EVALUATION OF A DUAL-GENERATION INTERVENTION ON LANGUAGE PROCESSING IN PRESCHOOLERS FROM LOWER SOCIOECONOMIC STATUS BACKGROUNDS

By

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Parents and Children Making Connections-Highlighting Attention (PCMC-A) is an eight-week, family-centered dual-generation intervention program designed at the University of Oregon to facilitate attention and school readiness skills in pre-school children from lower socioeconomic (SES) backgrounds. The current study evaluated the efficacy of PCMC-A on enhancing neural processes for language. Children aged 3-5 years and their parents were randomly assigned to participate in PCMC-A or Head Start Alone. Event-related brain potentials (ERPs) were elicited by semantically and syntactically correct and anomalous sentences both prior and after the completion of PCMC-A. Results indicated that children participating in both groups exhibited maturation of neural processes for semantics over the eight-week time period. However, children participating in PCMC-A exhibited a different pattern of development, a transition toward more adult-like semantic processing, compared to children in Head Start Alone. This finding suggests different patterns for maturation of neural mechanisms for semantics as a function of intervention. Results of linear regressions also indicated greater change in nonverbal IQ and receptive language performance on standardized assessments were associated with greater change in mean amplitudes for neural indices of both semantic and syntactic processing, relationships not evident in the Head Start Alone group. These results revealed positive impacts of PCMC-A on neural processes for language in preschool children from lower SES households.

This thesis is dedicated to my family, without whom, my success would not have been possible.

AWKNOWLEDGEMENTS

My thesis journey has been a collaboration from start to finish and I would like to thank a number of amazing people who guided me through this process. First and foremost, my advisor, Dr. Amanda Hampton Wray, for taking me under her wing for the better part of two years. Her endless patience, calm leadership, and exceptional investment in my learning and success have helped me grow as a researcher and person, for which I will be forever grateful. In addition, the richness and endless source of support, fun, and laughter you have added to my graduate experience is beyond words. I could not have asked for a better advisor and role model to lead me through this project.

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CHAPTER 1: INTRODUCTION

1.1 Theories of Language Development

A strong foundation for a healthy and productive life is typically formed early; with childhood experiences paving much of the way for later success in adulthood. The years of infancy are when habits of seeking new experiences, noticing novel environmental stimuli, and integrating increasingly complex information form and become engrained (Hart & Risley, 2003). Experience leads to functional activity and learned behavior at the cellular level, which shapes development to maximize performance within a particular environment (Blair & Raver, 2012). In this reciprocal fashion, young children whose surroundings are intellectually enriching are more likely to pursue more cognitively demanding activities and are more likely to achieve greater proficiency in crucial skill areas once they are old enough to seek out experiences independently (Hart & Risley, 2003)

Not all people are born with the same opportunities for robust environmental enrichment. Living in poverty can seriously undermine areas of an individual's life, including cognitive development, emotional regulation, psychosocial maturation, health, safely, and access to opportunities (Shonkoff, Richter, van der Gaag, & Bhutta, 2012). The current project aimed to evaluate the efficacy of an intervention program targeted at enhancing the household environment as well as self-regulation skills on neural processes supporting language in young children growing up in lower socioeconomic status (SES) households, which typically are less enriching and more stressful than households of higher SES.

Particularly relevant to this study are the effects of early life experiences on the development of brain regions underlying language. The language regions of the brain have evolved to be highly adept at processing, analyzing, and integrating linguistic stimuli, such as words, sentences, and speech within a pragmatically appropriate context (Kutas & Federmeier, 2011). However, having the capacity to acquire language does not mean that language develops spontaneously. Language is a learned process that is partially dependent on environmental input. Therefore, through the combination of environmental and genetic factors, humans have the potential to develop highly adept communication skills. It is this interplay of genetic expression and environmental experience that produces individual differences in brain development and language proficiency across generations and populations (Rao et al., 2009).

1.2 Neurodevelopment and Synaptogenesis

Early life experiences provide the scaffolding from which numerous cognitive, emotional and perceptual abilities are developed. Evidence suggests the timing of environmental experiences plays a critical role in gene expression, which influences neural structure and function (Fox, Levitt, & Nelson, 2010). Human brain development unfolds in a cascading progression, which begins two weeks after conception and differentially terminates at various points throughout the lifespan (Douet, Chang, Cloak, & Ernst, 2014). The formation of the nervous system involves the development of neurons, which takes place between 4 and 12 weeks gestational age, and neuronal axons undergo myelination at approximately 29 weeks gestational age (Blakemore, 2012).

The proliferation of synaptic connectivity between newly formed neurons and the intentional organization of synapses begins at approximately 20 weeks gestational age and continues through age 2 years (Huttenlocher, 1979). This constitutes a significant point in the neural developmental time course. The formation and strengthening of neural synapses is largely, but not entirely, dependent on enriching experiences encountered in this window of time (Lewis, 2005). This is due to the differential time course of gene expression, which is most rapid during fetal development and slowing in childhood and into adolescence, with the most significant changes in expression occurring just before birth and in early adulthood (Colantuoni et al., 2011). Humans have a uniquely prolonged period for brain development, as the majority of brain growth occurs postnatally. This allows ample opportunity for environmental, cultural, and social influence to have a robust impact on neural organization and connectivity.

Also occurring throughout cortical brain development is the phenomenon called synaptogenesis. Synaptogenesis refers to stages in development when the cortex undergoes a frenzy of synaptic connectivity in which multiple connections between neurons are formed. Synaptogenesis takes place throughout the lifespan, but is most robust between 28 and 40 weeks gestational age, and again at approximately 2 years of age (Huttenlocher & Dabholkar, 1997).

Exuberant synaptogenesis is beneficial as it facilitates rapid connectivity between neural regions throughout the cortex. However, the brain cannot sustain dense connectivity throughout all neural networks and simultaneously maintain rapid processing speeds. Therefore, periods of synaptogenesis are followed by periods of synaptic pruning in which neural density is decreased to approximately 60% of its original state, as illustrated in Figure 1.1 (Huttenlocker & Dabholkar, 1997). Neural networks that are highly used, are preserved, while processes that are not used, are inhibited and selectively eliminated (Huttenlocker & Dabholkar, 1997; Li et al., 2010; Zito & Svobodo, 2002).

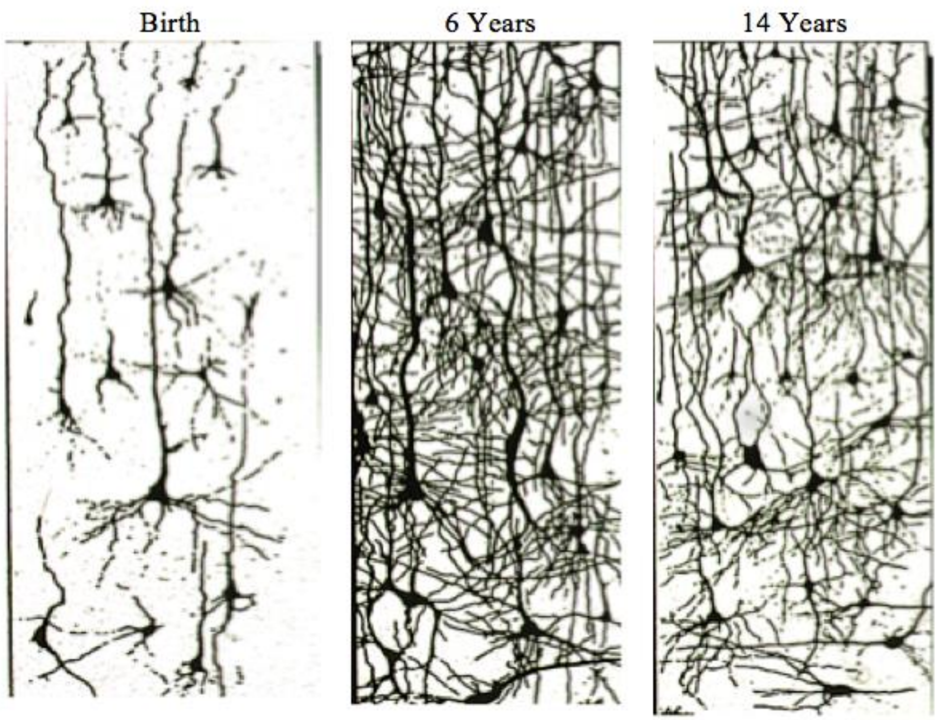


Figure 1.1 Neuronal Density Changes from Infancy Through Adolescence. Children undergo a ‘burst’ of connectivity in early childhood, which is selectively pruned in late childhood.

1.3 Critical/Sensitive Periods

The window of time in which synaptogenesis takes place and before synaptic pruning, represents so-called “sweet spots” for optimal development, which are referred to as critical, or sensitive, periods of development. This is because synaptogenesis can bolster underlying mechanisms for particular skills or processes, so they will be preserved during synaptic pruning. In this way, the influence of experience is strongest during critical periods of development, which represent limited increments of time when underlying mechanisms for certain abilities are highly malleable, or susceptible, to enhancement or prohibition established by environment (Fox et al., 2010). The modifiability of neural structure and function is known as experience-based neuroplasticity. Neuroplasticity is discussed as two-sided, or as a double-edged sword; systems that are modifiable by experience, such as systems underlying language, are enhanceable by enriched input or intervention programs but also vulnerable to deprivation (Stevens & Neville, 2013). A consequence of neuroplasticity can be seen when brain changes occur in response to negative environments, such as in the case of chronic stress, abusive treatment, or severe neglect in early childhood, which can have long-term negative effects on the developing brain.

1.4 Neuroplasticity and Implications for Development

Research suggests the type and quality of environmental and experiential input during critical periods is highly predictive of outcomes later in life. Numerous experiments involving animals have explored the effects of intentional enrichment or deprivation on brain development. In rat pups, enrichment and complexity of cage environment, as well as early nurturing following stressful experiences, have been shown to have direct impact on brain structure, namely number of neurons, blood supply, myelination, number of dendrites (Rozenzwag, 1966; Greenough, Black, & Wallace, 1987), hippocampal development, stress regulation and memory (Liu, Diorio, Day, Francis, & Meaney, 2000).

No directly comparable experimental studies exist that manipulate early life experiences in humans. While studies involving non-human primates are beneficial to the literature, experimenter manipulation of primate environment/experiences are generally not always directly reflective of those experienced within the normal variation that exists in human childhood. Therefore, extrapolation of primate studies to human childhood experiences has limitations.

1.5 Environment and Implications for Development

One area in which scientists have been able to compare brain structure and function in children is by assessing the environment in which a child grows up. While it has been suggested that genes offer an initial blueprint for brain structures, features of an individual's environment provide the context within which neural circuitry builds upon itself over time (Fox, Levitt, & Nelson, 2010; Shonkoff, 2012). It has been well documented that growing up within an impoverished home can affect multiple facets of an individual's life, and many areas of development in childhood (Bradley & Corwin, 2002; Noble, McCandliss, & Farah, 2007).

Poverty is commonly operationally defined as cash income; however, other indicators of socioeconomic status (SES) are parental employment, stability of work, loss of income, and paternal/maternal education level (Huston, McLoyd, & Garcia Coll, 1994). For research purposes, these indicators can be considered in insolation, or combined to produce a composite index of an individual's or family's SES. A large and growing body of scientific research exists, which investigates the health and developmental implications of SES on children and families.

On average, families considered to be lower SES experience more adversity throughout their daily lives, which include higher levels of stress, fatigue, chaos, crowding, noise, and unpredictability than families considered middle and upper SES (Bradley & Corwyn, 2002; Evans et al., 2005). Children from poor families are more likely to experience violence, a lack of nutrition, more dangerous relationships (Shonkoff, et al., 2012), unsafe housing conditions, and homelessness (Huston et al., 1994). In a study using parental education level as a proxy for SES, adolescents with less educated parents, on average, had an increase in risk for developing cardiovascular health problems (Goodman et al., 2005).

Chronic stress is posited to be a leading threat to the health of children from lower SES backgrounds. Higher basal cortisol levels, a hormone activated in response to stress, has been observed in elementary school children from lower SES families in comparison to same-aged peers from higher SES families (Lupien, King, Meaney, & McEwen, 2007). Additionally, poverty increases the probability that children will grow up in cognitively impoverished environments, with less family support, and fewer, less positive, parent-child interactions (Evans & Kim, 2013; Hart & Risley, 1995). Environmental stressors associated with living in poverty are likely contributors, as families living in poverty typically live in depressed communities, and therefore, experience more stressors across environmental contexts, including their neighborhood, school, home, and day care (Kim & Evans, 2013). This situation increases the likelihood of interacting with children and adults who are similarly exposed to unhealthy stressors, and whom may also be experiencing comparable physical and psychosocial difficulties (Evans & Kim, 2013).

Particularly relevant to the current study is the impact of SES on academic achievement, and specifically language development. Previous research suggests children from lower SES households are at a heightened risk of language delays and disorders compared to their higher and middle SES peers (Hart & Risley, 1995; Hoff, 2003; Pancsofar, Vernon-Feagans, & The Family Life Project Investigators, 2010).

1.6 The SES Achievement Gap

Effects of learning deprivation early in life can negatively impact academic performance. Children who have not been exposed to adequate learning opportunities in their first 5 years of life enter Kindergarten approximately 2 or more years behind their peers in school readiness skills (Ramey & Ramey, 2004). This achievement gap, which emerges early, only widens with time. In a study of language processing efficiency and its relationship with vocabulary learning in 18-month-old children from varying SES backgrounds, Fernald and colleagues reported a persistent performance gap between higher and lower SES children (Fernald, Marchman, & Weisleder, 2013). Specifically, the average performance level of lower SES children at 24 months of age was almost identical to the achievement of higher SES children at 18 months of age, which suggests that by age 2 years, a 6-month performance gap is already apparent between higher and lower SES toddlers (Fernald et al., 2013).

Growing up in lower SES households has also been associated with poorer performance on neurocognitive tasks assessing language and executive function systems when compared to peers from middle SES households; with children from lower SES backgrounds exhibiting greater disparities in the areas of visual, cognitive, visuo-spatial, and memory skills (Noble, Norman, & Farah, 2005). Subsequent studies have also identified language abilities as a possible mediator between SES and cognitive tasks, including cognitive control, visuo-spatial skills, and working memory (Noble, McCandliss, & Farah, 2007)

1.6.1 SES and Vocabulary

Valuable information on the language experiences of young children before they enter school has come from analyzing the language environment of the home. On average, lower SES children lag behind their peers from middle and higher SES families in vocabulary production at age 3 years as measured by comparing the amount of word types produced during mother-child dyad interactions (Pan, Rowe, Singer, & Snow, 2005). Research on the early experiences of children has found, from a very early age, dramatic discrepancies in vocabulary size, vocabulary use (Spencer, Clegg, & Stockhouse, 2012) and rate of vocabulary growth as a function of SES

(Fernald et al., 2013; Hoff, 2003). Differences found in intelligence quotient (IQ) as a function of SES were indicative of spoken vocabulary in the home between 7 and 36 months of age, as spoken vocabulary and MLU have been significantly correlated with factors of SES, such as parent education level, occupation, income, and parent IQ (Walker, Greenwood, Hart, & Carta, 1994).

The work of Betty Hart and Todd R. Risley (1995) has provided consistent, longitudinal insight into the language learning environments and vocabulary trajectories of children from families of differing SES. Children from professional, working-class, and welfare families were followed for two-and-a-half years, from age 7-9 months to age 3 years. Thousands of hours of parent and child interactions were recorded in the home and then coded, which revealed both similarities and striking differences in language use between SES groups. Consistently, 86-98% of vocabulary spoken by children across SES groups was also recorded in the parent's vocabulary; such that by age 3 years, word use, talking habits, and amount of talk became strikingly similar between parent and child (Hart & Risley, 1995; Hart & Risley, 2003). Even though all families were nurturing and teaching similar information to their children, children from welfare families had consistently smaller vocabularies and were slower at acquiring vocabulary. On average, children living in households receiving welfare were exposed to half as many words per hour (616 words/hr) as the average child living in a working-class family (1,251 words/hour), and were exposed to less than one third of the average amount of words children from professional families were exposed to each hour (2,153 words/hour) (Hart & Risley, 1995). These findings were extrapolated to estimate the number of words heard per week, and then per year. It was calculated that by age 3 years, a vocabulary gap exists based on social strata in the order of roughly 30 million words, as illustrated in Figure 1.2. Additionally, the researchers found that vocabulary use and rate of vocabulary growth at age 3 years was highly predictive of success at age 9 and 10 years on measures of language skill, including listening, speaking, semantics, syntax and reading comprehension (Hart & Risley, 2003).

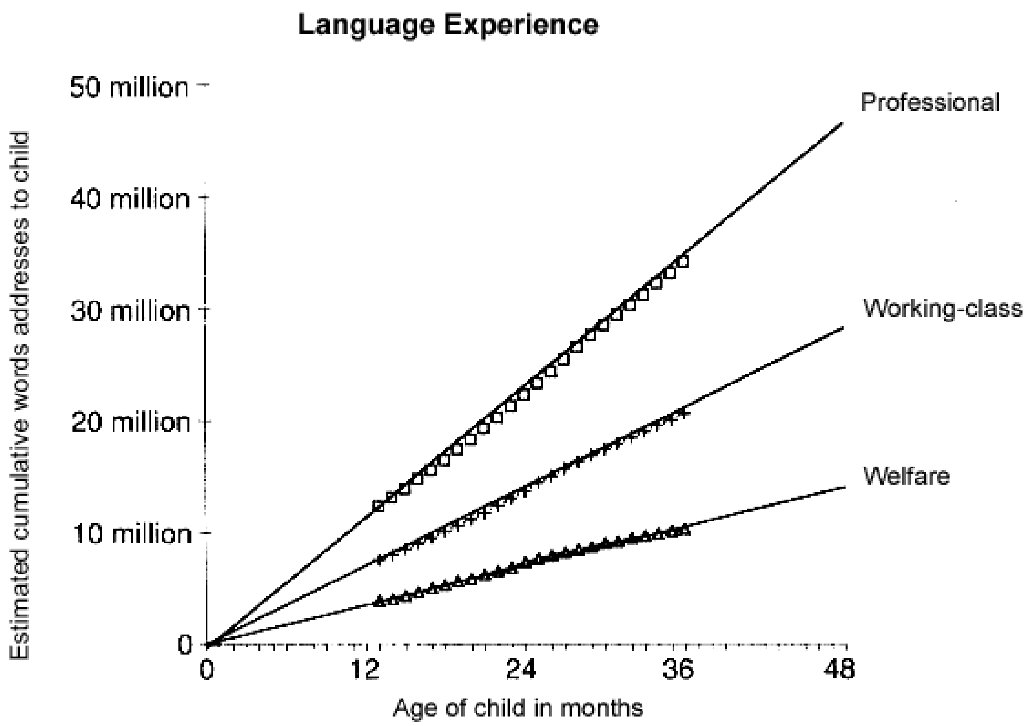


Figure 1.2 Language Experience as a Function of Home Environment. Estimated projections of cumulative words heard within the home environment at each year of life up to age 4 years for children living in higher, middle and lower SES families. Image taken from Hart & Risley (1995).

