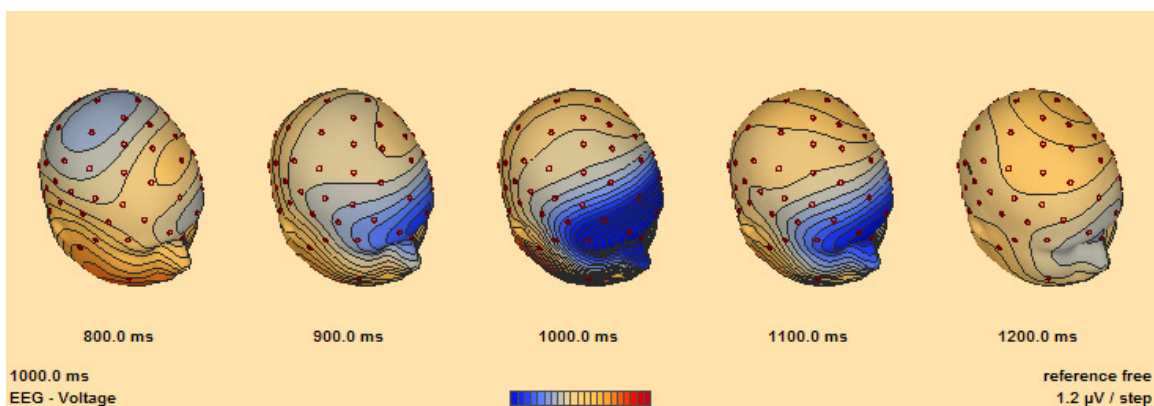
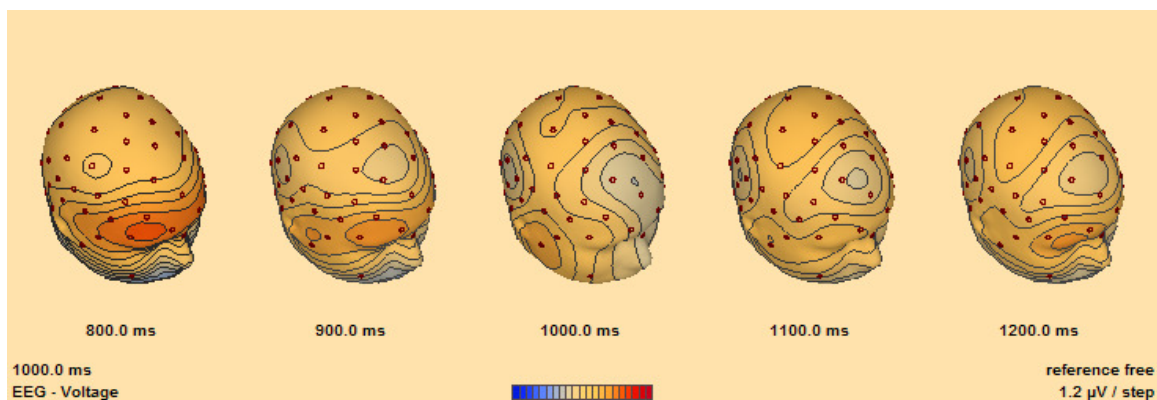
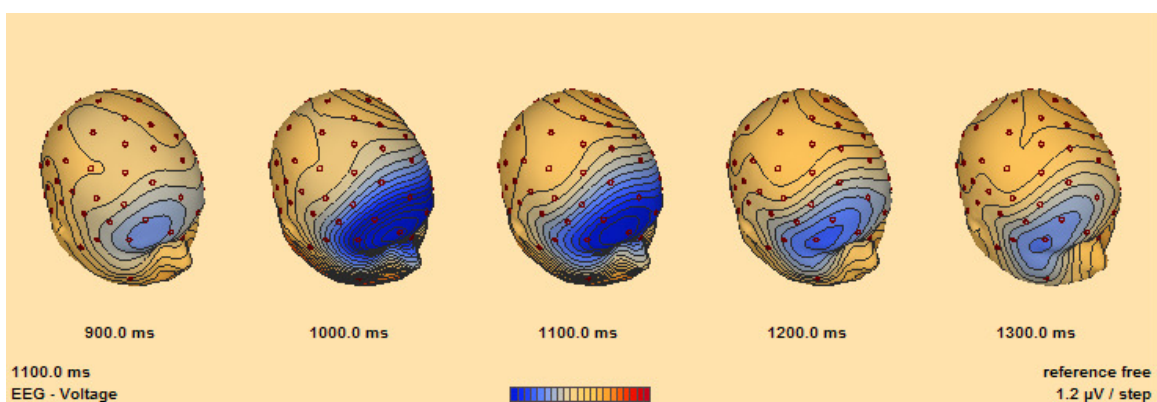


Figure K1. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-A children in the Linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

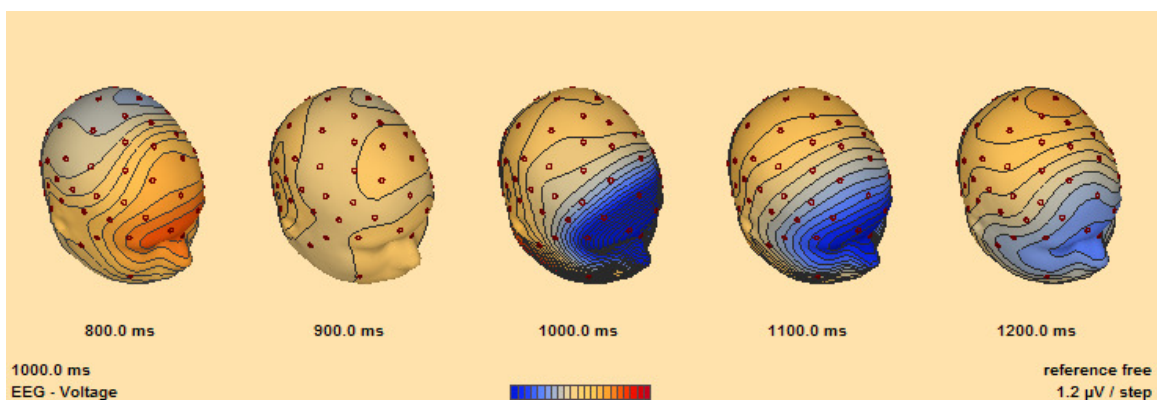
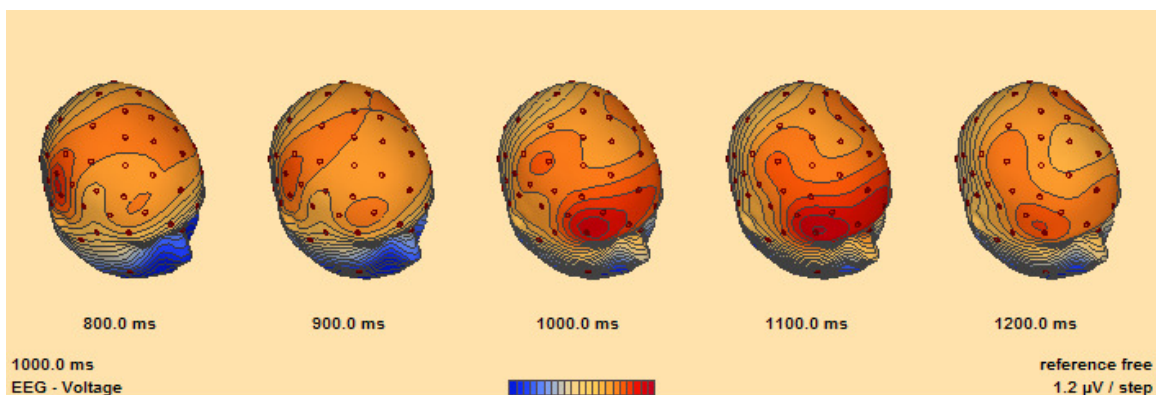
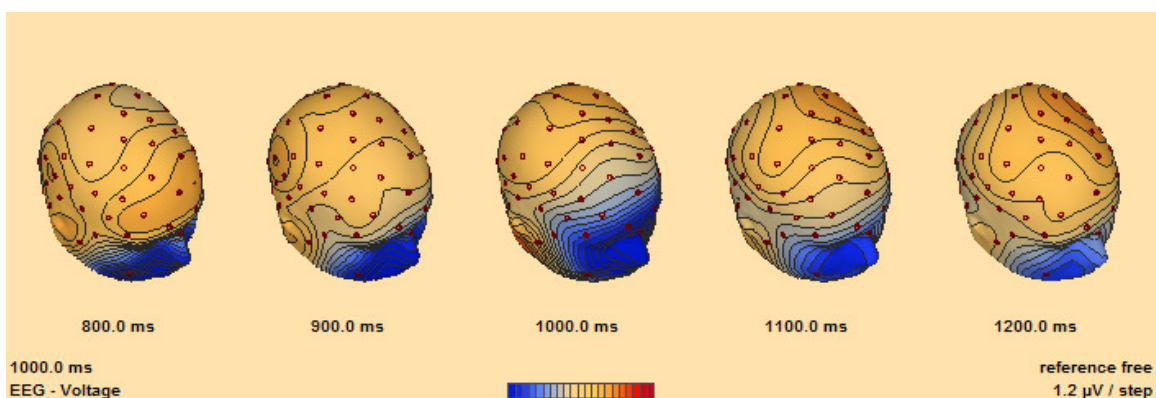


Figure K2. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in SLI children in the Linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

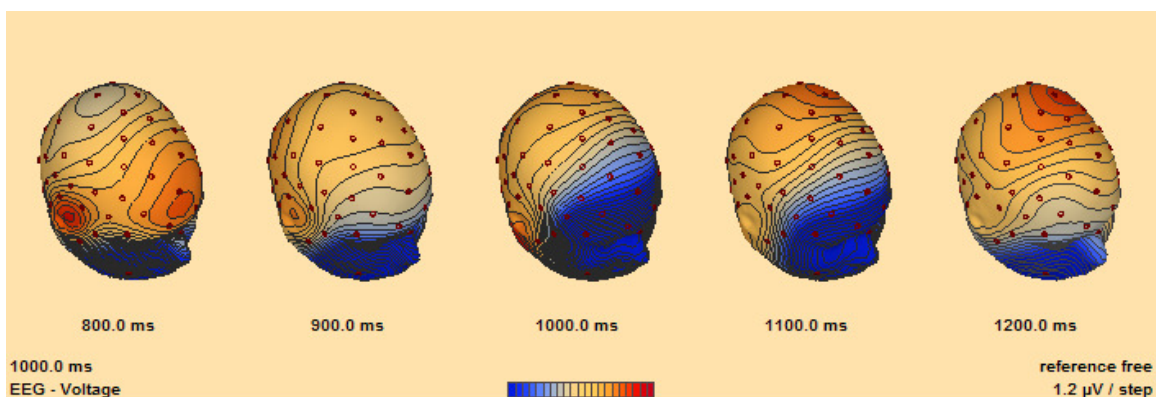
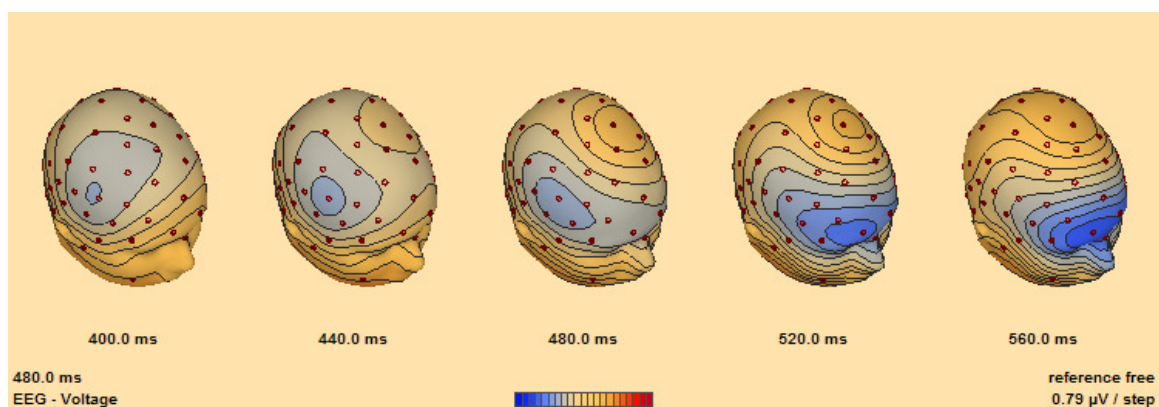


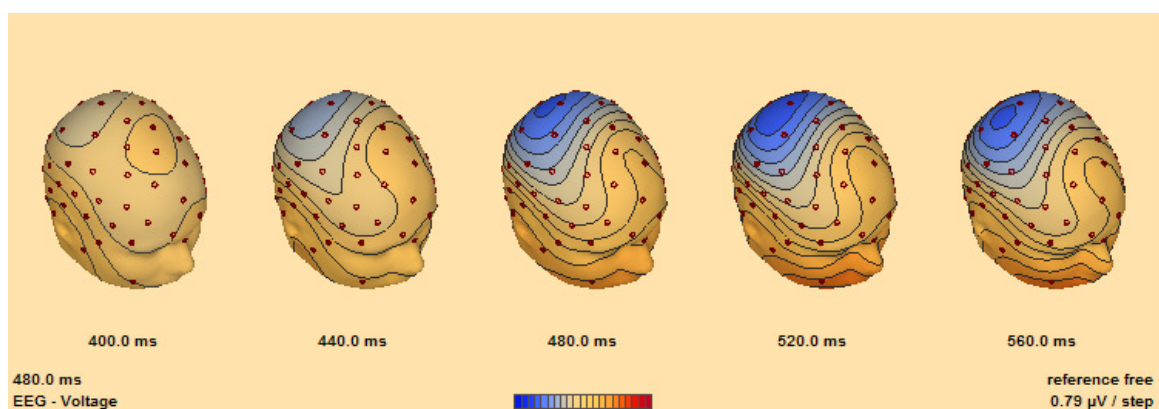
Figure K3. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-Y children in the Linguistic experiment (red - positive; blue - negative).