Collectively, these studies identify a discrepancy, as a function of environment, between children from lower and higher SES backgrounds. In an effort to augment the learning of underprivileged children, various forms of interventions have been developed with mixed outcomes. Interventions attempt to capitalize on neuroplasticity by supplementing a child’s environmental input with rich stimuli in order to reduce or ameliorate the adverse effects of environmental deficit or deprivation on learning and school readiness. The ideal outcome of childhood interventions for children living in lower SES households is to enhance and promote learning opportunities within the childhood years, thus helping to bridge the gap between disparities in learning experiences and skill, and give all children an opportunity for success (Hart & Risley, 2003).

1.7 Intervention Programs Targeting Children in Poverty

Head Start, created in 1965, is designed to provide childcare and improve the school readiness skills of 3-5-year-old children from impoverished families (U.S. Department of Health and Human Services, 2010b). The Head Start program has offered one of the best sources of long-term intervention data on preschool children. Combined with Early Head Start (EHS) adopted in 1994, which provides services to expecting mothers and their children from birth to age 3 years, the United States government works to ensure that families and children living in poverty can have access to continuous and comprehensive services beginning with prenatal care up to age 5 years. Analyses of the long-term outcomes of children who attended Head Start indicated higher earnings, decreased illegal activities, and positive health outcomes (Ludwig & Miller, 2007). Similar outcomes were seen as a product of EHS, including gains between age 2 and 3 years in cognitive, language, and social-emotional development, many of which were still evident at age 5 years, as well as sustained parental support for children's language and literacy (Love & Brooks-Gunn, 2010). Children who participated in EHS programming were also more likely to enroll in formal preschool than children not participating in EHS, and children who participated in EHS followed by formal preschool in the 3-5 year age range had the most favorable outcomes prior to entering Kindergarten (Love & Brooks-Gunn, 2010).

Although many other childhood intervention programs have been implemented, few have employed valid and reliable designs, which reduce their predictive power (Raizada & Kishiyama, 2010). However, two of the most well-studied preschool interventions, which utilized quasi-randomized study designs, are the High/Scope Perry Preschool Project (Schweinhart et al., 2005) and the Abecedarian Project (Campbell, Ramey, Pungello, Sparling, & Miller-Johnson, 2002).

The High/Scope Perry Preschool Project was implemented between 1962 and 1967 in Ypsilanti, Michigan. Briefly, African American children from lower income households were randomly assigned to preschool intervention at age 3 or 4 years of age, or a no-preschool intervention group. Intervention included half-day preschool services with weekly home visits provided by project staff. Data was collected at age 3 through 11 years, and again at ages 14, 15, 19, 27, and 40 years (Schweinhart et al., 2005). Children participating in the intervention out-performed the non-intervention group on intelligence and language tests from preschool through age 7 years, and on achievement tests at ages 9, 10, and 14 years. At ages 15 and 19 years, children who had participated in the intervention and their parents had significantly more positive attitudes toward school (Schweinhart et al., 2005). Longitudinal data acquired when the children were age 40 years indicated that intervention participants were more likely to be employed and had a significantly higher average annual income compared to non-intervention children, which was a continued trend from age 27 years. Results also indicated intervention participants at age 40 years had more stable dwellings and were more likely to have a savings account. Intervention participants were less likely to have been arrested for violent, property, or drug-related crimes, and were less likely to have served prison/jail sentences. Additionally, more intervention participants reported getting along well with their families and fewer males who were in the intervention group reported using sedatives, sleeping pills, or illicit drugs, such as marijuana or heroin compared to non-intervention peers (Schweinhart et al., 2005).

Similarly, the Abecedarian Project targeted children from lower SES households, although the implementation differed slightly from that of the High/Scope Perry Preschool Project. Low-income children received full-day care beginning in early infancy and continuing, year-round, over the course of 5 years. The Abecedarian preschool curriculum focused on fostering child-adult interaction and group orientation (Campbell et al., 2002). At 48 months of age, intervention and control children were matched and randomly assigned to a school-age intervention or a control group (Campbell, et al., 2002). On average, children who attended the Abecedarian program in preschool had lower placement in special education settings and lower rates of grade retention, as well as an academic advantage evidenced by higher IQ scores persisting through age 15 years (Campbell et al., 2002). Longitudinal evaluations at age 21 years indicated that program participants had higher scores on reading, mathematics, and cognitive tests, were more likely to attend a 4-year college or university, and were less likely to become teen parents than non-intervention controls (Campbell et al., 2002).

Together, these early studies provide evidence that early childhood programs targeting lower SES children appear to ameliorate many of the short-term and long-term adverse effects of poverty. However, a critique of these previous intervention programs is they fail to identify which specific neurobiological systems appear to be changing in response to intervention. This makes it virtually impossible to empirically identify which aspects of the intervention contribute to the greatest gains, or changes, in behavior and functioning. Additionally, these programs were resource-intensive, requiring significant funds and personnel to run. This makes them impractical to scale-up for broader implementation. A need has been identified to develop a cost-effective intervention program, which can be utilized for more widespread application. Additionally, it is imperative that interventions are evaluated using ecologically valid measures in order to assess the causal mechanisms underlying intervention outcome differences as a product of intervention in individuals of varying SES backgrounds, and then use these results to inform both intervention design and policy (Shonkoff et al., 2012; Shonkoff & Fisher, 2013).

Recent emphasis has emerged on targeting the neurobiological systems underlying behavior/functions of interest, which can help facilitate the effectiveness of childhood intervention programming (Fishbein, 2000). One assessment technique that employs biologically- based outcome measures is electroencephalography (EEG) and event-related brain potentials (ERPs) (Bruce, McDermott, Fisher & Fox, 2009). This neurophysiological measure can be a valuable tool to measure and compare the differential effects of individuals who participated in an intervention at the neural level. These findings can then contribute greater predictive power as to who can benefit from an intervention than behavioral data alone (Raizada & Kishiyama, 2010).

1.8 Event-Related Brain Potential (ERP) Indices of Language Processing

Advances in technology over the past thirty years have made it possible for scientists to capture neural processing within the human brain at the physiological level. This is done by fitting Ag/Ag-Cl electrodes embedded in an elastic cap onto the scalp, which captures and records the highly organized electrical transductions in the brain elicited by sensory, motor, and cognitive events, which occur spontaneously, or in response to sensory stimuli (Pilgreen, 1995). This electrical activity is generated by populations of neurons housed in the cerebral cortex firing in synchrony, which can be measured at the level of the scalp and is called electroencephalography, or EEG (Pilgreen, 1995). The electrical indices of neural processes recorded using EEG can be time-locked to specific stimuli, providing information about neural responses to a specific event. These time-locked neurophysiological responses are called event-related brain potentials, or ERPs, which when averaged together over many trials, appear as wave forms that reflect specific cognitive processing operations with exquisite temporal resolution, on the order of milliseconds, such as encoding, memorizing, integrating, or selecting information (Nunez, 1995). This results in a strong, clear ERP component (Kaan, Harris, Gibson, & Holcomb, 2000) that can be identified and analyzed. ERPs can be identified according to their shape, timing (latency), amplitude, and distribution across the scalp (topography) (Luck, 2012) and analyzed based on amplitude, latency, and scalp distribution characteristics (e.g., Luck, 2012). For example, reduced amplitude ERP components are suggested to reflect reduced synchronous firing of neurons in response to specific stimuli (Luck, 2012). ERPs are also beneficial because they show differences in timing, sensitivity, and scalp topography as a function of age and development, and can be used to index processes underlying language specific aspects of cognition, such as language (Holcomb et al., 1992; Friederici, 2002; Hahne, Eckstein, & Friederici, 2004; Friederici, 2011).

ERPs allow for the measurement of language processing abilities in young children. ERPs are noninvasive and child-friendly, with a quick application time and minimal limitations during acquisition. For example, children can take breaks and move around as needed, making ERPs more child-friendly than other neuroimaging techniques. ERPs can serve as an outcome measure to assess the effectiveness of interventions by providing essential information regarding changes in neurobiological systems for language, which are particularly malleable in young children, as a function of intervention.

The processing of language within sentences involves the brain integrating syntactic and semantic information from incoming words within the context of previous sentence information

(Kaan et al., 2000; Friederici, 2011; Friederici, 2015). ERP indices of language processing include the N400, which reflects the processing of semantic information, and the P600, which is the neural correlate of syntactic processing. These components are described in detail below.

1.8.1 Semantic Processing

Semantic processing in adults is typically indexed by a biphasic waveform consisting of a negativity, the N400, followed by a larger positivity, the Late Positive Component (LPC). The N400 is an ERP component widely considered to index semantic processing. The N400 is a negative component typically occurring between 200 and 600 ms post-stimulus onset, peaking around 400 ms in adults, with a centroparietal distribution (Figure 1.3; Kutas & Federmeier, 2011; Kutas & Hillyard, 1984). In sentences, the N400 is often elicited by semantic anomalies or violations of semantic expectancy, and as such is thought to reflect semantic access, retrieval and/or integration, or the degree of relationship between a word and the linguistic context preceding it (Kutas & Hillyard, 1984). The mean amplitude and peak latencies of the N400 are associated with degree of 'expectancy', in that words that end a sentence in an unexpected or nonsensical way elicit larger N400s compared with semantically appropriate or more anticipated words (Kutas Hillyard, 1984). The degree of expectancy of a word is the 'cloze probability', defined as the likelihood that a word is used in a given context. Cloze probability is determined by the number of individuals who would choose a particular word to continue a sentence when considering the context in which the word would appear (Kutas & Federmeier, 2011). The N400 can be elicited across modalities, including pictures, visual and auditory words and sentences, American Sign Language, and pseudo-words (Kutas & Van Petten, 1994).

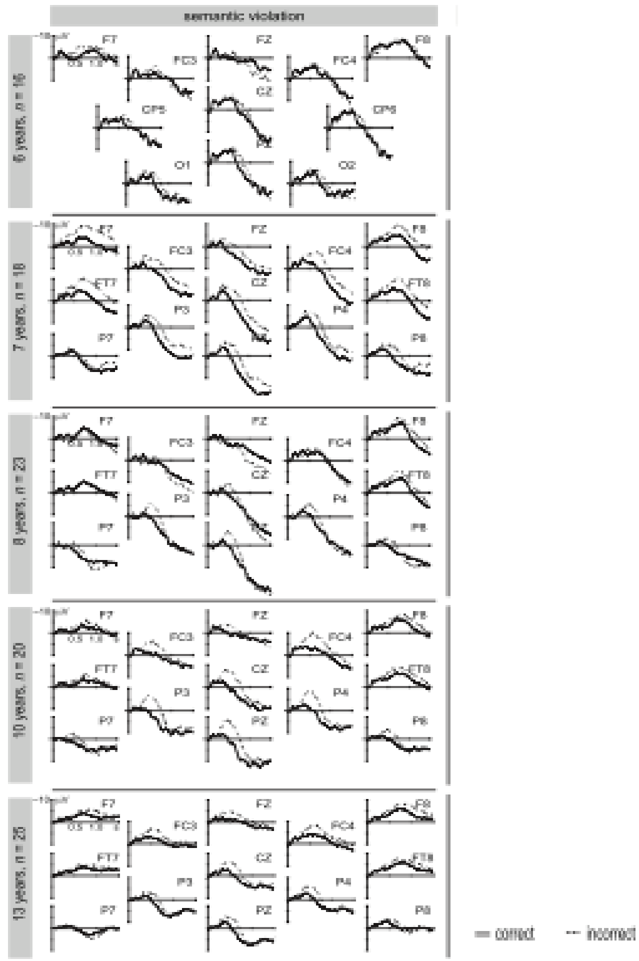


Figure 1.3 ERPs Elicited by Semantic Violation Sentences Across Age Groups. Graphic display of the average of ERPs elicited by critical words in a semantic violation condition across different age groups. The violation condition (dotted line) is plotted against the correct condition (solid line). The vertical line indicates the onset of the critical word and negative voltage is plotted upward. This figure illustrates the maturation of semantic processing from age 6 to 13 years. Image taken from Hahne, Eckstein, & Friederici (2004).

The N400 is present very early in development, as N400 effects have been observed in infants as young as 9 months of age (Reid, Hoehl, Grigutsch, Groendahl, Parise, & Striano). The amplitude of the N400 elicited in 19-month-old toddlers during a sentence-level semantic integration task, predicted stronger language skills at 30 months (Friedrich & Friederici, 2006). As children age, they gradually are less reliant on contextual information to comprehend sentences, evidenced by decreased amplitude and earlier latency of the N400 across development (Hahne et al., 2004; Holcomb et al., 1992). Older children exhibit smaller N400 amplitudes and earlier latencies than younger children (Hahne et al., 2004; Holcomb et al., 1992), and individuals who have higher language proficiency generally exhibit smaller N400 mean amplitudes and earlier latencies than individuals with lower language proficiency (Hampton Wray & Weber-Fox, 2013; Neville, Coffey, Holcomb, & Tallal, 1993; Weber-Fox Davis & Guadrado, 2003). For the N400, smaller amplitudes and earlier peak latencies are thought to indicate more efficiency and greater ease in integrating meaning during language processing (Hahne et al., 2004; Holcomb et al., 1992).

The second ERP component elicited by semantic constraints is the Late Positive Component, or the LPC, which has also been referred to in the literature as the Post-N400-Positivity (PNP). The LPC is an enhanced positive-going waveform that follows an N400 response, and is generally maximal over parietal electrode sites in adults (Van Petten & Luka, 2012). The LPC is considered to reflect reanalysis or a re-checking of sentences considered to be semantically incongruent, and is thought to index similar neural functions to that of the P600, discussed below (Van Petten & Luka, 2012).

1.8.2 Syntactic Processing

Syntactic processing is also indexed by a biphasic ERP response, with an earlier, more anterior negativity followed by a later, more posterior positivity in adults and typically developing children. The Left Anterior Negativity, or LAN, emerges between 200-600 ms post-stimulus onset and is most prominent in the left hemisphere. The LAN is consistent in adults, though is less reliable in children. The LAN is thought to reflect the identification of a violation which produces a mismatch, or error, in a predicted syntactic structure (Molinaro, Barber, & Carreiras, 2011), and is considered an index of syntactic processing (Friederici, 2002, Friederici, 2011; Batterink & Neville, 2013). More specifically, the LAN is considered an index of neural functions that assess syntactic and thematic relationships, and identifies mismatches of these relationships. Mismatches require reanalysis of the sentence, which is indexed by the P600 response. The P600 component, generally peaks around 600 ms after the onset of a stimulus in adults, with a centroparietal distribution (Figure 1.4; Kaan et al., 2000). The P600 is generally associated with reanalysis of violations of a rule-based expectancy (Schmidt-Kassow & Kotz, 2009), such as processes of syntactic repair and/or reanalysis (Friederici et al., 2006) or difficulty of syntactic integration (Kaan et al., 2000). The P600 is generally elicited by syntactic aberrations, such as ungrammatical sentences or garden-path sentences (Gouvea, Phillips, Kazanina, & Poeppel, 2010). Studies utilizing phrase structure violations to elicit a P600 have shown that increasing chronological age (Hahne et al., 2004), and greater language proficiency (Hampton Wray & Weber-Fox, 2013; Pakulak & Neville, 2010) are associated with a more robust, or larger amplitude, as well as earlier latency P600 to syntactic violations. This suggests that with age and the development of stronger neural connections for language, more neural resources are dedicated to reanalysis and repair of syntactic violations, and these processes may occur more quickly than in individuals with lower language proficiency (Hahne et al., 2004; Pakulak & Neville, 2010; Hampton Wray & Weber-Fox, 2013).

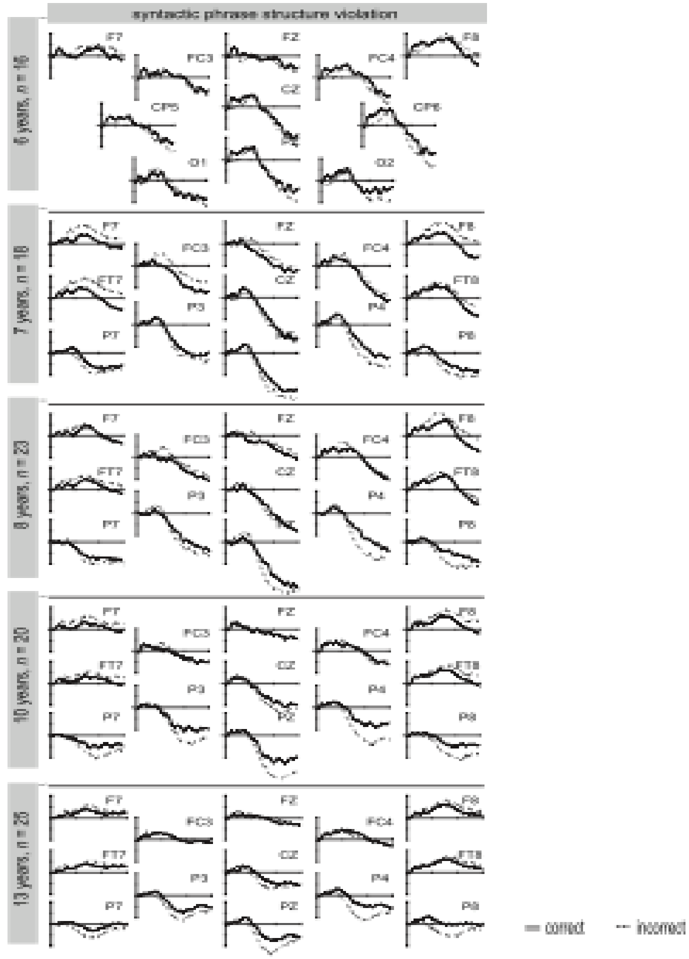


Figure 1.4 ERPs Elicited by Syntactic Violation Sentences Across Age Groups. Graphic display of the average of ERPs elicited by critical words in a syntactic violation condition across different age groups. The violation condition is plotted (dotted line) against the correct condition (solid line). The vertical line indicates the onset of the critical word and negative voltage is plotted upward. This figure illustrates the maturation of syntactic processing from age 6 to 13 years. Image taken from Hahne, Eckstein, & Friderici (2004).