Appendix L

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

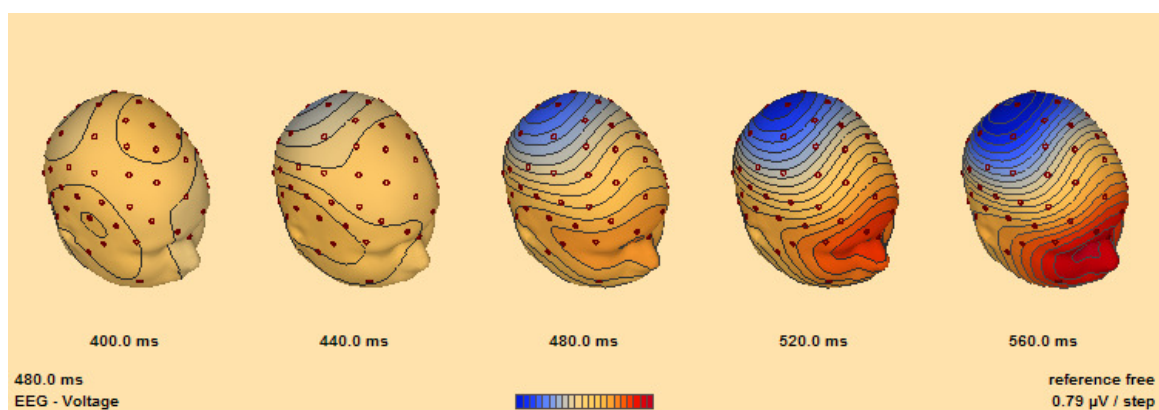
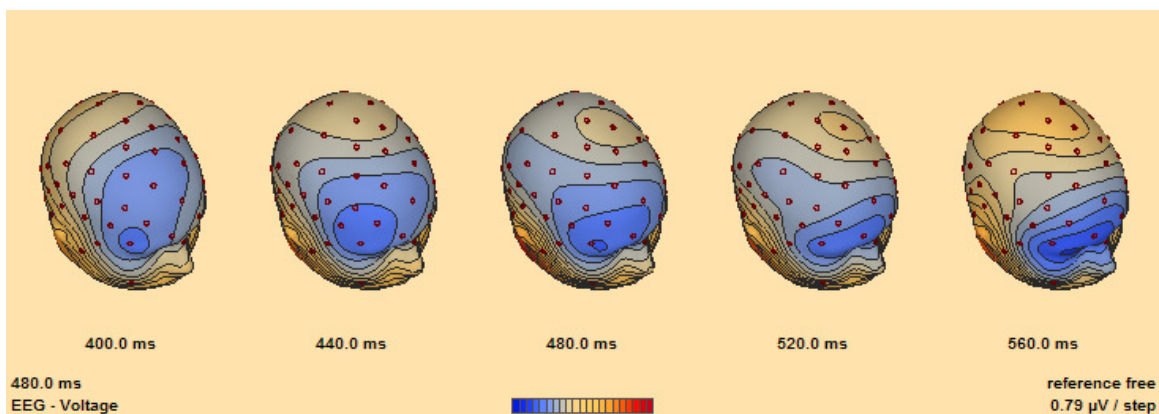
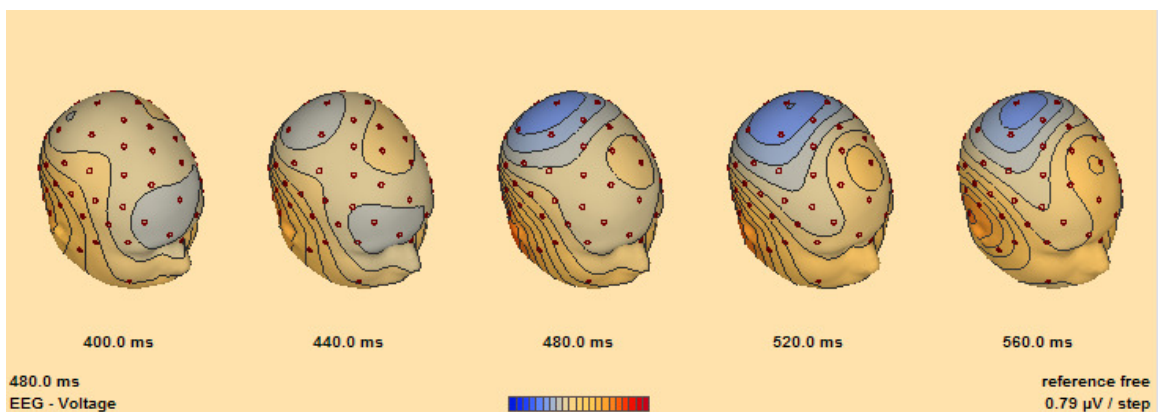


Figure L1. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-A children in the Non-linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