It is generally agreed that children have acquired the basic phonological, morphosyntactic and semantic rules of their primarily language by the age of 3 years (Pinker, 1984). Children, however, still make grammatical errors in their speech even after age 7 years, which are not heard in the speech of adults. This suggests the syntactic parsing system in children has a longer time course of development compared to other linguistic systems (Friederici, 1983). It has been postulated that skills in processing syntactic information in the absence of semantic context does not reach adult-level automaticity until around school age, which is quite late in language development (Friederici, 1983). It has also been observed that neural responses to syntactic violations occur even in the absence of conscious awareness (Batterink & Neville, 2013). Despite being in the early stages of syntactic development, preschool-age children have been found to exhibit a later positivity, or P600, to violations of syntax (Silva-Pereyra, Rivers-Gaxiola, & Kuhl, 2005; Weber-Fox et al., 2013). However, these responses peak later and have a broader scalp distribution in preschool children compared to adults (Silva-Pereyra et al., 2005; Weber-Fox et al., 2013).

There is evidence that engagement of syntactic processes varies as a function of language proficiency. Lower proficiency, adult English-speaking, monolinguals show a more focal, larger, and more diffusely distributed P600 effect than higher proficiency individuals. This suggests individuals with less sophisticated syntactic parsing systems are less efficient at processing the components of language; hence, they must recruit more cognitive regions to devote to syntactic reanalysis and repair (Pakulak & Neville, 2010). Similar findings have also been reported in 7-to 8-year-old children, as higher non-verbal IQ, stronger working memory capacities, and stronger receptive language skills have been associated with greater speed and efficiency of syntactic, as well as semantic processing (Hampton Wray & Weber-Fox, 2013).

1.9 Dual-Generation Intervention Programs

To maximize the potential effectiveness of intervention for young children, family-centered programs that incorporate parent trainings have been shown to produce robust gains in children's cognitive abilities and academic achievement (Burger, 2010). A multi-generational approach combined with a thorough understanding of the neural underpinnings of behavior should be of paramount consideration when designing and implementing prevention or intervention models (Bryck & Fisher, 2012). Some researchers also suggest that a neurocognitive "profile" of poverty could be developed for children in need, which could be used to identify and target vulnerable neural systems with strategic intervention, thus increasing the efficiency and effectiveness of treatment (Farah et al., 2006). These strategies would be beneficial in avoiding the challenges reported by previous early childhood intervention studies, such as the Perry Preschool and Abecedarian Projects. These projects did not employ neurophysiological outcome measures, leaving a gap in understanding of their mechanisms of change. Furthermore, these projects were unrealistically expensive, and the treatment duration was long, making it not realistic for them to be scaled up for broader implementation (Barnett, 1995; Burger, 2010) Therefore, a conscious blending of neurobiological, developmental, and preventative sciences, applied within a multi-generational intervention framework has the potential to create a unified model of practice. This intervention model could be used to generate a scientifically grounded, cost-effective method for monitoring the trajectories of children and families from disadvantaged backgrounds over time (Shonkoff & Fisher, 2013). A recent intervention designed to address these needs in a cost-effective program is Parents and Children Making Connections – Highlighting Attention (PCMC-A).

1.9.1 Parents and Children Making Connections - Highlighting Attention

PCMC-A has been specifically designed for young children and families from lower socioeconomic status backgrounds. PCMC-A is designed to reduce many of the challenges of previous interventions targeting children and families from lower SES environments; it is relatively short in duration building on research from developmental, behavioral, and cognitive neurosciences and intervention sciences, and engages the power of a dual-generation approach to early childhood intervention. PCMC-A employs a teaching model with a strong family-centered focus to improve home environment and school readiness skills, with a focus on parent-child interactions. This training program also utilizes electrophysiological outcomes measures (ERPs) to assess changes in neural processes as a function of intervention.

PCMC-A was designed and previously evaluated by Neville and colleagues (2013); the original study of PCMC-A investigated the plasticity of neural processes underlying selective attention. PCMC-A was developed to target attention using an approach, which engaged not only the child, but also the child's family and home environment. 141 children from lower SES backgrounds attending Head Start preschools participated in the original study and were randomly assigned to PCMC-A or to one of two comparison groups: the active comparison group, Attention Boost for Children (ABC), or Head Start Alone (HS-Alone). Children assigned to PCMC-A received weekly small group training while parents/caregivers of children in PCMC-A simultaneously participated in weekly small group parent training in the evenings or on weekends for eight weeks. ABC consisted of a strong emphasis on child, with 40-minute small-group training sessions within their regularly scheduled Head Start program four days/week for eight weeks daily, with only three parent training sessions over eight weeks. The children assigned to HS Alone comparison group attended their typical half-day Head Start program as usual over the course of the 8-week treatment phase and received no direct intervention from project staff. Details of the parent and child components of PCMC-A, as well as the HS alone condition, are described in detail in the Method section. For ease of explanation, all subsequent references to parents and/or caregivers who participated in PCMC-A or comparison groups will be referred, henceforth, as 'parents' or 'families'.

Consistent with the design of the current study, Neville and colleagues (2013) used ERPs as a neurobiological outcome measure to assess changes in selective attention as a function of intervention. A battery of standardized behavioral assessments was administered to evaluate nonverbal intelligence (IQ), receptive language, and pre-literacy skills. Parent self-reports of parenting confidence and ability, as well as parent report of children's social skills and problem behaviors were also administered. The researchers hypothesized that children randomly assigned to PCMC-A would exhibit enhanced neural processes for selective attention as indexed by ERP components, which would be facilitated by the greater engagement of parents/caregivers in weekly training. It was also hypothesized these changes would be accompanied by gains in nonverbal IQ, receptive language, and pre-literacy skills as measured by standardized assessments.

As hypothesized, differences in the degree of improvement in selective attention skills from pre- to post- intervention were observed between groups. Children assigned to PCMC-A showed significantly greater changes in their neural responses elicited by attended probes following the 8-week intervention compared to children in the ABC group and HS-Alone group (Neville et al., 2013). Neither the ABC group nor HS-Alone group exhibited significant changes in their neurophysiological responses elicited by attended stimuli from pre- to post- intervention testing. In addition, children in the PCMC-A group exhibited greater improvement in nonverbal intelligence scores relative to children in the HS alone and ABC groups, and the PCMC-A group also displayed significantly enhanced receptive language scores compared to the HS-Alone and the ABC groups.

Parents of children in PCMC-A reported larger improvement in their child's social skills when compared to HS alone and ABC groups, as well as a greater reduction in their child's problematic behaviors relative to parental reports from both comparison groups. Teacher reports of skills and problem behaviors followed a similar pattern to parent reporting. In addition, as indexed by self-reports, parents who participated in PCMC-A reported a reduction in parenting stress relative to the HS alone parents, and a trend toward less stress relative to the parents in the ABC group.

This study provided evidence that the neural mechanisms underlying selective attention in preschool children from lower SES backgrounds can be enhanced using a strategic dual-generation intervention within a relatively short time course of 8-weeks, such as PCMC-A. In addition, the overwhelmingly positive outcomes from parent who received PCMC-A lend support to its use as a family-based training.

Neville and colleagues (2013) provided the initial steps in detailing the multi-faceted positive impact PCMC-A can have on preschool children and their families; however, to date, there has been no evaluation of its efficacy on enhancing the neural mechanisms underlying language. Children from lower SES backgrounds are particularly susceptible to language-related deficits (Hoff, 2003), and early language skills have been consistently cited as a key contributor to children's academic growth and future academic and social success (Bradley & Corwyn, 2002; Hart & Risley, 2003). Therefore, it is critical to determine if language regions of the brain can also be enhanced using a brief, 8-week intervention, such as PCMC-A.

1.10 Objectives and Research Questions

The objective of the current project was to determine whether a relatively short (8-week) strategic dual-intervention would enhance the neural processes underlying language in preschool-age children from lower SES backgrounds. PCMC-A enhanced behavioral language proficiency and nonverbal IQ, and the effects of selective attention on neural processes in children from lower SES backgrounds compared to both active and passive control groups. This study aimed to determine whether PCMC-A also effects similar change on neural processes underlying language. The specific aims of this study are as follows:

Aim 1: Determine whether neurobiological markers of language change as a function of intervention. We hypothesized that children participating in PCMC-A would exhibit significant changes in neural processes underlying language as indexed by a reduction in N400 amplitudes elicited by semantic violations, and increased amplitudes of the P600 elicited by syntactic violations after intervention, which would not be observed in children participating in Head Start alone.

Aim 2: Characterize the relationships between behavioral measures of language and mechanisms for language processing resulting from exposure to PCMC-A intervention. We hypothesized that children who exhibited greater changes in neural processes for language would also exhibit larger increases in performance on behavioral assessments.

The findings from this project will inform the nature and extent of changes in language skills following a brief dual-generation intervention that targets attention. If the hypotheses are upheld, this project will provide direct evidence that early education programs targeting attention that include parents as key players can impact both attention and language skills in younger children. These are foundational abilities for long-term academic achievement and could improve the academic and life outcomes for children growing up in lower SES environments. Furthermore, findings from this study could have implications for the development of novel, or refinement of existing, early childhood programs and provide support for funding of early childhood education programs. Both of these long-term outcomes could potentially benefit a significant number of children and their families living in poverty in the United States and around the world.

2. METHOD

2.1 Participants

The current study involved data from 118 children recruited from Head Start preschools in Eugene and Springfield, OR. All children were part of a broad-scale evaluation of a dual-generation intervention program for families from lower SES backgrounds, part of which has already been published (Neville et al., 2013). Inclusionary criteria included data from both pre-intervention and post-intervention behavioral and electrophysiological testing; each child was a right handed, native, monolingual speaker of English; no diagnosis of behavioral or neurologic conditions; no medications which may alter their mental status or neurophysiological function; normal nonverbal IQ, language, and hearing abilities, and no Individualized Family Service Plan (IFSP). Of the 118 participants qualified for this study, 13 participants were excluded from the PCMC-A group and 7 participants were excluded from the Control group due to excessive artifact in pre-test and/or post-test data. This yielded a final sample of 98 total participants who were previously randomly assigned after pre-testing was complete to participate in the experimental group, PCMC-A, N = 55 (33 F), or to the Control group, N = 43 (28 F). The majority of children whom participated were White/Caucasian, followed by 17% who reported more than one race, 3% Black/African American, 6% American Indian, and 9% whom did not identify a race or ethnicity. Based on previous studies of neural processes for language in children (Hahne et al., 2004; Hampton Wray & Weber-Fox, 2013; Neville et al, 1993; Weber-Fox et al., 2013; Usler & Weber-Fox, 2015) and power analyses, 98 participants provided adequate power (0.08) to detect effects sizes comparable to previous behavioral and ERP studies in children with alpha = 0.05.

Children participating in this study were from lower SES backgrounds. A composite score of each family's social status was derived from the Hollingshead Four-Factor Index of SES (Hollingshead, 1975). Status scores are computed from information regarding Head or Heads of household's education, calculated on a 1-7 scale, and their occupation, calculated on a 1-9 scale (Figure 1.2 a-b). Scoring instructions are provided to identify which person or persons constitute a Head or Heads of a household, and scoring also accommodates situations in which a Head of household has never been married, or if a Head of household is separated, divorced, deceased, or is retired. When the Head or Heads of a household have been identified, the status score is derived by multiplying an individual's scale value for occupation (1-9) by a factor of 5, and the scale value for education (1-7) by a factor of 3. In cases where two Heads of households are identified, each individual's status score is summed and divided by 2. Computed scores for families range from a low of 8 to a high of 66. Demographic information, including SES, for each family participating in the current study is presented in Table 2.1. On average, families in both groups participating in this study fell within the second tier of social strata, generally indexing semiskilled workers. There were no significant differences between groups in all demographic characteristics, including age, SES, maternal education, and paternal education (all $F(1,96) < 2.1$, all $p > 0.15$).

Table 2.1 Participant Demographic Characteristics by Group. Summary of participant demographic characteristics by group, as well as standard scaled scores of behavioral assessments at pre-and post-test.

	PCMC-A		Head Start Alone	
	Pre-Test	Post-Test	Pre-Test	Post-Test
N	55		43	
# Females	33		28	
Age in Years (*SD*)	4.53 (*0.08*)		4.44 (*0.08*)	
Maternal Education (*SD*)	4.48 (*0.14*)		4.73 (*0.14*)	
Paternal Education (*SD*)	4.36 (*0.14*)		4.42 (*0.16*)	
Socioeconomic Status (*SD*)	29.47 (*1.52*)		29.22 (*1.75*)	
Nonverbal IQ (*SD*)	11.72 (*0.28*)	12.24 (*0.26*)	12.38 (*0.37*)	12.36 (*1.96*)
Receptive Language (*SD*)	10.29 (*0.28*)	11.39 (*0.25*)	10.47 (*0.21*)	11.41 (*0.19*)

Table 2.2 Scoring Values from Hollingshead Four-Factor Index of SES. Summary of scoring values to compute (a) scale values of an individual's education, as measured in years of school completed, and (b) computed scores to determine household social status, as measured by combining scale values of an individual's education and occupation of the Head or Heads of household. (Taken from Hollingshead, 1975)

(a)

Level of School Completed	Score
Less than seventh grade	1
Junior high school (9^{th} grade)	2
Partial high school (10^{th} or 11^{th} grade)	3
High school graduate (whether private preparatory, parochial trade, or public school)	4
Partial college (at least one year) or specialized training	5
Standard college or university graduation	6
Graduate professional training (graduate degree)	7

(b)

Social Strata	Range of Computed Scores
Major business and professional	66-55
Medium business, minor professional, technical	54-40
Skilled craftsmen, clerical, sales workers	39-30
Machine operators, semiskilled workers	29-20
Unskilled laborers, menial service workers	19-8

2.2 Behavioral Testing

Each child participated in behavioral and electrophysiological testing. Data acquisition was performed on two separate days within 30-day windows prior and upon completion of the 8-week program to assess changes as a function of intervention. Each behavioral testing session lasted approximately 2 hours, with rewards and breaks as needed. All children completed a battery of behavioral assessments evaluating aspects of nonverbal intelligence, receptive language, self-regulation, and pre-literacy skills.

The Stanford-Binet Intelligence Scales (SB-5; Roid, 2003) was used to assess nonverbal IQ. Scaled standard scores of the Working Memory, Fluid Reasoning, and Quantitative Reasoning subtests from the SB-5 were compiled to produce an Average Composite IQ score (CIQ) for each participant, which are indexed in Table 1.1. No significant difference in nonverbal IQ scores existed between groups at pre-test (F (1,96) = 2.1, $p > 0.15$).

All participants were administered the Clinical Evaluation of Language Fundamentals-Preschool-2 (CELF-P2; Wiig, Secord & Semel, 2004) to evaluate receptive language skills before and after the 8-week intervention phase. Scaled standard scores from the Concepts and Following Directions and Sentence Structure subtests of the CELF-P2 were compiled to obtain an average Composite Receptive Language score (CLA) for each child. Average receptive language scores of each group are detailed in Table 1.1; with no differences in language scores between groups present at pre-test (F (1,96) = 1.01, $p > 0.32$).

Behavioral assessments also included the Preschool Individual Growth and Development Indicators (Early Childhood Research Institute on Measuring Growth and Development, 1998) to assess pre-literacy and phonological awareness skills; parent and teacher reports of child social skills and problem behaviors, and parental self-reports of parenting confidence and ability. Pre-literacy measures and parent and teacher reports are not reported in the current study. The exact same battery of tests was administered at pre- and post-test, using alternative test forms as available.

2.3 Intervention

Following the successful completion of behavioral and EEG pre-testing sessions, all children and families were randomly assigned to PCMC-A intervention (PCMC-A) or to continue participating in Head Start as usual (HS-alone). Neville and colleagues (2013) described the results of the effects of PCMC-A on attention and included an active control group. However, as PCMC-A was found to be more effective in changing child outcomes (Neville et al., 2013), data acquisition for this group was discontinued. Therefore, the current project only includes data from PCMC-A and Head Start alone groups. Children and families randomly assigned to the PCMC-A treatment group participated in their respective training component one evening per week for 8 consecutive weeks. Child and adult sessions occurred simultaneously, but in separate rooms. Meals were provided for both children and parents during the weekly child-parent classes as well as to additional children in the home during each intervention session.

2.3.1 Child Component of PCMC-A

The child component of PCMC-A encompassed a set of 20 activities, which were completed in groups of 4-6 children and 2 adults. Child component activities were designed to increase school readiness skills, such as emotional awareness and regulation, task switching, vigilance, and selective attention. In each session, 2-4 activities were targeted and all activities were vetted by Head Start teachers who were not participating in the study prior to the activity being selected for intervention. An evidence-based instructional model was used to address the goals of intervention, which incorporated teacher scaffolding, multi-sensory activities, transitions from externally to internally mediated behavior, and a hierarchical succession of task difficulty, which moved from simple to complex. For example, one selective attention activity required children to engage in a task demanding a high degree of focused attention (e.g. coloring within the lines of an intricate picture) while suppressing their attention to simultaneously occurring distracting stimuli (e.g. other children in the group bouncing balloons in the area near them). Children would switch roles so all children had an opportunity to have an attending and distracting role within the session. This activity would progress in difficulty so that distraction methods became more intense and demanded greater skill in distraction suppression.

Intervention activities also targeted skills in self-regulation and the identification of emotional states. Session activities included games such as "Emotional Bingo" in which children matched common emotions with their corresponding facial expression. This activity fostered the use of emotional vocabulary and the recognition of emotional states (e.g. identifying body language associated with a specific emotion). This task progressed to practice in emotional communication and emotional regulation techniques (e.g. taking a deep "bird breath" to promote calming of one's emotional response), which were reinforced with visuals during intervention and at home.

2.3.2 Parent Component of PCMC-A

The parents of children enrolled in PCMC-A participated in 8 weekly 2-hour small group sessions, which followed an instructional curriculum adapted from Linking the Interests of Families and Teachers (LIFT) developed at the Oregon Social Learning Center (Reid, Eddy, Fetrow, & Stoolmiller, 1999). Sessions consisted of 4-6 parents/caregivers and 1 interventionist who targeted a set of 25 strategies over the course of the 8-week intervention using a goaloriented, self-motivating, and self-reflective approach. These strategies focused on increasing parent/caregiver responsiveness, effective problem solving, contingency-based discipline, stress management, and ways to promote language use with their children. For example, parents/caregivers were asked to monitor their language when addressing their children, with particular attentiveness to the proportion of positive language (praise) and negative language used during communicative exchanges at home. Training was provided in techniques to modify child-directed speech so it included more positive feedback (e.g. a decrease in "neutral" words and an increase in using "specific praise" and "specific noticing") to enhance self-confidence in their child.

In addition to the quality of language input parents were providing, parents were also encouraged to be aware of their proportion of language use relative to their child. A 'piggy bank' analogy was used to help families understand and remember to "match" their child's number of utterances during communicative exchanges. This metaphor was used to facilitate more balanced turn-taking between parents and children.

Strategies to reduce stress and enhance predictability within the home environment were also encouraged. These strategies included training for families in implementing picture-based schedules and weekly success charts. Training also focused on increasing success with daily routines, such as getting ready for school, meals, and bedtime. Structured routines were scaffolded throughout the 8-week intervention to incorporate child-directed daily and weekly schedules to facilitate independence and decision-making. In addition to group sessions, weekly phone calls were made by research personnel to clarify instructions and answer questions about the implementation of home-practice activities.

2.3.3 Comparison Group: Head Start Alone (HS-Alone)

Children randomly assigned to the control group for this study attended Head Start preschool as usual over the course of 8-weeks. Typical Head Start classes do not involve any specific instruction in selective attention or language. The Head Start curriculum does contain a parent education component; however, it is limited. Head Start Family Advocates (FAs) are responsible for making three visits to the family home per year and parents are encouraged to make a visit to their child's classroom at least twice per school year. Phone calls are made at least once per month to provide reminders for upcoming family events and also to share information regarding Head Start services and policies. Importantly, there is no *required* parent component to the Head Start curriculum.

2.4 Sentence Stimuli

A child-friendly language processing paradigm was used to assess semantic and syntactic processing. This paradigm consisted of experimentally manipulated sentences presented in a narrative format with an accompanying cartoon. The sentence stimuli and paradigm were developed at the University of Oregon's Brain Development Laboratory under the direction of Dr. Helen Neville, and involved five cartoon movies featuring a Claymation penguin, named "Pingu". Presentation software was used to display the cartoons on monitors subtending a visual angle of approximately 5° horizontally and 4° vertically to minimize eye movement. Each of the five movies lasted approximately 5-7 minutes, and were overlaid with 100 auditory sentences narrated by a naturally spoken male or female voice presented at an average intensity of 70-75 dB SPL. To ensure the sentence stimuli contained age-familiar vocabulary, the words used to construct the sentences were chosen from the MacArthur Communicative Development

Inventories: Words and Sentences component (Fenson, Marchman, Thai, Dale, Reznick, & Bates, 2007). The “Pingu” paradigm has been used in previous studies with different populations of young children, including children who stutter (Weber-Fox, Hampton Wray, & Arnold, 2013; Usler & Weber-Fox, 2015).

There were a total of 500 auditory sentences used to narrate the “Pingu” cartoons. These sentences contained five different violation conditions, which consisted of semantic anomalies, phrase-structure violations, irregular verb agreement, regular verb agreement, and jabberwocky sentences. Each linguistic constraint consisted of 50 correct and 50 anomalous sentences (Weber-Fox et al., 2013) and each violation sentence had a corresponding English control/canonical sentence. For example, the semantically anomalous sentence, “She closes her *head* on Pingu” would have a corresponding control sentence of, “She closes her *door* on Pingu”. An example of a phrase structure violation sentence would be, “Pingu chews with that *his* mouth open”, which would have a corresponding control sentence of, “Pingu chews with *his* mouth open”. An example of a regular verb agreement violation sentence would be, “His mommy *hug* him”, and the canonical counterpart would be “His mommy *hugs* him”. An irregular verb agreement violation sentence would be, “This *are* Pingu’s family” and the corresponding canonical sentence would be, “This *is* Pingu’s family.”

Jabberwocky sentences were constructed by replacing all content words (nouns and verbs) with phonologically pronounceable, meaningless non-words, however English grammar remained intact. Embedded in the Jabberwocky sentences were identical violations that matched a corresponding English sentence, which acted as a control to the Jabberwocky sentence. An example of a phrase structure violation sentence in Jabberwocky would be, “Moonoo and dobah hokee at that *their* sim", which would have a corresponding Jabberwocky phrase structure control sentence of "Moonoo and dobah hokee at *their* sim".

Although data was collected from all five linguistic constraints for each child at pre- and post-testing, the current project focused only on the semantic and phrase-structure conditions. For ease of abbreviation, the phrase-structure condition will be referred to as the "syntactic" condition.

2.5 Procedures

All children were seated approximately 172 cm from a 47.5-cm video monitor inside of a sound-attenuating room. An experimenter accompanied each child into the booth and gave specific instructions regarding what each child was about to watch and the importance of sitting still while the movies were playing. Children were also informed that if they sat quietly, they could pick out a sticker after each movie and place it on an activity sheet to be redeemed for a prize after the session was over. The experimenter remained in the booth to monitor the children and facilitate the selection of stickers following each "Pingu" movie.

2.6 Data Acquisition: Electroencephalographic Recordings

Each child was fitted with an elastic cap (Biosemi) embedded with 32 Ag/Ag-Cl electrode scalp channels arranged according to the International 10-20 System. Electrodes to monitor horizontal eye movement were placed on the left and right outer canthi, and electrodes placed on the right inferior orbital ridge monitored eye blinks. Additionally, data was recorded without a reference, then referenced offline to the averaged left and right mastoids. The EEG data were digitized online at a rate of 512 Hz.

The neural activity recorded via EEG was time time-locked to target stimuli, elicited by anomalous or correct critical words embedded in the auditory sentence stimuli, which then elicited event-related brain potentials (ERPs). It was possible to evaluate changes in neural processes underlying language by comparing ERPs elicited by semantically and syntactically correct and violation sentences between groups.

2.7 Behavioral Measurements and Analyses

All behavioral measures were scored at pre- and post-testing and evaluated for change over the 8-week intervention period. Behavioral data were analyzed using repeated measures ANOVAs with a between-subjects factor of intervention group (PCMC-A, HS-Alone) and within-subject factors of testing time (Time: Pre-test, Post-test).

2.8 ERP Analyses

To assess changes as a function of intervention, pre-test and post-test data were analyzed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) software. Offline, data were downsampled to 256 Hz to increase data processing time. Bipolar eye channels were created for vertical (VEOG: VE-FP1) and horizontal (HEOG: Right HE–Left HE) eye movements. Eye blinks and other movement artifacts were removed from the EEG recordings prior to analysis using independent component analysis (ICA). Two independent researchers determined which components contain eye artifact, and then the artefactual components were removed from the data. Following ICA, EEG data were epoched between 1000 ms prior to and 2000 ms following the onset of the target word. Each epoch was baseline corrected to zero in the period prior to the onset of the stimulus (e.g., -1000 to 0 ms). After epoching, a single pass of a moving window artifact rejection parameter, with a 200 ms window moving at 50 ms increments was used to identify epochs containing artifacts. Epochs were rejected if the movement in eye channels exceeded 100 μV within the 200 ms window or if any other channels exceeded 200 μV within the window. Following automatic rejection, each epoch was manually inspected for any remaining artifact, and any additional epochs containing artifact were rejected. Epochs of like trials without artifact were averaged together to form grand averages. Each participant was determined to have enough artifact-free trials for reliable ERP data. The number of trials rejected for each condition did not differ between groups (all *r*s (1,98) < 1.331, *p*s > .186). The mean (*SE*) number of trials rejected for each condition for each group are presented in Table 2.3.

Table 2.3 Summary of Mean (*SE*) Number of Trials Rejected for Each Condition and Group. Trials rejected are reported at pre-test and post-test.

	PCMC-A		Head Start Alone	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Semantic				
Canonical	19.27 (*.81*)	17.39 (*.82*)	18.57 (*1.06*)	17.57 (*.91*)
Violation	19.52 (*.55*)	16.57 (*.77*)	18.45 (*.87*)	16.27 (*.85*)
Syntax				
Canonical	16.73 (*.75*)	15.68 (*.92*)	16.36 (*1.01*)	13.91 (*.96*)
Violation	16.88 (*.76*)	15.38 (*.70*)	15.43 (*.84*)	14.45 (*1.01*)

The mean amplitudes of ERPs were calculated and analyzed within specified time windows for each ERP component of interest. These time windows are based on visual inspection of the data and guided by, and consistent with, previous ERP studies of language processing in preschool- and school-age children (Hahne et al., 2004; Hampton Wray & Weber-Fox, 2013; Holcomb et al., 1992; Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). The semantic condition elicited a broad N400 component, which was analyzed in an earlier time window, between 400 and 700 ms post-stimulus onset, and a later time window, between 850 and 1550 ms. The syntactic conditions also elicited earlier and later changes, thus, was also analyzed within earlier and later time windows (400-700 ms and 850 -1550 ms post-stimulus onset, respectively). These time windows are later than typically measured for the N400 and P600 in adults because ERP components elicited by language are slower in children compared to adults. To facilitate illustration of ERP amplitudes between conditions and from pre-test to post-test, difference waves were calculated, which involved the subtraction of ERP amplitudes elicited at each electrode site (violation minus canonical) to yield the difference in neural response elicited by each condition.

ERP data for each component and time window of interest were analyzed using repeated measures ANOVAs with a between-subjects factor of intervention group (PCMC-A, HS-Alone) and within-subjects factors of testing time (Time: Pre-test, Post-test) and scalp distribution, including Hemisphere (Hemi: Left, Right), Anterior/Posterior (AP: Frontal, Frontocentral, Central, Centroparietal, Parietal, Occipital) and Laterality (Lat: Lateral, Midlateral). In order to clarify significant interactions, step-down ANOVAs were performed separately for the two groups (PCMC-A or HS-Alone) or separately for pre-test and post-test. All other ANOVA factors remained the same, as described above. Significance values were set at p <.05. For all comparisons with greater than one degree of freedom, Huyn-Feldt corrected p-values were used.

2.9 Correlations Between Behavioral and Neurophysiological Change

Regression analyses were performed to evaluate relationships between behavioral measures and ERP responses elicited by semantic and syntactic constraints. The change in performance on behavioral measures was calculated as the post-test score minus the pre-test score. This change score was calculated separately for nonverbal IQ and receptive language performance.

In order to limit the number of regressions performed, difference waves were computed as the mean amplitude of the violation condition minus the mean amplitude of the canonical condition for semantic and syntactic conditions both pre- and post-test. Then a single value for the change from pre- to post-test was calculated as the post-test difference wave minus the pre-test difference wave, resulting in the change in mean amplitude elicited by the violation condition over time. Finally, two aggregate electrode values were computed. The first value was calculated as the mean score of the change-over difference waves across the anterior three rows of electrodes (F7/8, F3/4, FT7/8, FC5/6, T7/8, C5/6). The second aggregate value was calculated as the mean score of the change-over-time of difference waves across the posterior three rows of electrodes (CP5/6, C3/4, P7/8, P3/4, PO3/4, O1/2). This process was performed separately for the early and late time windows for both the semantic and syntactic conditions. Separate anterior and posterior values were calculated because studies of language processing in adults (Hagoort, Brown, & Groothusen, 1993; Kaan et al., 2004; Friederici, 2011; Tanner & Van Hell, 2014) and children (Hahne et al., 2004; Weber-Fox et al., 2013; Usler & Weber-Fox, 2015) reported biphasic ERP patterns for both semantic and syntactic processing. Since ERP patterns may differ over anterior and posterior electrode sites, separate comparisons between change in behavior and ERPs over the front versus the back of the head may yield divergent patterns, motivating separate anterior/posterior analyses.

CHAPTER 3: RESULTS

3.1 Behavioral Data

3.1.1 Nonverbal IQ

Scaled standard scores indexing nonverbal IQ were compiled from all participants at pre- and post-test (see Table 1.1 where the reader can find those scores). Significant improvement in performance on nonverbal IQ standardized assessment was observed across both groups (Time: F (1,96) = 5.134, p = 0.026, n_p^2 = 0.051). However, no significant changes in nonverbal IQ were observed over time between groups (Time x Group: F (1,96) = 1.8, p > 0.181).

3.1.2 Receptive Language Skills

Significant improvement in performance on receptive language assessments was also observed across groups over time (Time: F (1,96) = 39.088, p = .001, n_p^2 = .289). However, no significant changes in receptive language were observed over time between groups (Time x Group: F (1,96) < 1, p > .523.

3.2 Neurophysiological Responses

3.2.1 Semantics

The ERP patterns elicited by canonical and semantic violation conditions at both pre- and post-test are illustrated for the PCMC-A group in Figure 3.1 and 3.2 and for the Head Start Alone group in Figure 3.3 and 3.4. A larger negativity, N400, was elicited by semantic violations across both groups for the earlier time window (pre-test Cond: F (1,96) = 33.55, p = .001, n_p^2 = .259; Post-test Cond: F (1,96) = 7.15, p = .009, n_p^2 = .069) at pre- and post-test. A trend toward a significant interaction of time and condition in the earlier time window (Time x Cond: *F* (1,96) = 3.795, p = .054, n_p^2 = .038) reflects a smaller N400 effect at post-test compared to pre-test. For the later time window, the N400 effect was present at pre-test (Pre-test Cond: *F* (1,96) = 14.96, p <.001, n_p^2 = .135), but not at post-test (Post-test Cond: *F* (1,96) = 7.153, p = .009, n_p^2 = .069). A significant interaction of time and condition across groups in the later time window (Time x Cond: *F* (1,96) – 6.081, p = .015, n_p^2 = .060) indicates that across all children, the N400 at pre-test was broader, continuing into the later time window, while at post-test, it was most focal, largely resolved by the later time window.

3.2.1.1 Early Time Window by Intervention Group

Comparisons of ERP mean amplitudes elicited by the semantic conditions in the earlier time window (400-700 ms) indicated no significant interactions of time or condition with group (Time x Condition x Group: all Fs < 2.31, all ps > 0.1). These findings suggest at 400-700 ms post-stimulus onset, children participating in PCMC-A intervention did not exhibit differences in earlier semantic processing compared to children participating in Head Start alone (Figures 3.2 & 3.4).

3.2.1.2 Late Time Window by Intervention Group

In the later, 850-1550 ms time window, there was a trend for the ongoing N400-like negativity elicited by semantic violations to be larger for the PCMC-A group compared to the HS-alone group (Time x Condition x AP x Group: *F* (5,480) = 2.651, p = 0.069, n_p^2 = 0.027). These differences are illustrated in Figure 3.5.

Step-down ANOVAs isolating pre-test, post-test, and group (described in Method) were performed to clarify the nature of the interaction. A step-down ANOVA for pre-test responses was performed to evaluate group ERP patterns prior to the intervention phase. No significant interactions of condition and group were present (all *F*s < 1.523, all *p*s > 0.2), revealing no differences in neural patterns in the later time window between groups at pre-test. A step-down ANOVA was also performed between groups for post-test responses, which similarly revealed no significant interactions of condition and group at post-test (all *F*s < 1.63, all *p*s > 0.2).

Step-down analyses of PCMC-A group alone revealed significant interaction of time, condition, and scalp distribution (Time x Condition x AP: $F\ (5,270) = 3.258$, $p = 0.045$, $n_p^2 = 0.057$). These findings indicated a more positive posterior neural response to semantic violations at post-test, maximal over posterior electrode sites at post-test compared to pre-test. For ease of illustration, difference waves (violation minus canonical) for pre-test and post-test were plotted to represent the changes over time for each group (Figure 3.6). The increase in posterior positivity at post-test can be seen on the left side of the plot for the PCMC-A group.

Step-down analyses of Head Start Alone group alone were also performed to evaluate changes from pre-test to post-test with the Control group. A significant interaction of time and condition (Time x Condition: $F\ (1,42) = 4.295$, $p > 0.04$, $n_p^2 = 0.093$) was revealed. This interaction indicated a smaller N400 amplitude (less negative neural response) elicited by the violation condition at post-test compared to pre-test in the Head Start Alone group. This interaction is illustrated by the difference waves (violation-canonical) for pre- and post-test for the Head Start Alone group on the right side of Figure 3.6.

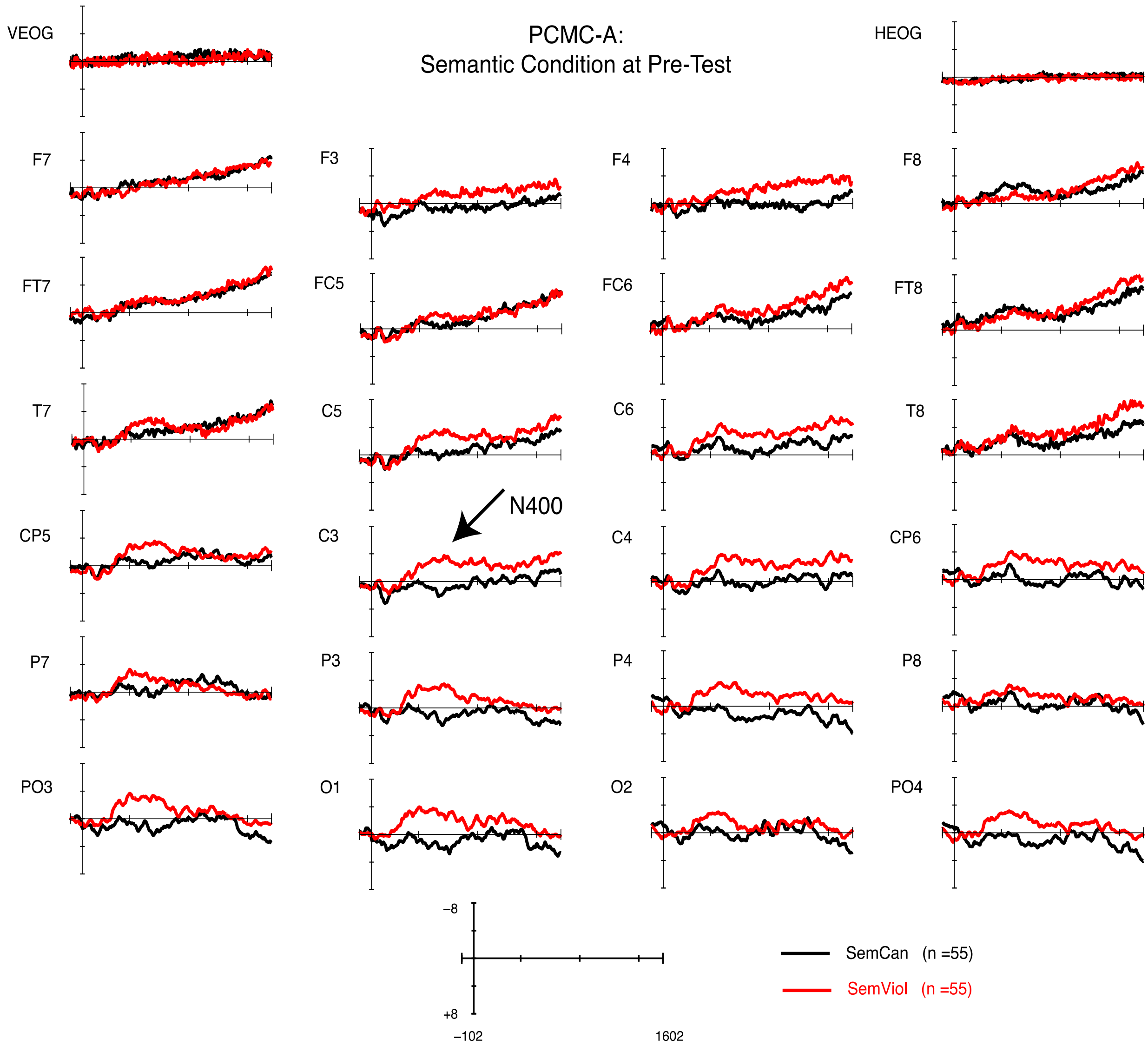


Figure 3.1 Grand Average ERPs for PCMC-A, Semantic Condition at Pre-Test. An N400 elicited by semantic violations was present, largest over central and posterior electrode sites. For this and all subsequent ERP figures, negative is plotted upward.