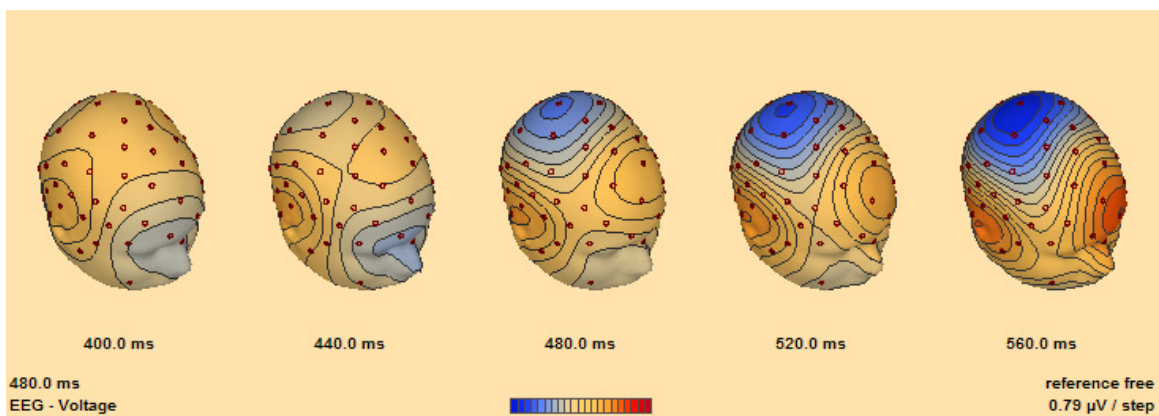
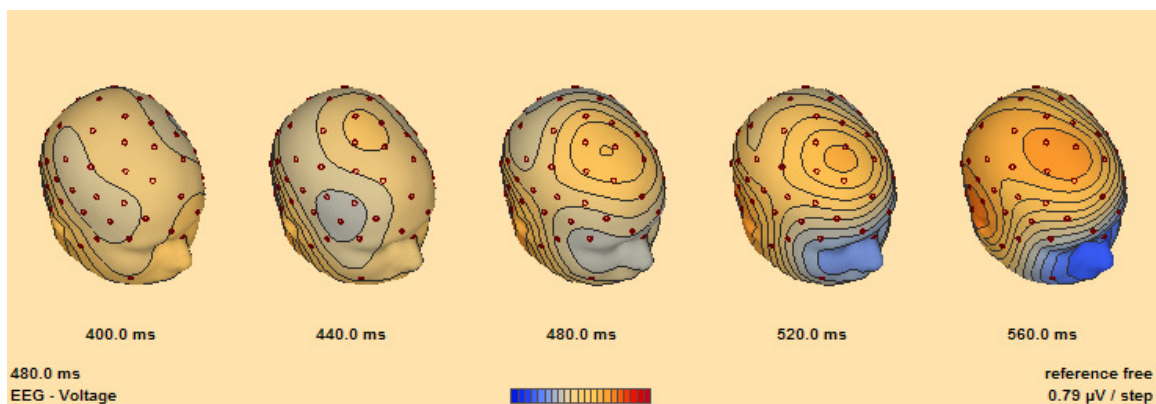
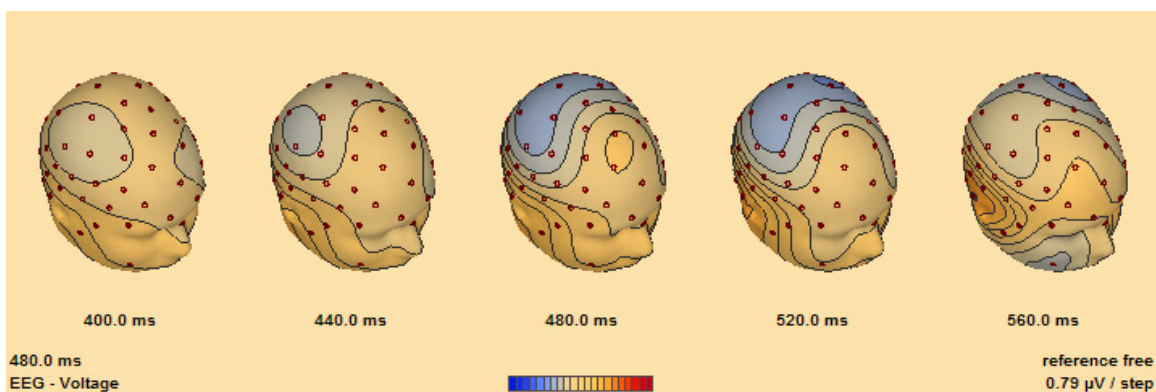


Figure L2. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in SLI children in the Non-linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

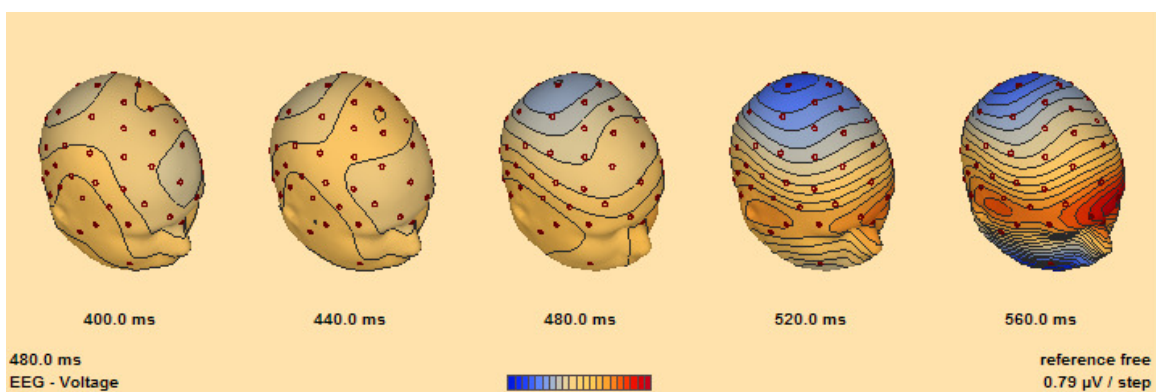


Figure L3. Topographical maps of N2 (400-560 ms) difference waves (No-GO - GO) in TLD-Y children in the Non-linguistic experiment (red - positive; blue - negative).

Appendix M

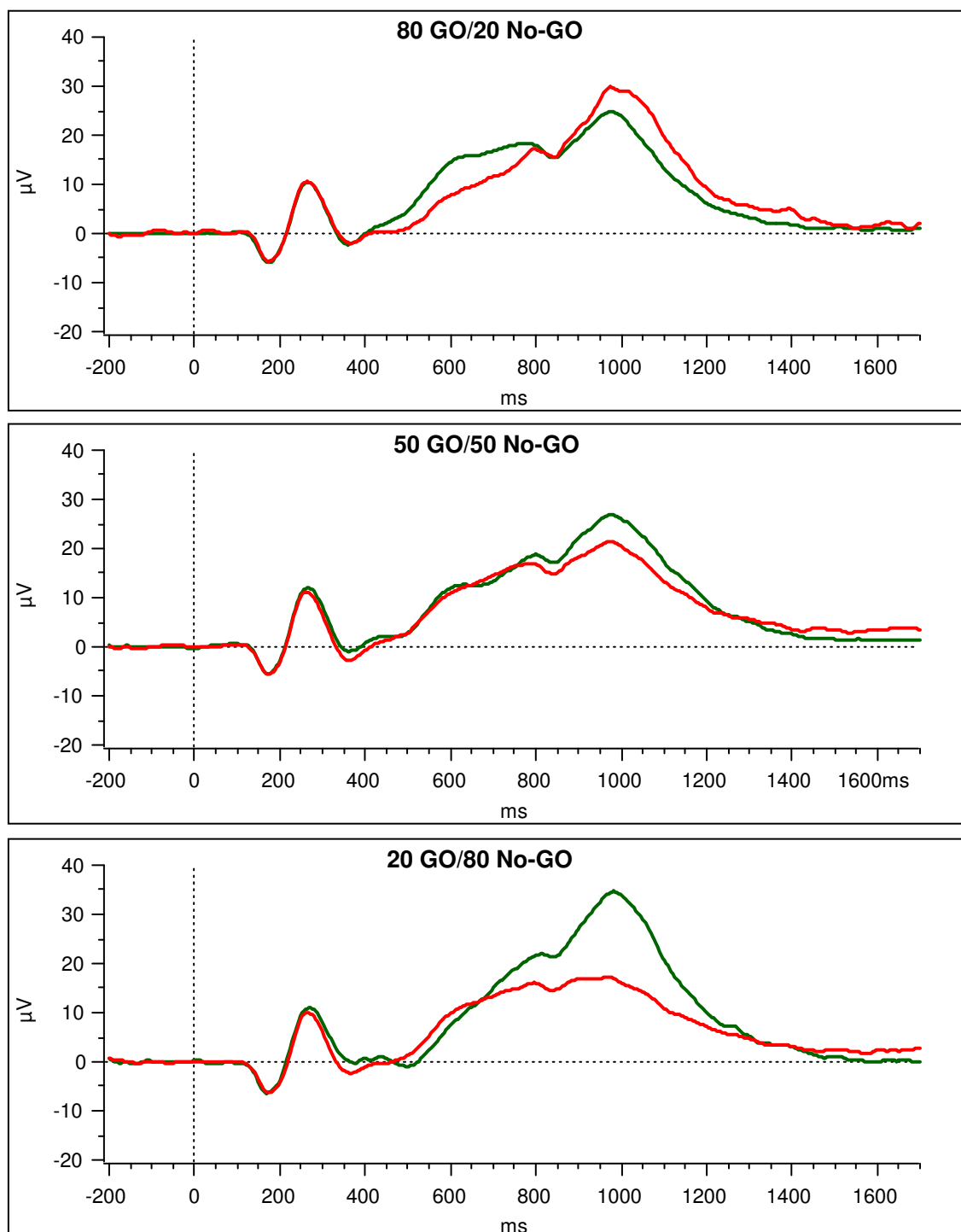


Figure M1. Grand average waveforms of TLD-A children ($n = 22$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment (green - GO; red - No-GO).