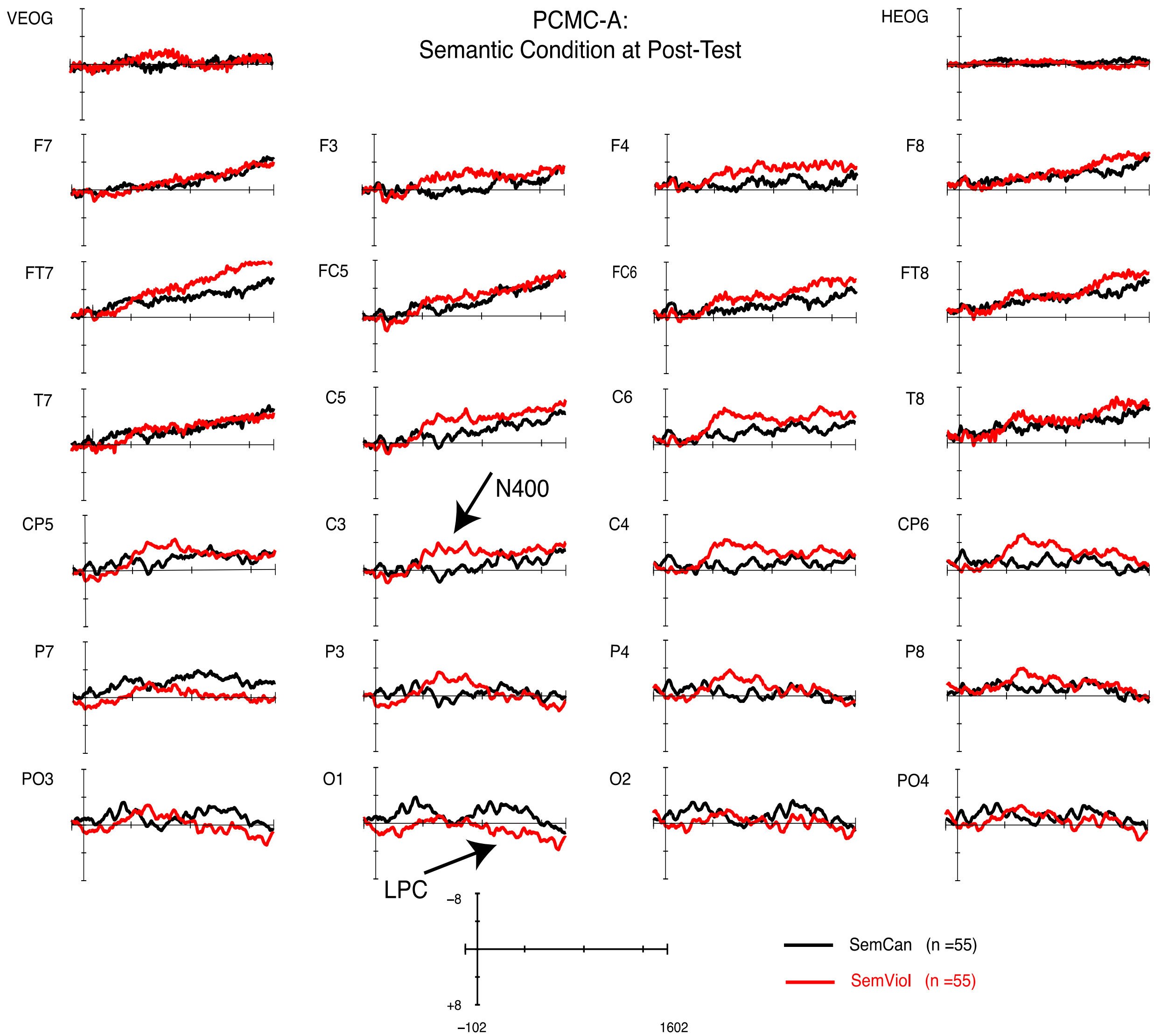


Figure 3.2 Grand Average ERPs for PCMC-A, Semantic Condition at Post-Test. An N400 along with a more positive response elicited by semantic violations was present at posterior electrode sites.

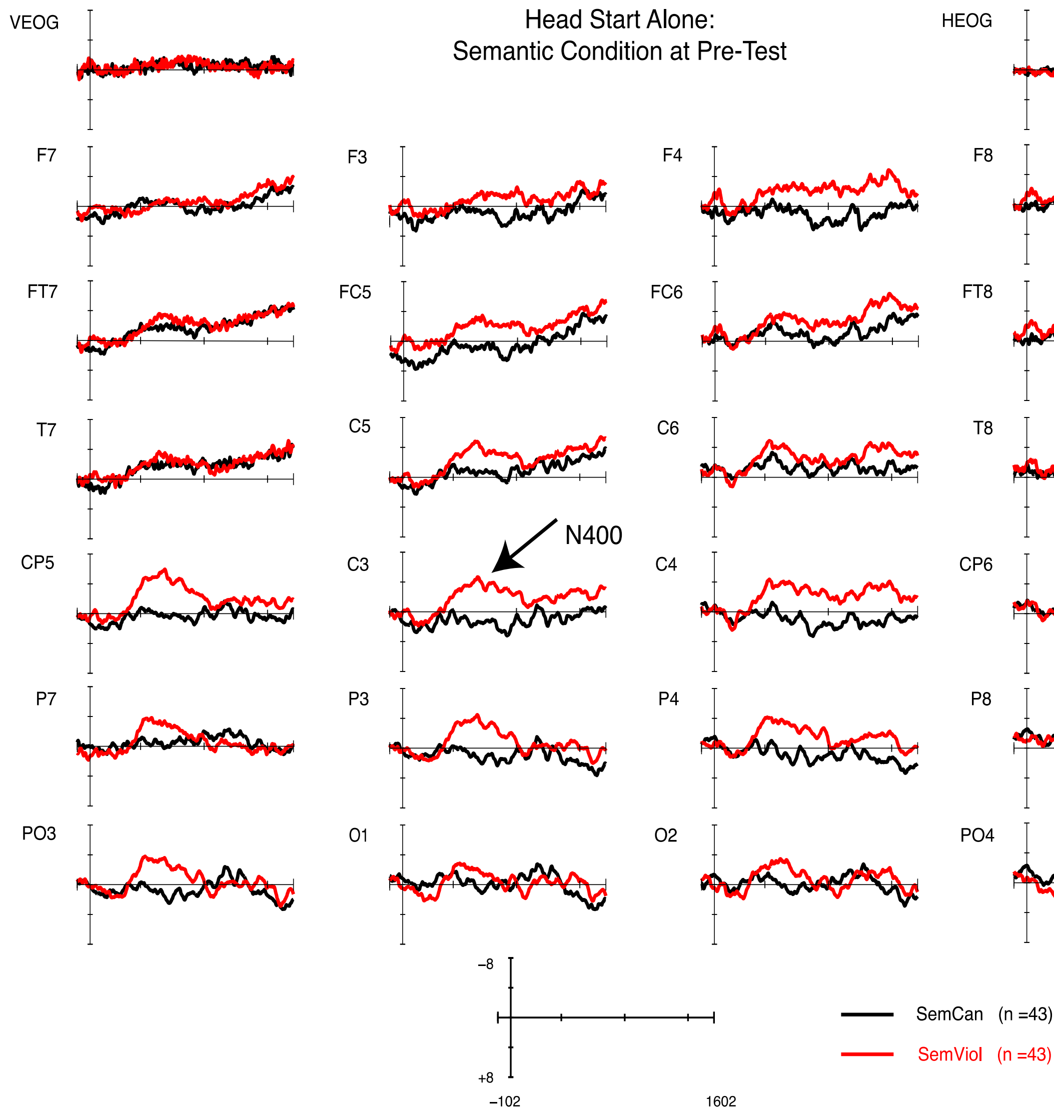


Figure 3.3 Grand Average ERPs for Head Start Alone, Semantic Condition at Pre-Test. An N400 elicited by semantic violations was present, largest over central and posterior electrode sites.

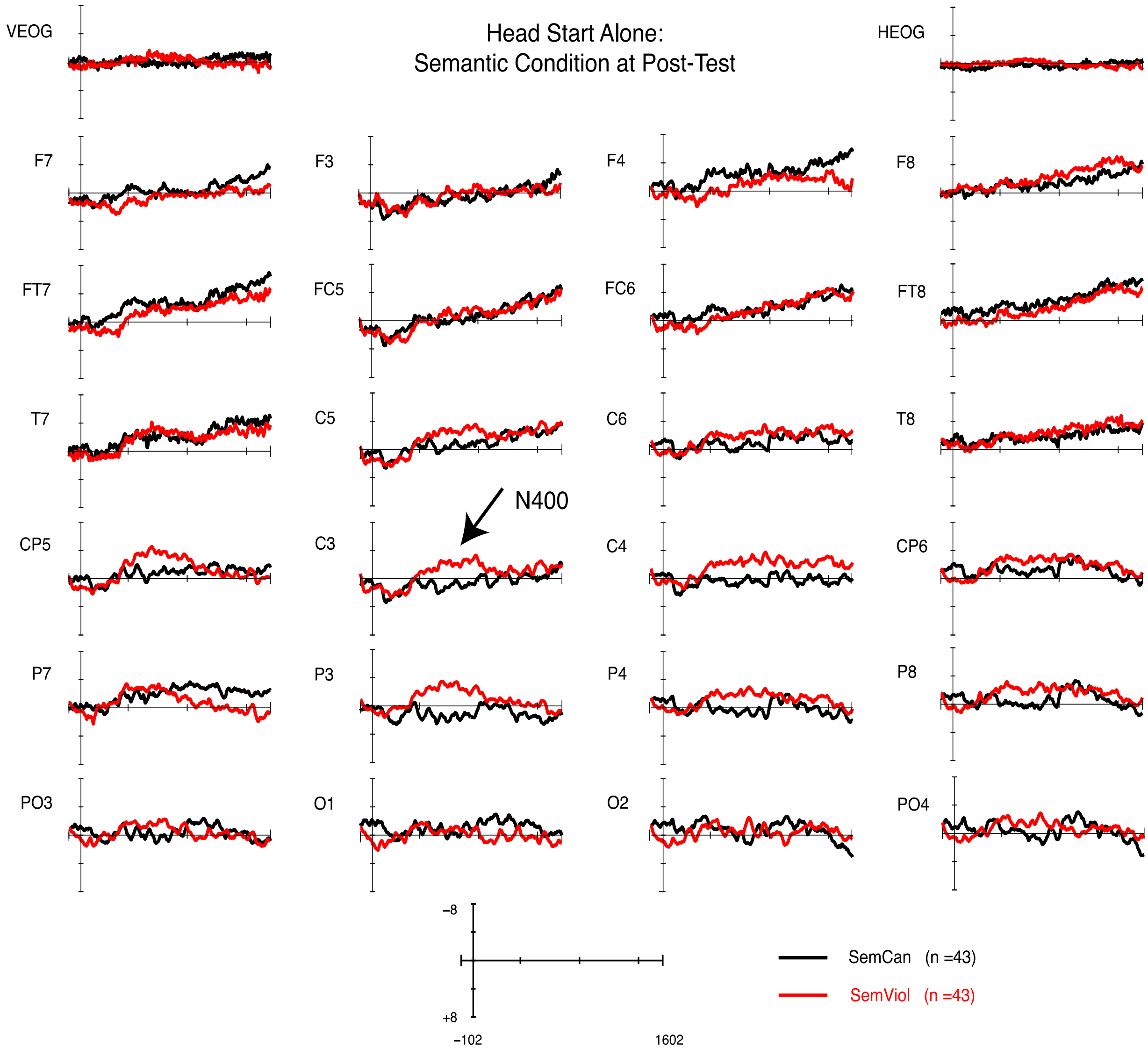


Figure 3.4 Grand Average ERPs for Head Start Alone, Semantic Condition at Post-Test. A reduction in amplitude (less negative response) was visualized in response to semantic violations than those present at pre-test over central and posterior electrode sites.

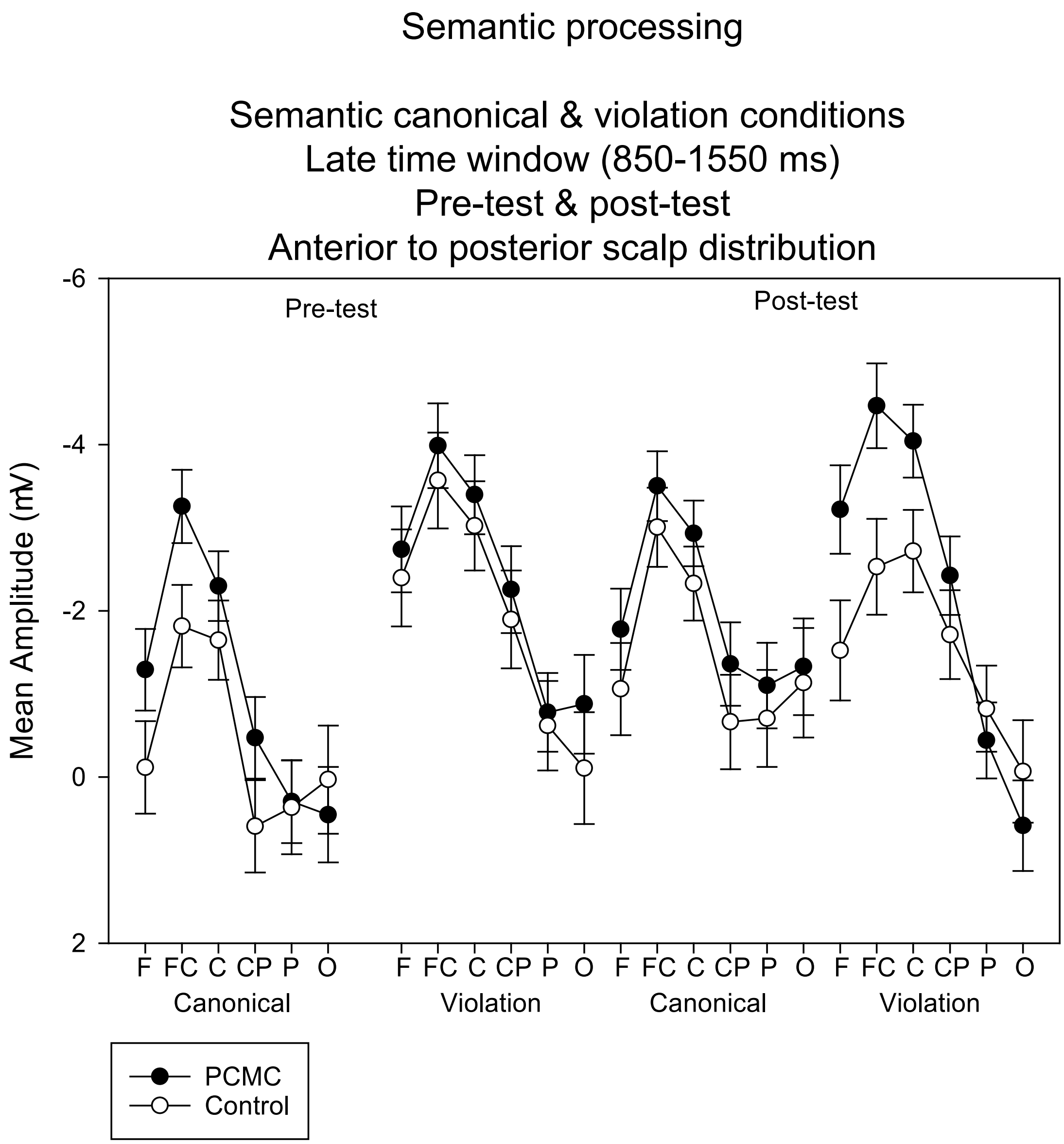
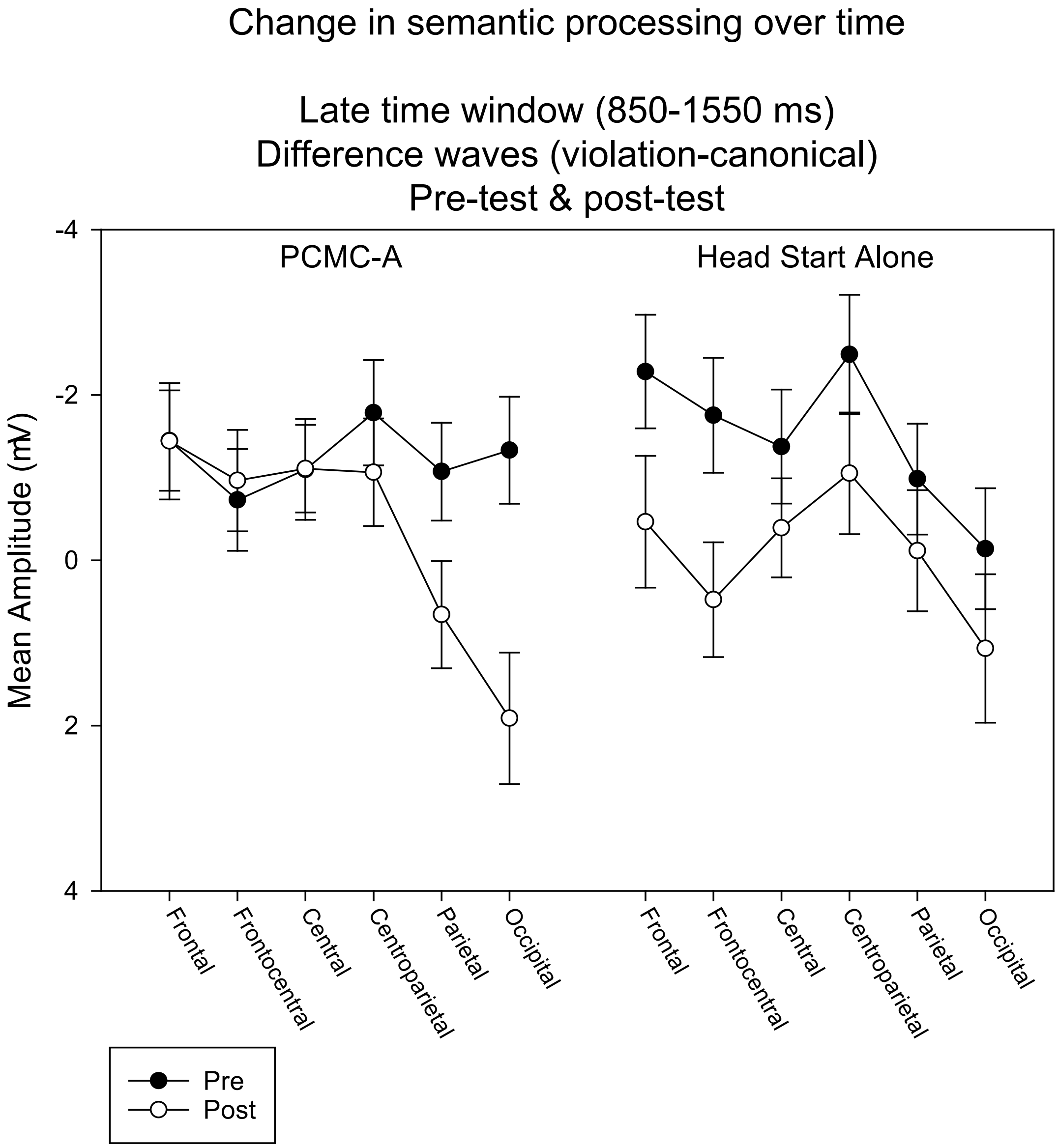


Figure 3.5 Amplitude of Semantic ERP Component Across Electrode Sites by Group. Graph illustrating mean amplitudes elicited by semantic canonical and violations conditions across anterior-to-posterior electrode sites (averaged across lateral and mid-lateral sites) at pre-test and post-test for both PCMC-A and Head Start Alone. A larger negativity elicited by semantic violations can be seen in the PCMC-A group relative to Head Start Alone at post-test



Fi**gure 3.6 Change in Semantic Processing Over Time**. Graph illustrating the change in mean amplitudes elicited by the semantic conditions from pre- to post-test, plotted as differences waves (violation-canonical) for pre- and post-test over electrode sites from anterior to posterior distribution (averaged across lateral and mid-lateral sites). A more positive response elicited by syntactic violations over posterior electrode sites at post-test can be seen for the PCMC-A group, while a reduced N400 mean amplitude at post-test can be seen for the Head Start Alone group.

3.2.2 Syntax

The ERP pattern elicited by canonical and syntactic violation conditions at both pre- and post-test are illustrated for the PCMC-A group in Figure 3.7 and 3.8 and for the Head Start Alone group in Figure 3.9 and 3.10. In the earlier time window, no significant effects of condition were observed at pre-test (Pre-test Cond: F (1,96) = 1.639, p = .204) or post-test (Post-test Cond: F (1,96) < 1, p = 0.412) and there was no interaction of time and condition across groups at pre- and post-test (Time x Cond: F (1,96) < 1, p = 0.802). For the later time window, no differences were observed across groups between condition at pre-test (Pre-test Cond: F (1,96) < 1, p = 0.442) or post-test (Post-test Cond = F (1,96) < 1, p = 0.869), and there was no interaction of time and condition (Time x Cond: F (1,96) < 1, p = 0.859). These findings suggest limited differences in processes for canonical and syntactic violations across this young lower SES population.

3.2.2.1 Early Time Window by Intervention Group

For the earlier time window, 400-700 ms, no significant interactions of group with time or condition were observed (Time x Group & Time x Cond x Group: all Fs (1,96) < 1, ps > 0.37). These results suggest that across time, participants in both groups appear to be processing both syntactic canonical and violation sentences similarly within this early time period.

3.2.2.2 Late Time Window by Intervention Group

For the later time window, 850-1550 ms, a significant interaction of time, condition, group, and scalp distribution was observed (Time x Condition x AP x Group, F (5,480) = 3.303,

$p = 0.006$, $n_p^2 = 0.033$). In order to better identify the changes indicated by this interaction, step down analyses were performed within each time period (pre- and post-test) and group (PCMC-A, HS-Alone).

Step-down analyses at pre-test alone revealed a significant interaction of condition, group, and anterior-posterior distribution (Cond x AP x Group: F (5,480) = 3.21, $p > 0.029$, $n_p^2 = 0.032$), as well as a trend toward an interaction of condition, group, anterior-posterior distribution, and hemisphere (Cond x Hemi x AP x Group: F (5,480) = 2.102, $p = 0.068$, $n_p^2 = 0.021$). These interactions indicated differences between groups at pre-testing, prior to random group assignment, in the neural processes underlying syntax, reflecting a slightly larger anterior negativity and posterior positivity in the Head Start Alone group compared to the PCMC-A group. These pre-test differences can be seen on the left side of Figure 3.11. These differences were not seen in the step-down analyses for post-test, with no significant interactions of Time and Group (all Fs < 1.345, all ps > 0.249). The lack of interactions at post-test suggests that pre-test differences between groups may be driving the group interaction observed in the omnibus ANOVA of time, condition, group, and scalp distribution.

To further explore the omnibus interaction, step-down analyses were performed for the PCMC-A group alone. No significant interactions of time and condition were present (all Fs < 1.078, all ps > .35), indicating that no significant changes in syntactic processing over time following participation in intervention. The similar ERP patterns at pre- and post-test are illustrated by the difference waves (violation minus canonical) plotted on the left side of Figure 3.12.

Step-down analyses were also performed for the Head Start Alone group. To contrast to findings for the PCMC-A group, the analyses revealed significant interactions involving time, condition, and scalp distribution (Time x Cond x Hemi: F (1,42) = 3.33, p = .075, n_p^2 = .074; Time x Cond x AP: F (5,210) = 3.95, p = .015, n_p^2 = .086). The interaction including AP can be seen in the difference waves (violation-canonical) for pre- and post-test on the right side of Figure 3.12. This interaction revealed a biphasic ERP pattern elicited by syntactic violations at pre-test in the Head Start Alone group – a more anterior negativity and posterior positivity – that is no longer observed at post-test.

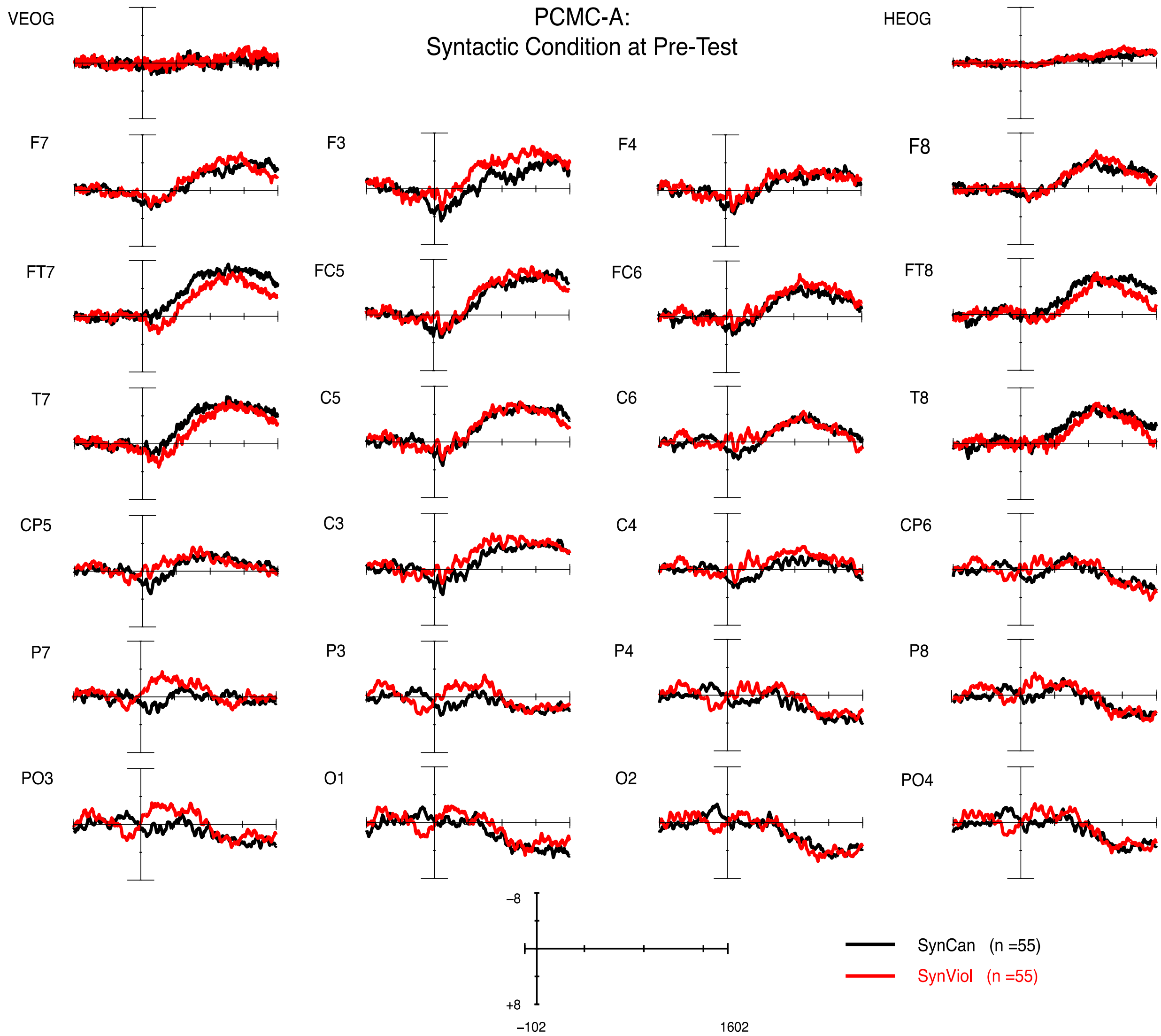


Figure 3.7 Grand Average ERPs for PCMC-A, Syntactic Condition at Pre-Test. The grand average ERPs elicited by syntactic canonical and violation sentences at pre-test.

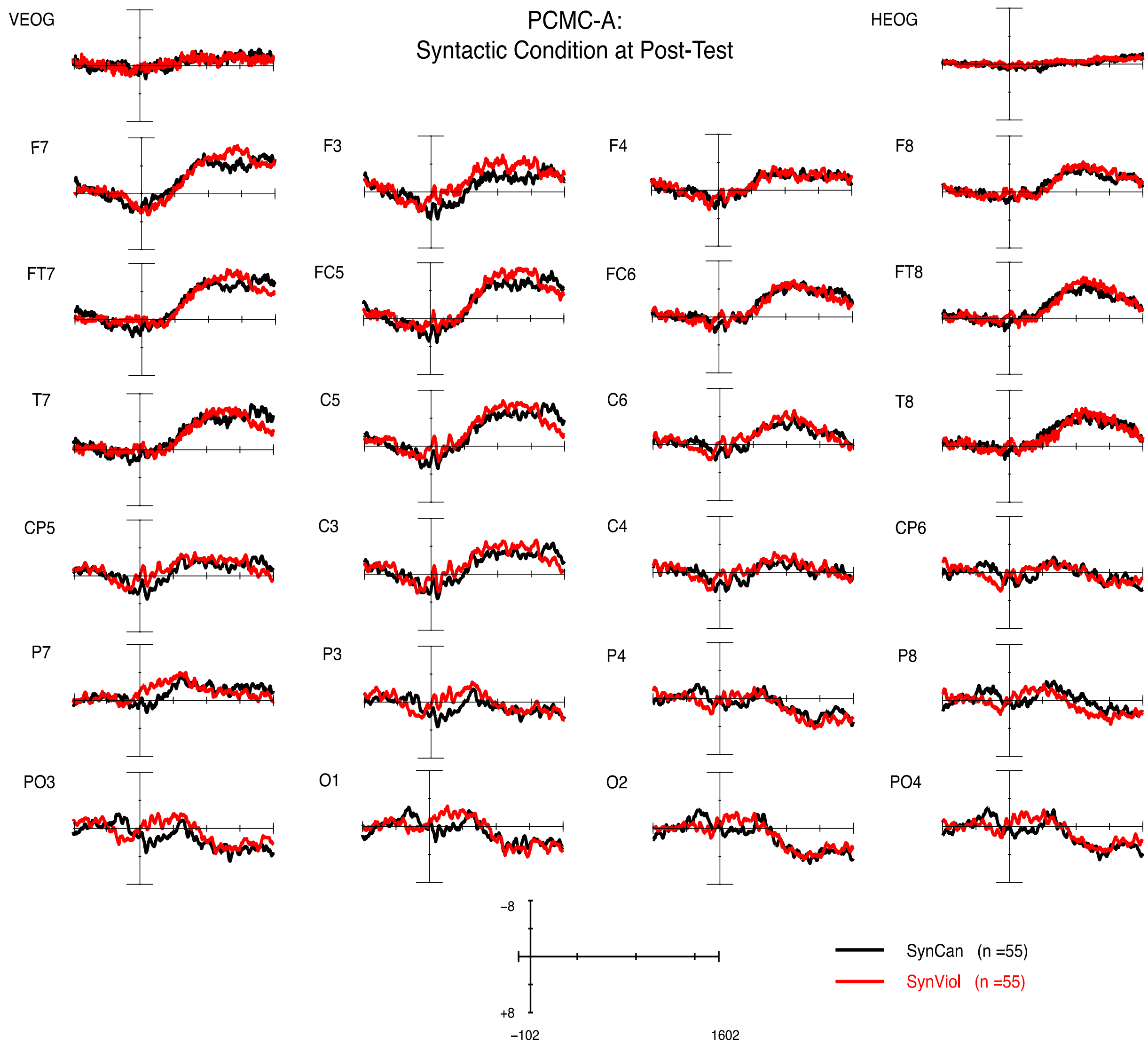


Figure 3.8 Grand Average ERPs for PCMC-A, Syntactic Condition at Post-Test. No significant change over time in syntactic processing was evident following participation in intervention.

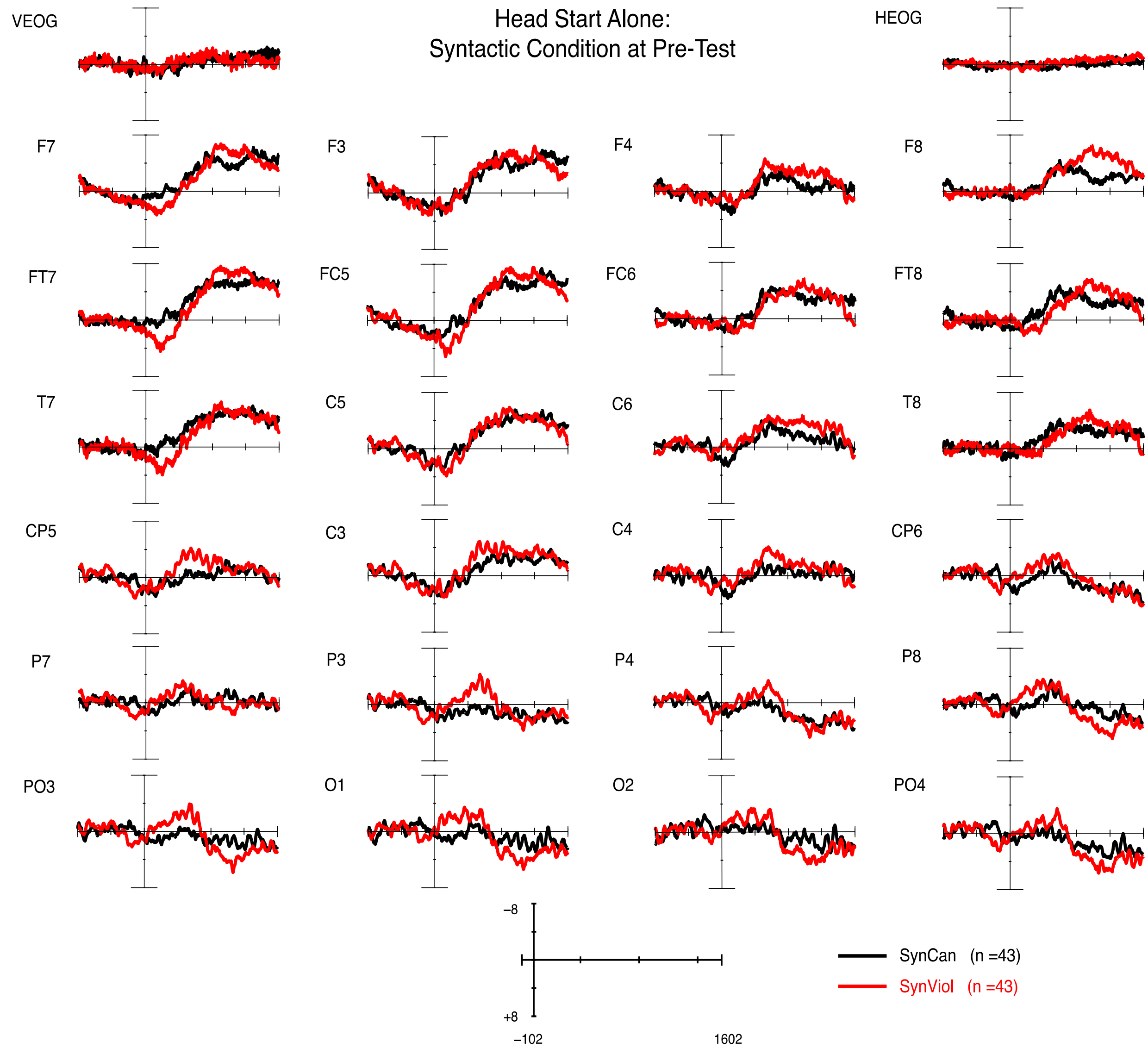


Figure 3.9 Grand Average ERPs for Head Start Alone, Syntactic Condition at Pre-Test. The grand average ERPs elicited by syntactic canonical and violation sentences at pre-test.