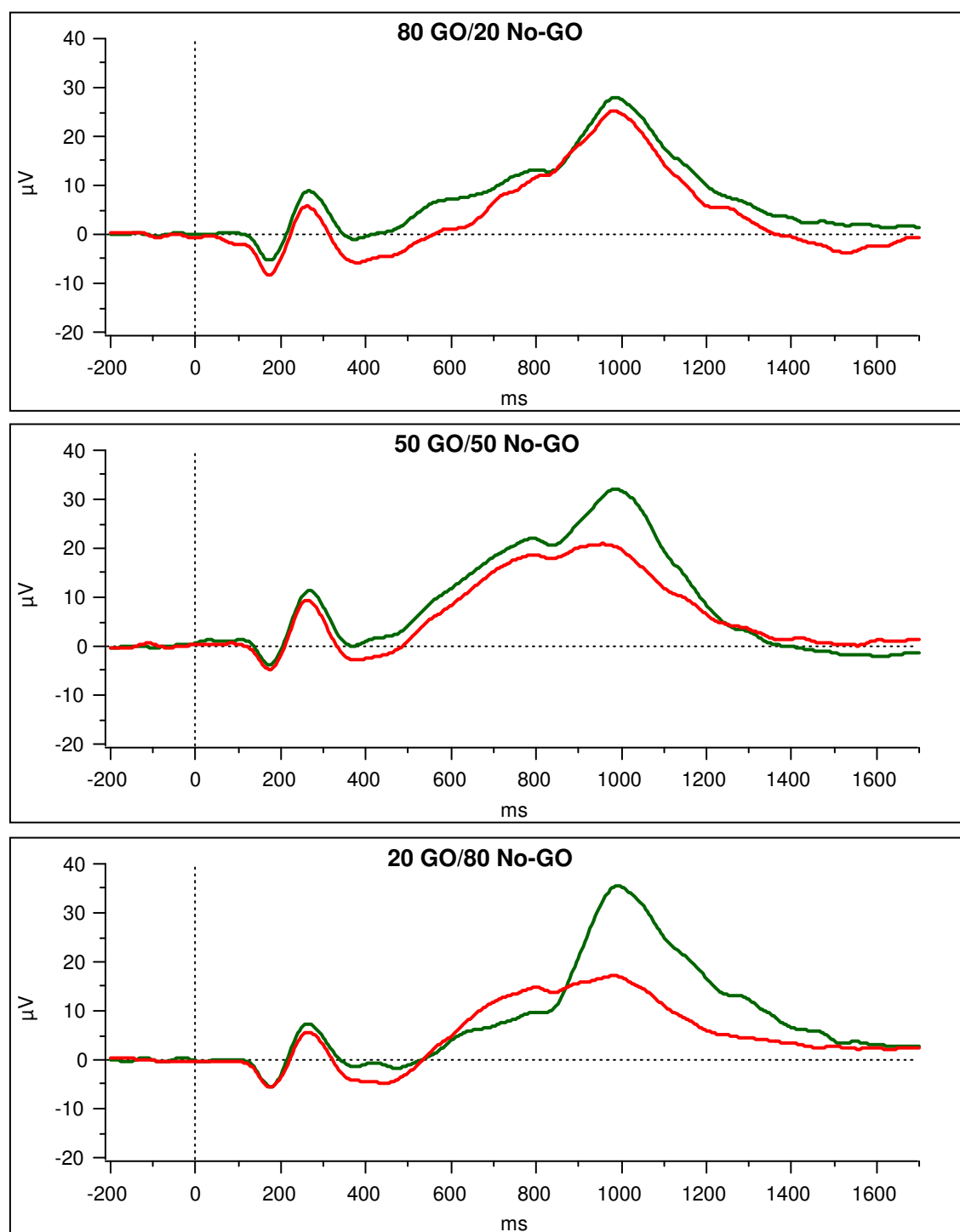


Figure M2. Grand average waveforms of SLI children ($n = 11$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment (green - GO; red - No-GO).

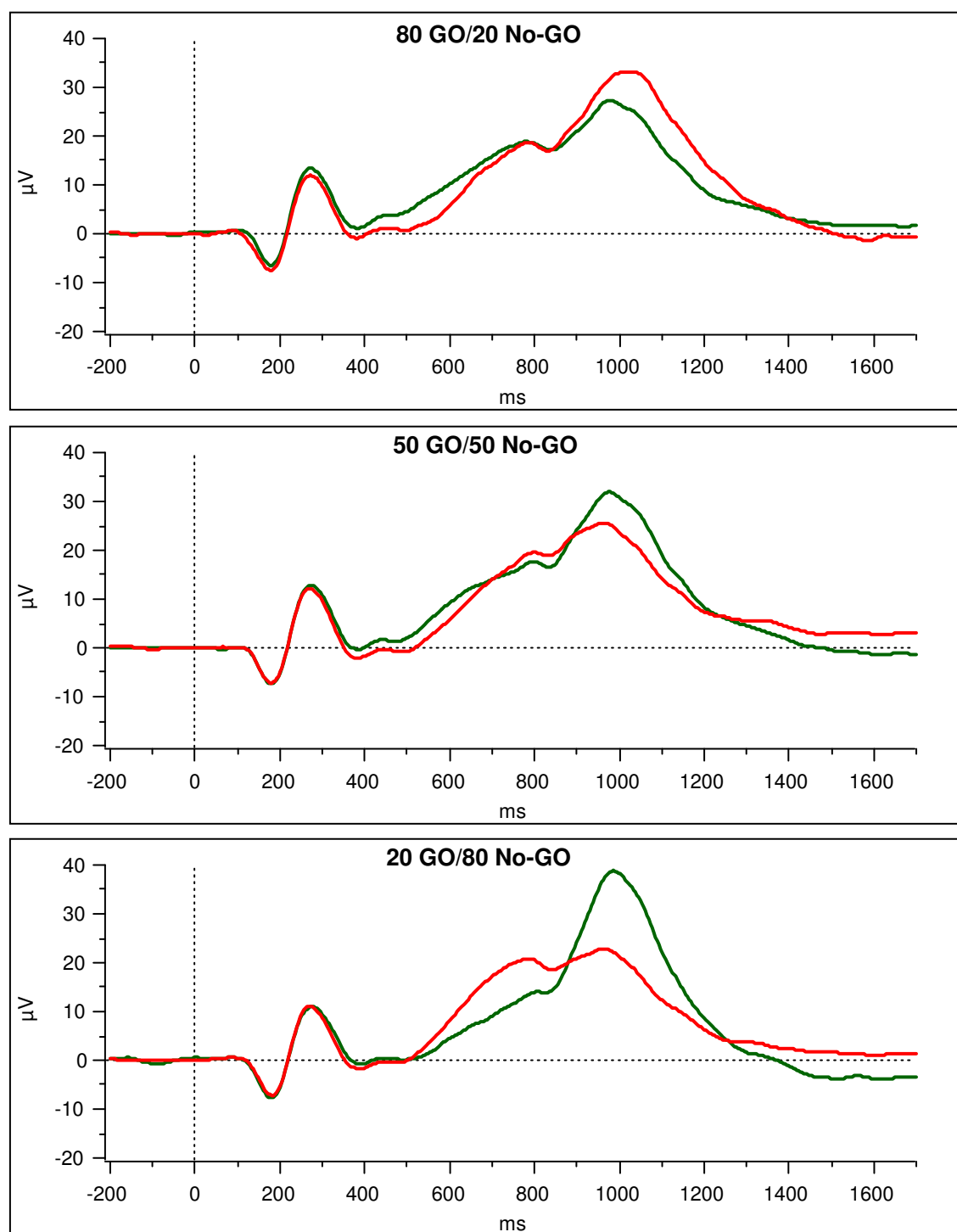


Figure M3. Grand average waveforms of TLD-Y children ($n = 14$) at left, midline, and right frontal sites (average of Geodesic 2, 6, 7, 11, & 12) as a function of condition in the Non-linguistic experiment (green - GO; red - No-GO).

Appendix N

N2-P2 Equal *n* Analysis in the Non-Linguistic Experiment

A follow-up analysis was conducted to determine whether the observed N2 effects were accurate in view of the imbalanced participant *n* across groups (TLD-A = 22; SLI = 11; TLD-Y = 14). N2-P2, rather than N2, mean amplitude values were used in the current analysis because the results detailed above indicated that N2-P2 values were more representative of the N2 effects for this experiment.

The SLI and TLD-A groups were matched on the following variables: age (± 7 months; 1 pair: ± 10 months); gender; handedness; and non-verbal intelligence, based on TONI-3 raw scores (± 5 points). One of the 11 SLI children could not be matched with a TLD-A child according to the above criteria and was therefore excluded from the analysis. The data for the remaining 10 pairs, which were the same as those included in the equal *n* analysis in the Linguistic experiment, were entered into a repeated measures ANOVA. This analysis examined whether the groups showed different effects of condition on mean amplitudes of the N2-P2 for GO/No-GO responses over time. As in the Linguistic experiment, this 2 (Group: TLD-A, SLI) $\times$ 2 (Response Type: GO/No-GO) $\times$ 3 (Condition: 80 GO/20 No-GO, 50 GO/50 No-GO, 20 GO/80 No-GO) $\times$ 4 (Time: 400-440, 440-480, 480-520, 520-560 ms) analysis was identical to the one performed for the three groups of participants, differing only in the number of participants included. Tukey's HSD post-hoc tests were used to follow up significant interactions.

The results of the current analysis are comparable to those of the ANOVA performed for the unequal participant groups. A significant interaction of Response Type $\times$ Condition, $F(2, 36) = 6.99$, $p < .01$, $\eta_p^2 = .28$, indicated that condition impacted N2

responses to GO versus No-GO stimuli. N2 amplitude was greater in response to rare stimuli in the 80 GO/20 No-GO condition ($p < .05$) only. The influence of condition on GO/No-GO responses varied over time, [Response Type x Condition x Time, $F(6, 108) = 10.32$, $p < .0001$, $\eta_p^2 = .36$, $\epsilon = .40$]. Tukey's HSD post-hoc test identified the time intervals in which differential GO/No-GO responses were exhibited. The results of this analysis, which are presented below in Table N1, closely resemble those of the preceding N2-P2 analysis for unequal ns . In fact, the only time interval in which different findings were observed across analyses is from 480-520 ms in the 20 GO/80 No-GO condition; in the present analysis, rare GO stimuli elicited greater amplitude than No-GO stimuli, whereas no differential responses were observed for this time interval and condition in the analysis with unequal ns .

Table N1. Results of Tukey's HSD post-hoc test for analysis of the N2-P2 effect (GO vs. No-GO) over time using mean amplitude values at frontal sites in TLD-A ($n = 10$) and SLI ($n = 10$) children matched on age, gender, handedness, and non-verbal intelligence in the Non-linguistic experiment.

80 GO/20 No-GO				50 GO/50 No-GO				20 GO/80 No-GO			
400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560	400-440	440-480	480-520	520-560
-	*	***	***	-	-	-	-	-	-	**	***
Significance of effects: *** $p < .001$; ** $p < .01$; * $p < .05$; - $p > .05$											

An interaction arose between Condition x Time, $F(6, 108) = 10.32$, $p < .0001$, $\eta_p^2 = .36$, $\epsilon = .40$, because amplitude decreased significantly from the third to fourth time interval of the N2 (480-520 to 520-560 ms) in each condition ($p < .01$). No other relevant interactions were significant, as indicated in Table N2.

Table N2. Results of the ANOVA for the N2-P2 using mean amplitude values at frontal sites in TLD-A ($n = 10$) and SLI ($n = 10$) children matched on age, gender, handedness, and non-verbal intelligence in the Non-linguistic experiment.

Effect	Df	<i>F</i>
Group (G)	1, 18	< 1
Response Type (R)	1, 18	< 1
Condition (C)	2, 36	2.13
Time (T)	3, 54	10.40 **
R x G	1, 18	1.12
C x G	2, 36	< 1
T x G	3, 54	< 1
R x C	2, 36	6.99 **
R x C x G	2, 36	2.53
R x T	3, 54	2.12
R x T x G	3, 54	< 1
C x T	6, 108	3.29 *
C x T x G	6, 108	1.52
R x C x T	6, 108	10.32 ***
R x C x T x G	6, 108	1.43