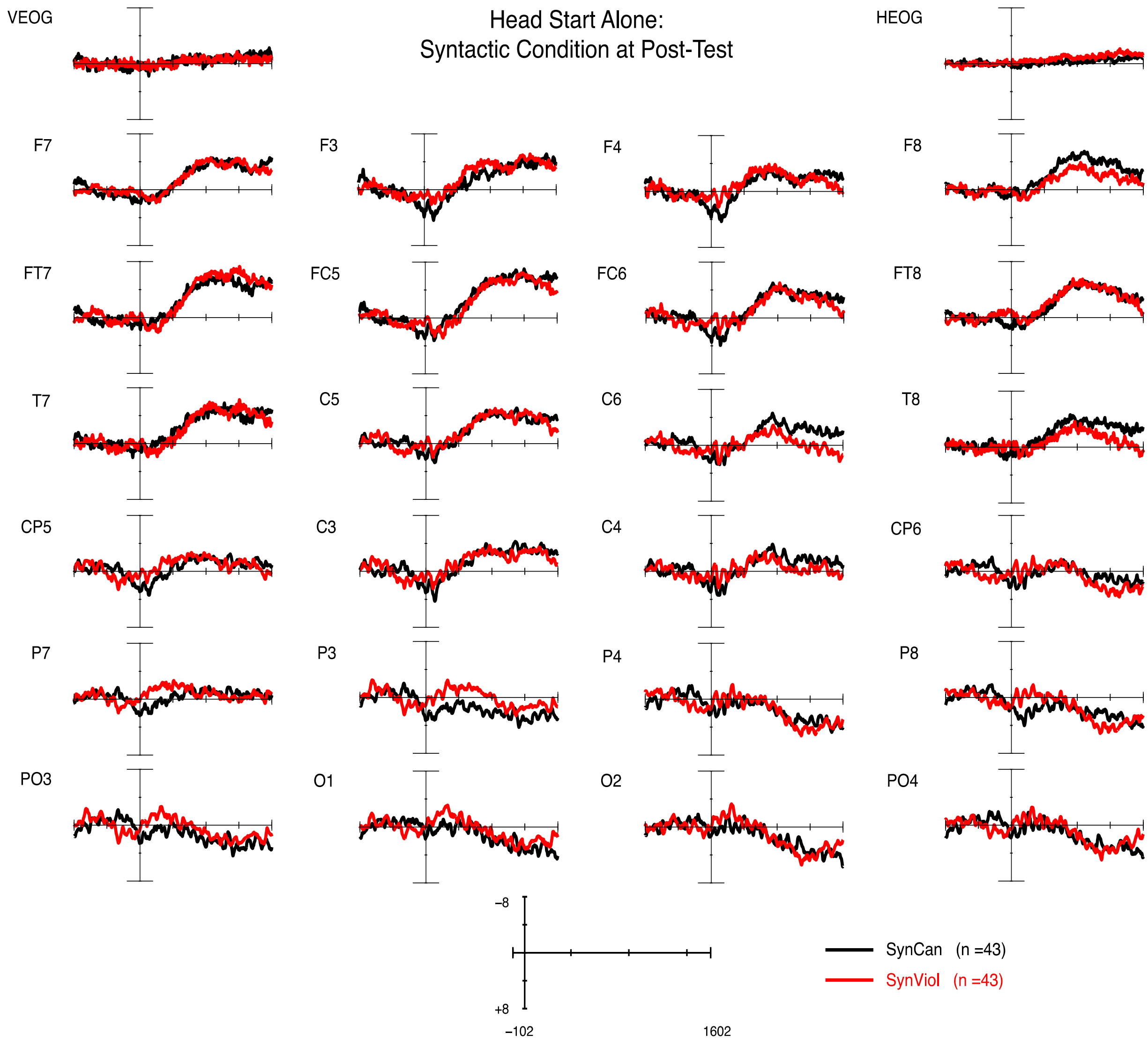


Figure 3.10 Grand Average ERPs for Head Start Alone, Syntactic Condition at Post-Test. The grand average ERPs elicited by syntactic canonical and violation sentences at post-test.

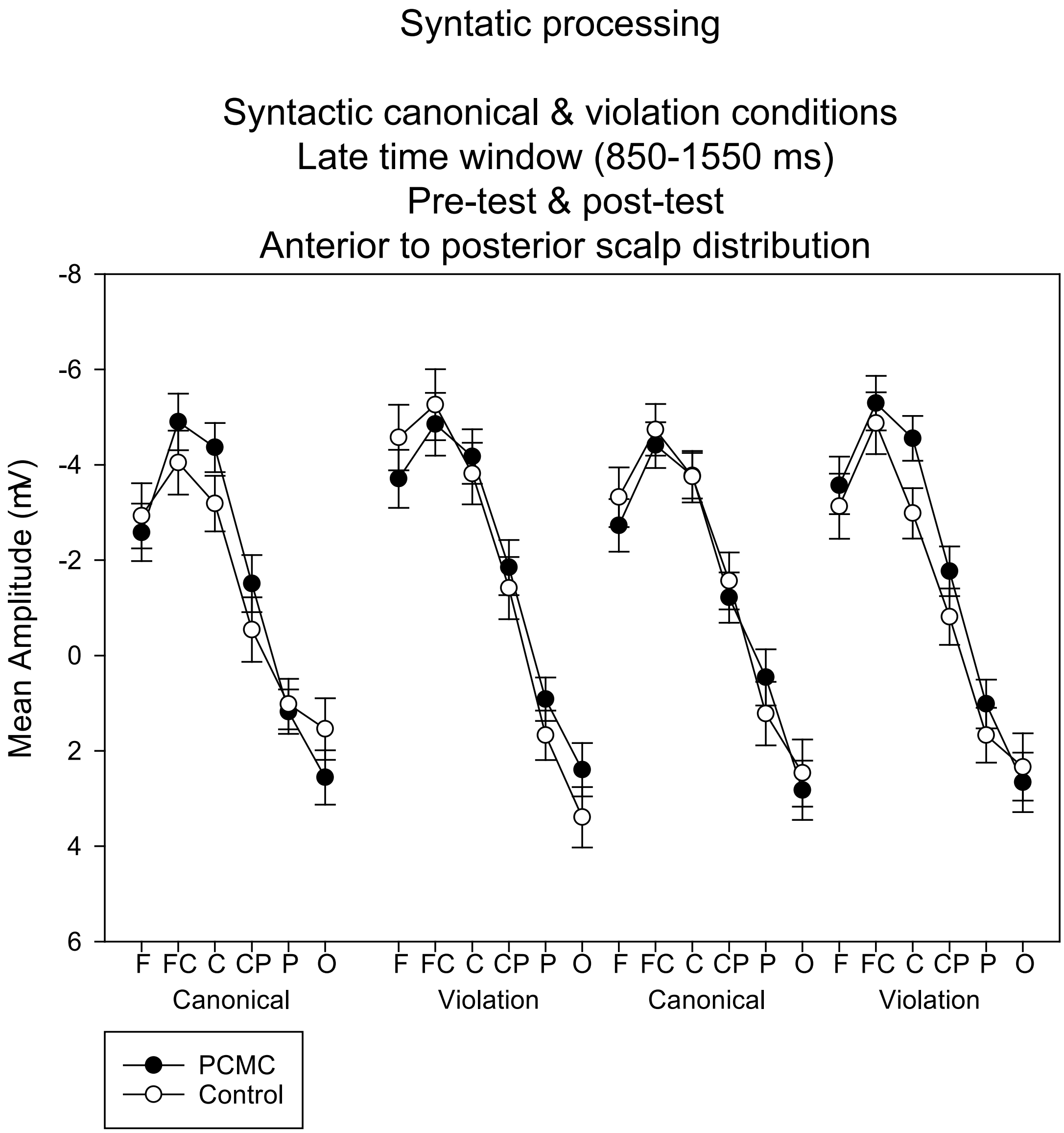


Figure 3.11 Amplitude of Syntactic ERP Component Across Electrode Sites by Group. Graph illustrating mean amplitudes elicited by syntactic canonical and violations conditions across anterior-to-posterior electrode sites (averaged across lateral and mid-lateral sites) at pre-test and post-test for both PCMC-A and Head Start Alone. A larger anterior negativity and a more posterior positivity were elicited by the syntactic violations at pre-test in the Head Start Alone group relative to PCMC-A (left side of figure). However, these differences are not observed at post-test between groups. Instead, the PCMC-A group exhibited a larger negativity elicited by syntactic violations over central electrode sites at post-test compared to the Head Start Alone group.

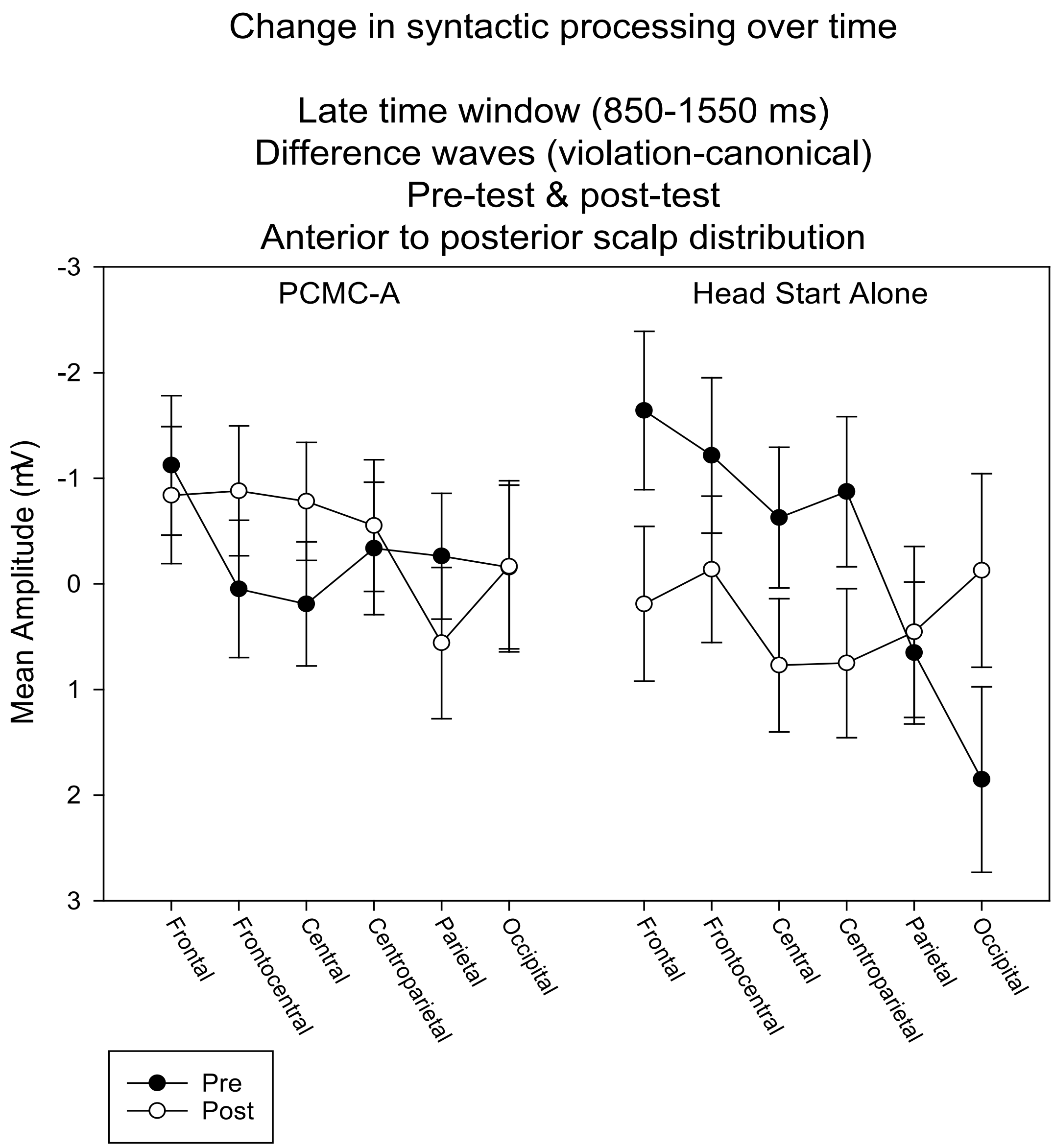


Figure 3.12 Change in Syntactic Processing over Time. Graph illustrating the change in mean amplitudes elicited by the syntactic conditions from pre- to post-test, plotted as differences waves (violation-canonical) for pre- and post-test over electrode sites from anterior to posterior distribution (averaged across lateral and mid-lateral sites). No significant changes in syntactic processing were observed for the PCMC-A group from pre- to post-test. The Head Start Alone group exhibited a larger positivity elicited by syntactic violations over posterior electrode sites at pre-test (right side of figure), which was not evident in the Head Start Alone group at post-test.

3.3 Relationships Between Behavior and ERPs

Regression analyses were conducted separately between nonverbal IQ and receptive language performance and ERP responses over anterior and posterior aggregate mean amplitudes. These analyses were conducted for each linguistic constraint and each time window (see Method). For ease of illustration, a summary of significance and correlation values by condition, time window, scalp distribution (anterior or posterior), behavioral assessment (nonverbal IQ or receptive language) are provided in Table 3.1 (semantic condition) and Table 3.2 (syntactic condition). Significant correlations across both groups were followed up with the same correlations for each group separately to better understand the patterns driving the correlations.

3.3.1 Relationship Between Semantic Processing and Nonverbal IQ, Late Time Window

There was no correlation in the early time window (400-700 ms) for nonverbal IQ (p = .099, r = -.132) or receptive language (p = .402, r = - .026), nor was there a significant correlation in the late time window (850-1550 ms) for receptive language (p = .430, r = .018) across both groups. However, there was a significant overall correlation across both groups for nonverbal IQ (p = .023, r = -.203). Follow-up regressions revealed a significant negative relationship was present in the late time window between change in nonverbal IQ performance and change in N400 amplitude over posterior electrode sites in the PCMC-A group (p = .001, r = - .406), but not for the Head Start Alone group (p = .265, r = -.099), illustrated in Figure 3.13. These results indicate that greater change in IQ performance was associated with a more negative N400 effect in the PCMC-A group, which was not observed in the Head Start Alone group.

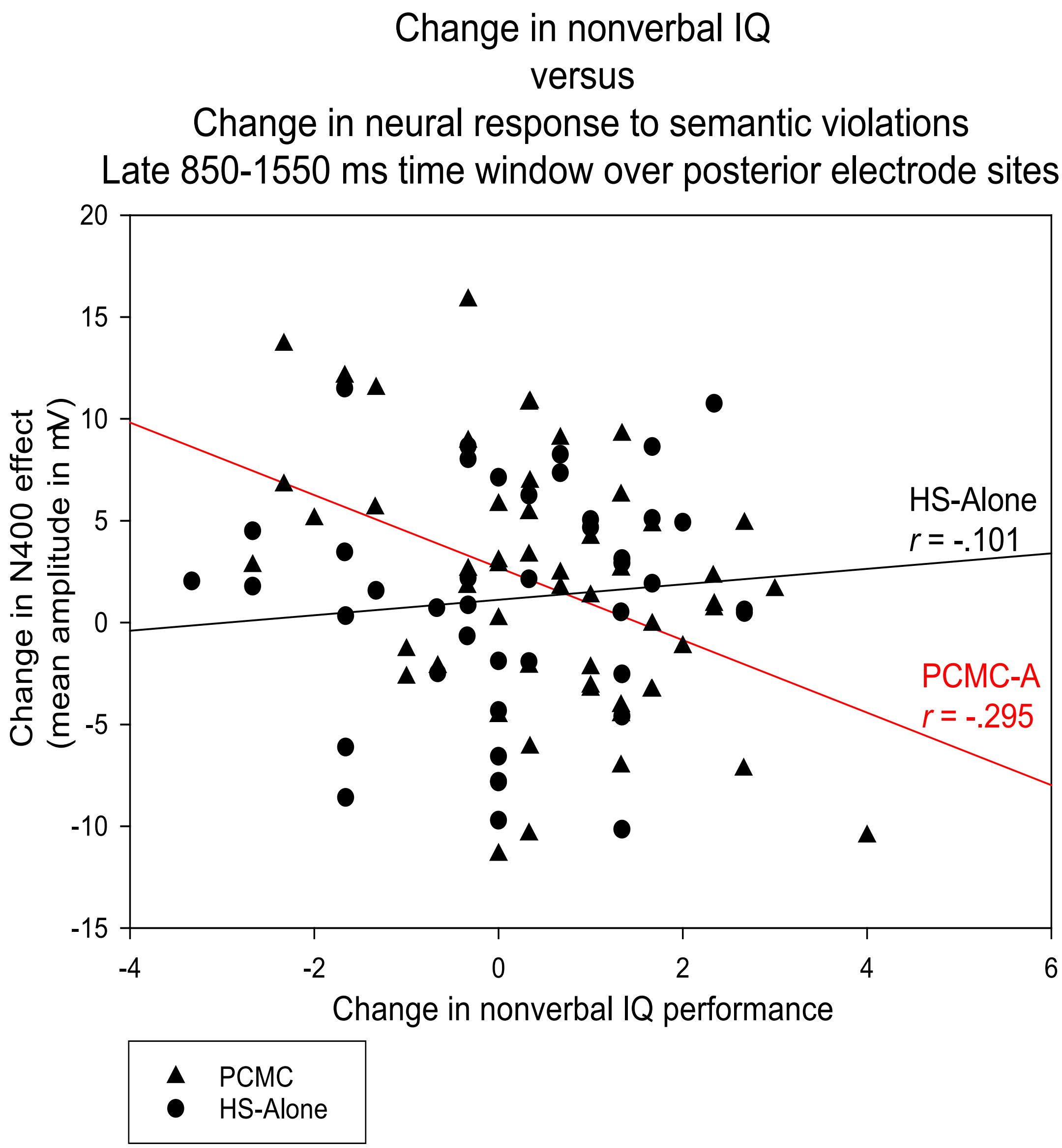


Figure 3.13 Change in Nonverbal IQ by Change in Neural Response to Semantic Violations. Plot depicting relationship between change in performance on standardized measures of nonverbal IQ over time with change in mean amplitudes elicited by the semantic condition over posterior electrode sites over time, plotted for each group. A negative correlation was observed in the PCMC-A group, indicating greater increase in nonverbal IQ performance was associated with more negative N400 response over posterior electrode sites over time.

3.3.2 Relationship Between Syntactic Processing and Nonverbal IQ, Late Time Window

There was no correlation in the late time window for receptive language across both groups (p = .387, r = -.030). Follow up regressions for each group separately revealed a significant negative relationship in the late time window (850-1550 ms) between change in nonverbal IQ performance and change in ERPs elicited by syntactic violations over anterior electrode sites in the PCMC-A group (p = .020, r = - .280) but not in the Head Start Alone group (p = .441, r = .023), illustrated in Figure 3.14. These results indicate that greater change in IQ performance was associated with a more negative neural response elicited by syntactic violations in the PCMC group. This relationship was not evident in the Head Start Alone group.