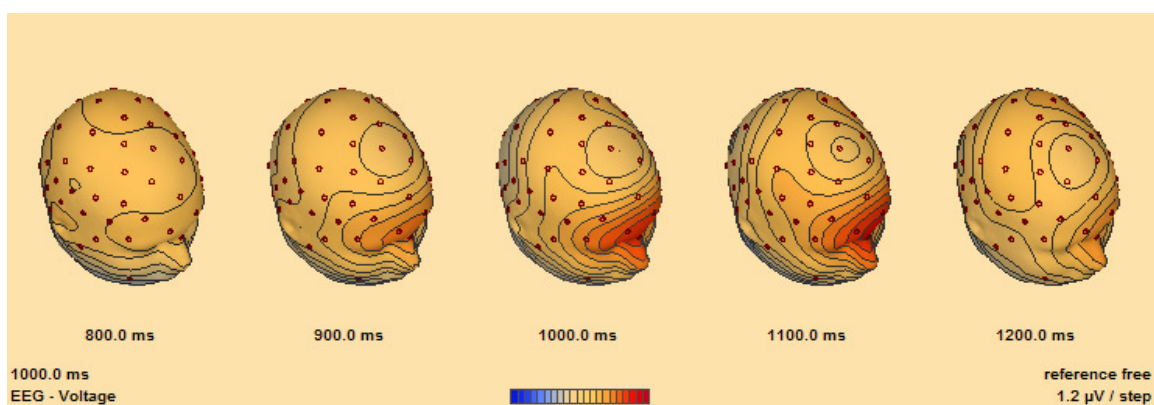
Significance of effects: *** $p < .0001$; ** $p < .01$; * $p < .05$

Summary of N2-P2 Equal n Analysis

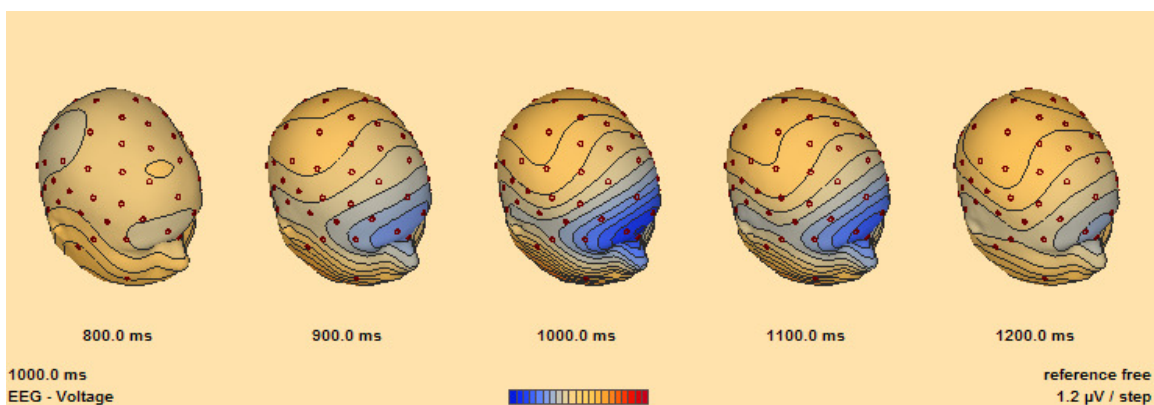
An analysis of N2-P2 effects in groups of TLD-A and SLI children with equal n s revealed that the statistically insignificant group differences in the analysis with unequal n s were not rooted in the disparate numbers of participants across groups. The current analysis revealed the expected N2 effects in at least two time intervals in the 80 GO/20 No-GO and 20 GO/80 No-GO conditions but no response type differences throughout the baseline condition. Although the anticipated N2 effects apparently emerged later in the SLI group, no group differences were statistically significant in this analysis.

Appendix O

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

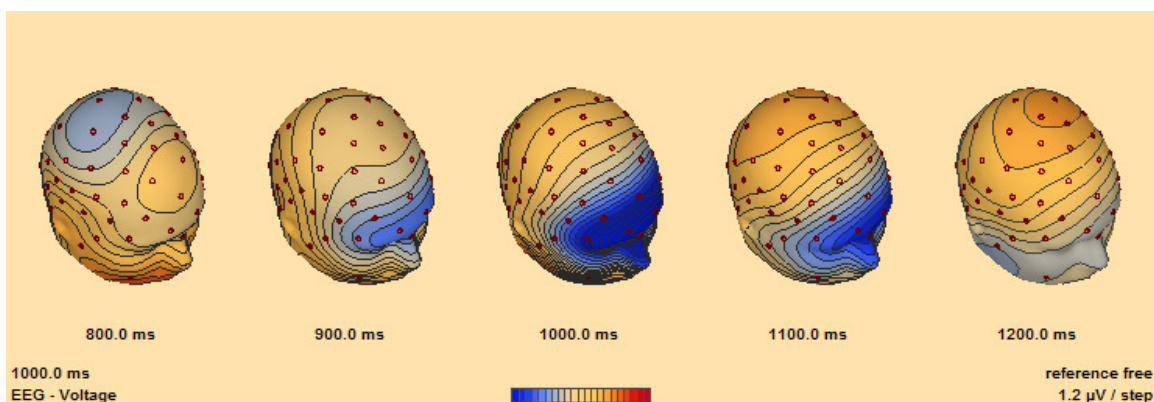
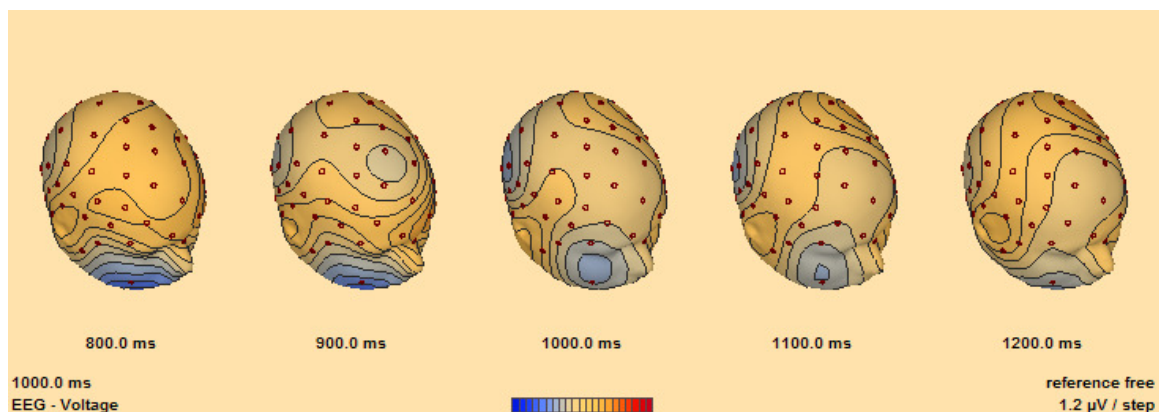
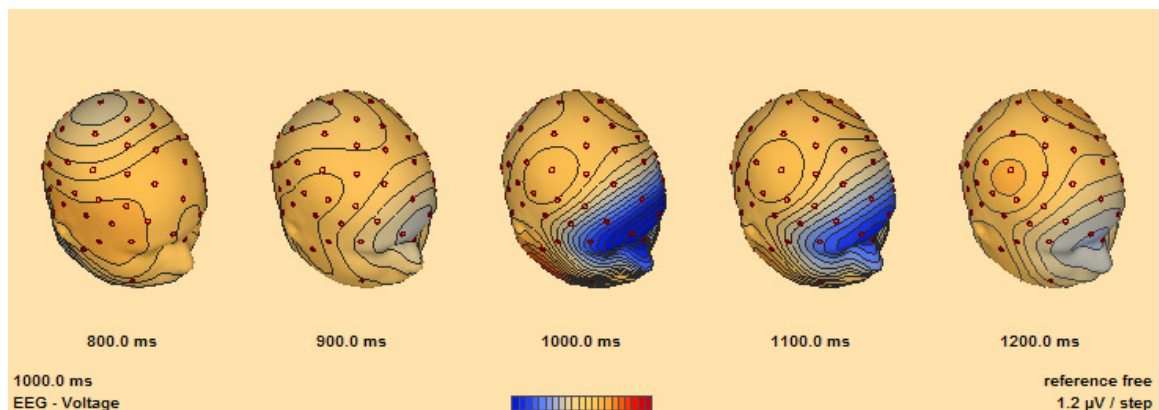


Figure O1. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-A children in the Non-linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

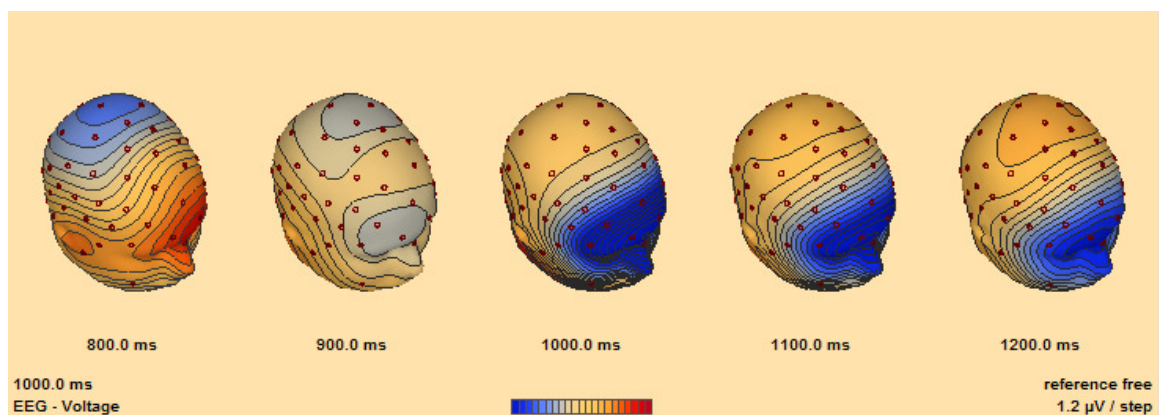
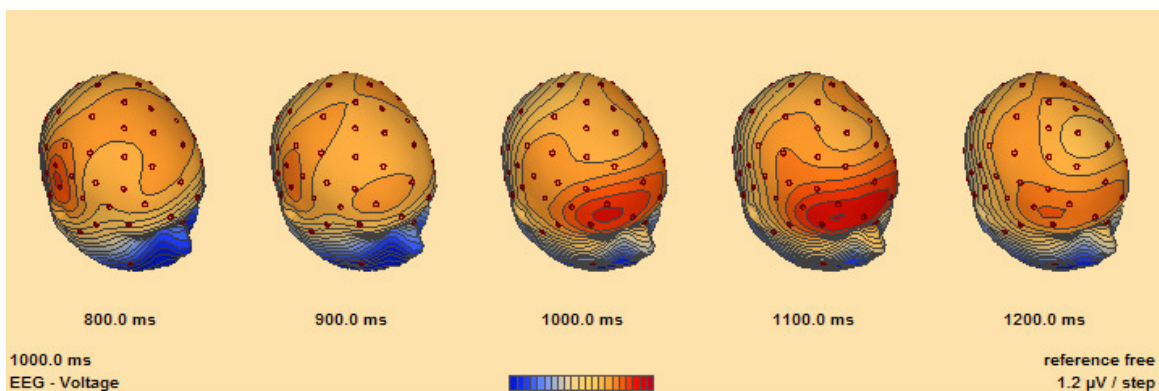
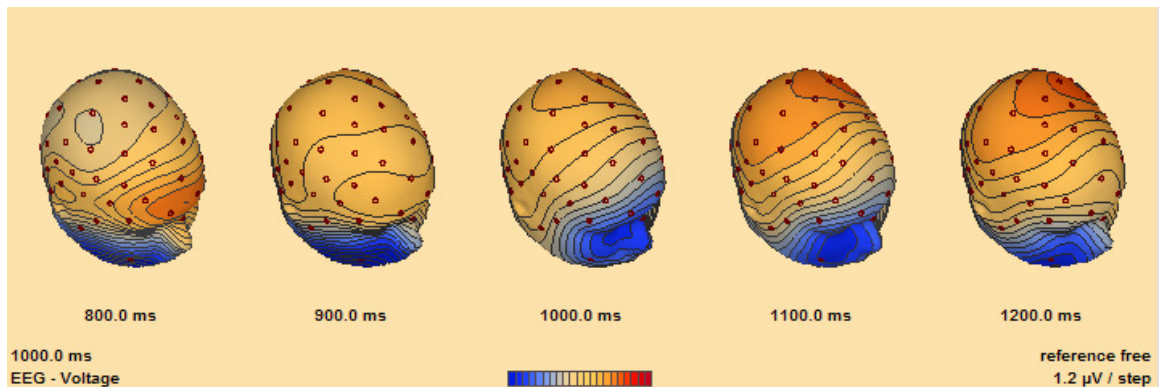


Figure O2. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in SLI children in the Non-linguistic experiment (red - positive; blue - negative).

80 GO/20 No-GO



50 GO/50 No-GO



20 GO/80 No-GO

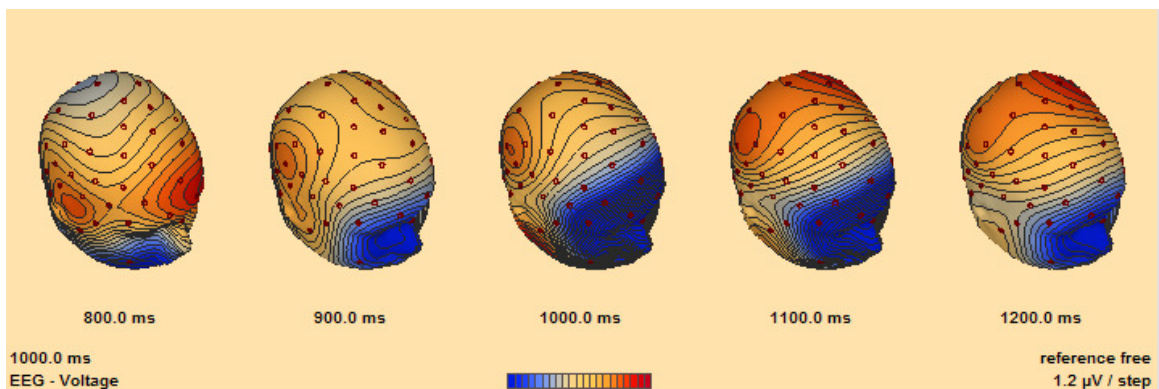


Figure O3. Topographical maps of P3 (800-1200 ms) difference waves (No-GO - GO) in TLD-Y children in the Non-linguistic experiment (red - positive; blue - negative).

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