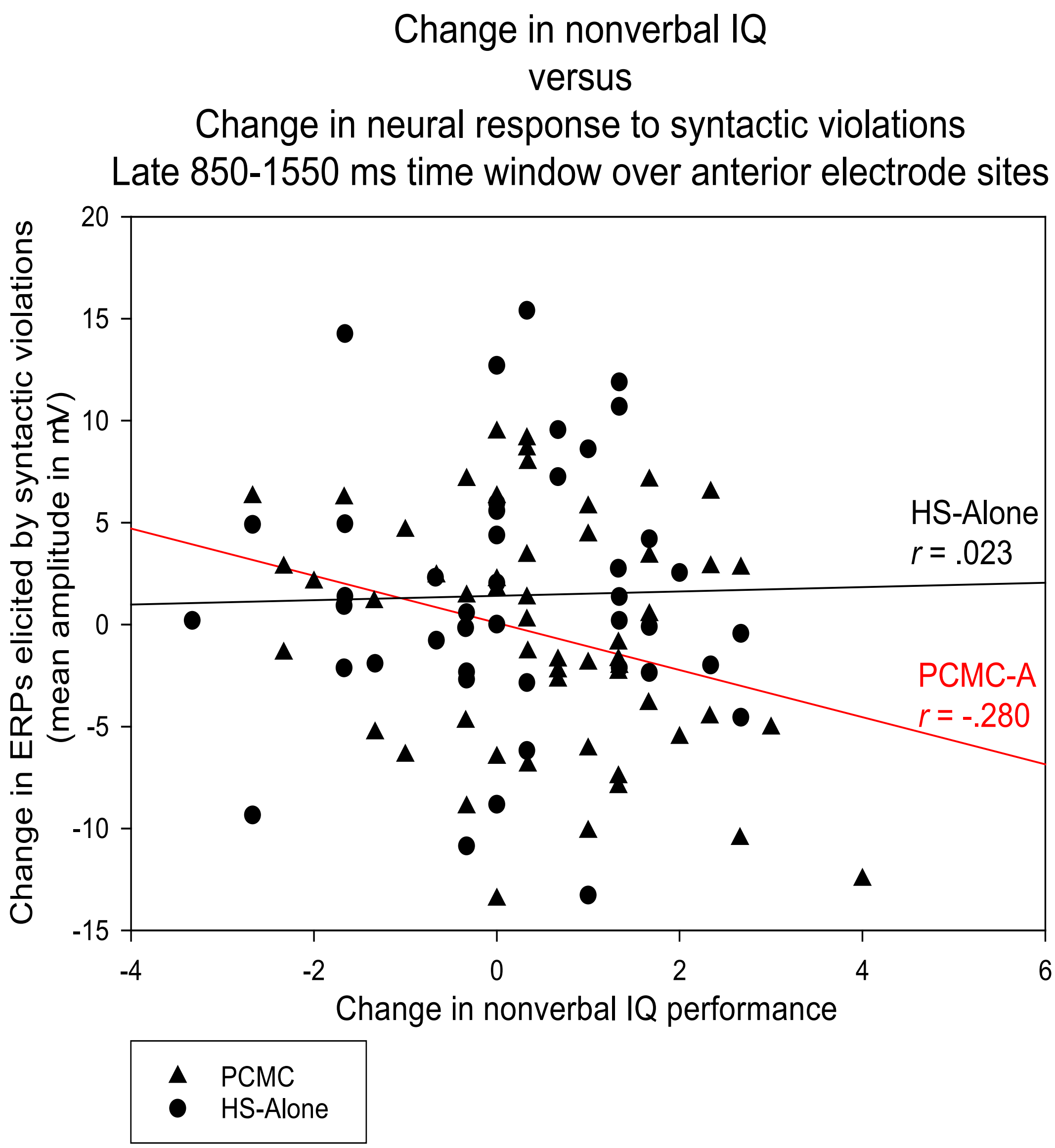


Figure 3.14 Change in Nonverbal IQ by Change in Neural Response to Syntactic Violations. Plot depicting relationship between change in performance on standardized measures of nonverbal IQ over time with change in mean amplitudes elicited by the syntactic condition over anterior electrode sites over time, plotted for each group. A negative correlation was observed in the PCMC-A group, indicating greater increase in nonverbal IQ performance was associated with more negative ERP response over anterior electrode sites over time.

3.3.3 Relationship Between Syntactic Processing and Receptive Language, Early Time Window

No significant correlations in the early time window (400-700 ms) for nonverbal IQ were present across both groups ($p = 4.18$, $r = -.030$). A marginally significant positive relationship was present in the early time window (400-700 ms) between change in receptive language standard score and change in ERPs elicited by syntactic violations over anterior electrode sites in the PCMC-A group ($p = .091$, $r = .184$), which was not observed for the Head Start Alone group ($p = .152$, $r = .160$), illustrated in Figure 3.15. These results indicated that greater change in performance on a standardized measure of receptive language was associated with a more positive mean amplitude of ERP response elicited by syntactic violations in the PCMC-A group over time. Participants in the Head Start Alone group showed a similar relationship between change in receptive language performance and change in ERP response elicited by syntactic violations over time; however, the relationship was not marginally significant.

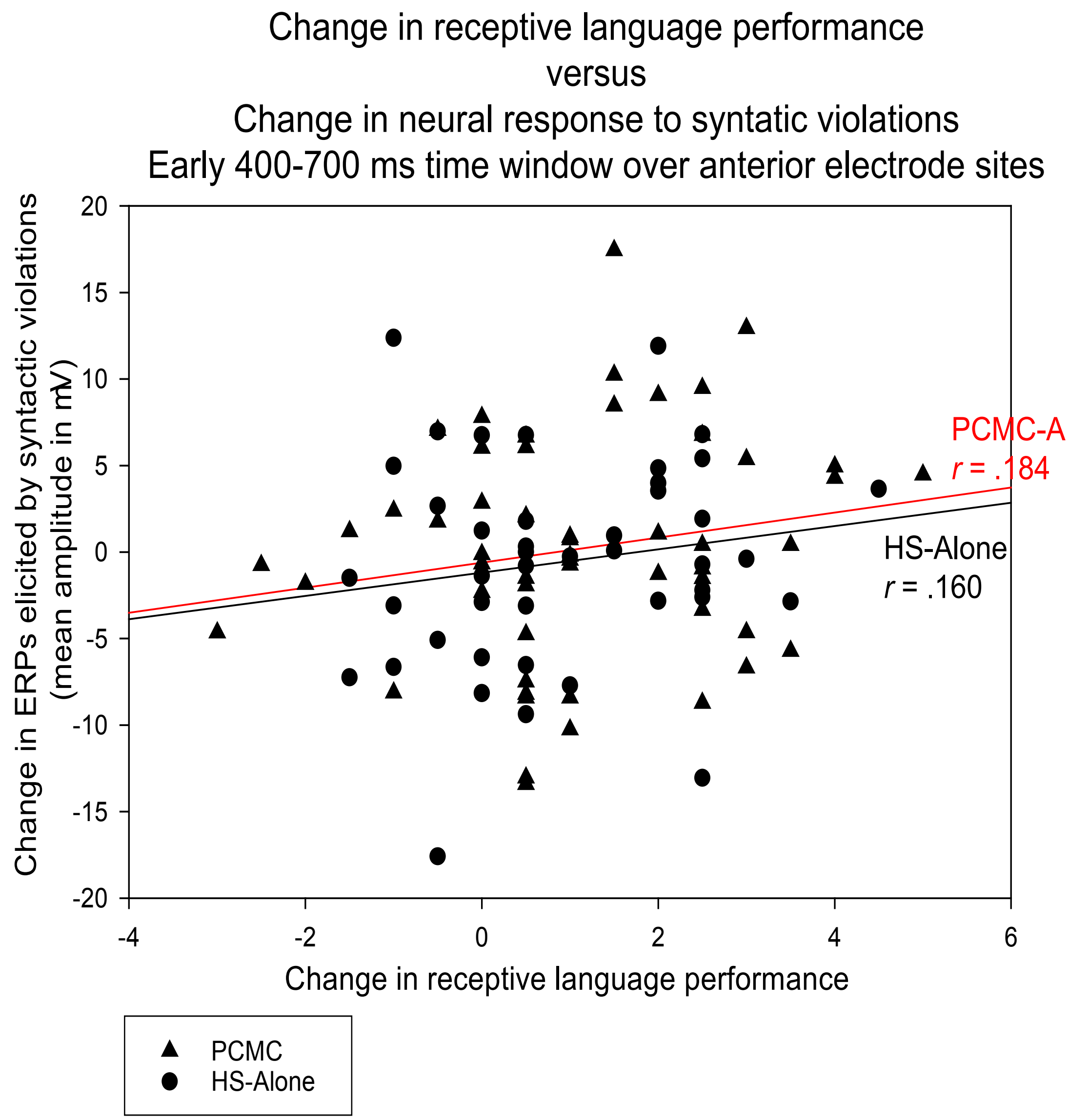


Figure 3.15 Change in Receptive Language by Change in Neural Response to Syntactic Violations. Plot depicting relationship between change in performance on standardized measures of receptive language over time with change in mean amplitudes elicited by the syntactic condition over anterior electrode sites over time, plotted for each group. A positive correlation was observed in the PCMC-A group, indicating greater increase in receptive language performance was associated with more positive ERP response over anterior electrode sites over time.

Table 3.1 Summary of *p* and *r* Values from Linear Regressions in Semantic Condition. Summary of significance (*p*) and correlation (*r*) values for linear regressions between the change in behavioral performance and the change in neural responses elicited by the semantic condition over time. Separate regressions were performed for nonverbal IQ and receptive language performance for the early and late time windows at both anterior and posterior electrode sites.

Semantics	*p*	*r*
Early Time Window:		
CIQ: Anterior:	.099	.132
PCMC:	.185	-.125
Head Start Alone:	.282	-.090
CIQ Posterior:	.282	-.059
CLA Anterior:	.402	-.026
CLA Posterior:	.495	-.001
Late Time Window:		
CIQ: Anterior:	.451	.013
CIQ Posterior:	.023	-.203*
PCMC:	.015	-.295*
Head Start Alone:	.260	-.101
CLA Anterior:	.430	.018
CLA Posterior:	.206	-.084

* p ≤ 0.05, ** p ≤ 0.01, ***p ≤ 0.001

CIQ = Composite Nonverbal IQ Score
CLA = Composite Receptive Language Score

Table 3.2 Summary of *p* and *r* Values from Linear Regressions in Syntactic Condition. Summary of significance (*p*) and correlation (*r*) values for linear regressions between the change in behavioral performance and the change in neural responses elicited by the syntactic condition over time. Separate regressions were performed for nonverbal IQ and receptive language performance for the early and late time windows at both anterior and posterior electrode sites.

Syntax	*p*	*r*
Early Time Window:		
CIQ: Anterior:	.418	.021
CIQ Posterior:	.346	-.041
CLA Anterior:	.040*	.178
PCMC:	.091	.184
Head Start Alone:	.152	.160
CLA Posterior:	.399	.026
Late Time Window:		
CIQ: Anterior:	.064	-.155
PCMC:	.020*	-.280
Head Start Alone:	.441	.023
CIQ Posterior	.278	-.061
CLA Anterior:	.387	-.030
CLA Posterior:	.263	.065

* $p \leq 0.05$, ** $p \leq 0.01$, ***$p \leq 0.001$

CIQ = Composite Nonverbal IQ Score
CLA = Composite Receptive Language Score

CHAPTER 4: DISCUSSION

The current project evaluated the effects of a dual-generation intervention on neural processes underlying language in preschool children from lower SES backgrounds. Results indicated that while both groups showed enhancement of neural structures underlying semantic processing, children participating in PCMC-A exhibited different maturational patterns for semantic processing than those seen in children participating in Head Start Alone. Limited differences in changes in syntactic processing were observed between groups. These findings support the hypothesis that within a relatively short time span of eight weeks, an intervention specifically designed to target attention in preschool-age children has the potential to also enhance neural mechanisms underlying at least some aspects of language processing in children from lower SES households.

4.1 Changes in Behavior Over Time

4.1.1 Nonverbal IQ and Receptive Language

Behavioral outcome measures are the standard for evaluating efficacy in most childhood intervention programs. Behavioral data can provide a means for comparison with existing literature and are particularly powerful when paired with neurobiological outcome measures, such as EEG, to more fully assess change in neural mechanisms over time.

A marginally significant increase in standardized measures of IQ, and an overall enhancement of standardized receptive language scores were evident in all children, across both groups, over time. Although typical development might account for a small part of the increase in scores, the nonverbal IQ and receptive language scores are standardized, so increases in age are taken into account. For example, a higher raw score, indicating better task performance, at an older age would result in the same standardized score as a lower raw score at a younger age. Therefore, the observed increases in standardized scores reflect nonverbal IQ and receptive language improvements beyond what is expected for typical development. The acquisition of increased skill over time may be a product of continued participation in Head Start. As previously discussed, growing up in lower SES households has been shown to have detrimental effects on cognitive development and language skills, which likely results from multiple factors, including lack of nutrition, chronic stress, and family instability (Bradley & Corwyn, 2002; Farah et al., 2006; Goodman et al., 2005; Shonkoff 2012). The general Head Start curriculum is designed to promote school readiness skills through play, increase social interaction, and structured learning opportunities. Specifically, participation in group tasks with multiple children, as occurs in the structure of Head Start, can promote language use and increased language exposure, as well as better inhibitory control, working memory, and cognitive flexibility (U.S. Department of Health and Human Services, 2010). Many of these skills contribute to executive functioning abilities. As studies with children from lower SES backgrounds have shown global deficits in aspects of executive functioning (Noble, Norman, Farah, 2004; Sansour, Sheridan, Jutte, Nuru-Jeter, Hinshaw, & Boyce, 2011), participation in group-based play or preschool may be driving the marginal increase in non-verbal IQ, as well as improvement in language skills, beyond typical development, as measured by behavioral testing. It has also been discussed that children from lower SES backgrounds have the potential to benefit the most, especially early on, from early intervention and education incorporating aspects of social and emotional development and executive functioning skills, such as Head Start

(Diamond & Lee, 2011). This might explain the small gains in IQ and language scores over the relatively short time frame of 8 weeks.

Children participating in PCMC-A did not exhibit significant enhancement in behavioral test scores relative to children participating in Head Start Alone, which was contrary to predicted outcomes and also differs from previous findings reported by Neville and colleagues (2013). A possible explanation for this difference may be a result of changes in Head Start curriculum, as some of the data reported by Neville and colleagues was collected several years before some of the data included in the current study. Head Start programs undergo routine curriculum updating, therefore more recent curriculum changes may have enabled Head Start to further enhance cognitive and language skills in children, resulting in less group differences between children participating in Head Start alone and those participating in PCMC-A. It is also postulated that were the intervention phase extended from 8-weeks to possibly 10-12 weeks, more group differences may have emerged as a function of intervention.

4.2 Semantic Processing

The presence of an N400 effect was evident in both groups, with larger N400 amplitudes elicited at pre-test compared to post-test in response to semantic violations in the earlier time window. Reduced amplitude N400 effects are generally thought to be indicative of greater ease of semantic integration (Hagoort & Brown, 2000; Kutas & Hillyard, 1980), which suggest that both groups are becoming less reliant on context to extract meaning from words within sentences, even over a brief period of time. This may be reflecting marginally enhanced nonverbal IQ and language proficiency observed on behavioral measures, as N400 amplitudes are inversely related to language proficiency (Hampton Wray & Weber-Fox, 2013; Kutas & Federmeier, 2011; Osterhout & Holcomb, 1992).

At pre-test, the N400 elicited by semantic violations was broad, present in the early 400-700 ms time window and also in the late 850-1550 ms time window. However, the N400 effect at post-test was not as broad; the N400 was only significant in the early, but not the late, time window. These findings suggest the N400 became less broad from pre- to post-test, largely resolved by the late time window at post-test. A more focal N400 effect indicates a reduced neural response to semantic violations, which is thought to reflect more efficient semantic processing. Previous studies have reported similar changes as a function of age and language proficiency (Osterhout & Holcomb, 1992; Friederici, Pfeifer, Hahne, 1993; Silva Pereyra, Lin, Kuhl, 2005), as well as SES (Pakulak, Sanders, Paulsen, & Neville, 2005). Together with the current findings, this may suggest that over time, children in the current study were able to process semantic violation errors more efficiently, with greater ease of lexical access/integration, indexed by the more focal N400.

The smaller and more focal N400 at post-test compared to pre-test across all children may be associated with marginally increased nonverbal IQ and language proficiency observed across groups in the current study. This is also thought to be a product of participation in Head Start. As discussed, Head Start provides multiple opportunities for social interaction between large groups of children and Head Start personnel. Through these interactions, daily opportunities to use language and be exposed to language are possible, which may be less frequent for children not participating in Head Start. Coupled with maturational changes one might expect in children of this age group over time, the reduction in breadth of the N400 response observed in both groups could be a product of increased language skills through the learning experiences facilitated by Head Start.

4.2.1 Differences in Semantic Processing in Children Participating in PCMC-A

As predicted, the change in N400 mean amplitude from pre- to post-test differed between groups. However, the specific pattern of those differences was slightly unexpected. Children participating in PCMC-A exhibited an increased positivity over posterior electrode sites at post-test compared to pre-test, which was not seen in children participating in Head Start Alone. Instead, children in the Head Start Alone group exhibited a reduction in N400 amplitude from pre- to post-test in response to semantic violations.

The appearance of an increased positivity in response to semantic violations may indicate the emergence of the late positive component, or LPC. The existence of the LPC, elicited by semantic violations, has been reported in the literature and is thought to reflect processes of semantic reanalysis and repair of the entire linguistic message after an error is detected (Van Petten & Luka, 2012; Juottonen, Revonsuo, & Lang, 1996). The LPC is present in adults as well as young children from higher SES households (Van Petten & Luka, 2012; Weber-Fox, Hampton Wray & Arnold, 2013) and has been shown to emerge around age 5 years in higher SES children (Hampton Wray, Pakulak, Yamada, Weber, & Neville, 2016). When a language error is identified, emergence of the LPC is thought to reflect development of neural-processes responsible for accurately reassessing an already predicted linguistic meaning. These tasks involve the ability to both effectively anticipate the meaning of incoming linguistic stimuli, as well as reprocess incoming information given the new, less expected meaning. As the LPC is thought to index whole-sentence processing and is considered to reflect more adult-like processing, it may be that the direct child-training in attention provided by the PCMC-A intervention is facilitating stronger attention skills, making it easier for children in PCMC-A to attend to higher volumes of linguistic information, such as whole sentences. This increased attention to the whole sentence is then reflected by the emergence of neural processes indexing sentence-level reanalysis.

In addition to training in attention, parent training may also play a role in the emergence of the LPC component in the PCMC-A group. The parent trainings involved instruction in specific strategies to promote more balanced conversational turn-taking (i.e., piggy bank model), and more specific listening and direct commenting on child language productions. This may have enhanced a child's awareness of language input in the home environment and may have facilitated language development, reflected by the development of the LPC.

Importantly, children participating in Head Start Alone also exhibited maturation in language processing of semantics over time. In the Head Start Alone group, decreased N400 amplitudes to semantic violations were observed at post-test. This pattern indicated less reliance on sentence context for semantic integration, a more mature semantic processing pattern (Holcomb et al., 1992; Hahne et al., 2004). This pattern suggests that participation in Head Start may be improving semantic processing in preschool children from lower SES backgrounds.

Finally, despite seeing more mature semantic processing skill from pre- to post-test across groups and differences in processing patterns between groups, only small, significant changes in language scores were evidenced on standardized behavioral assessments. This suggests that event-related potentials may be more adept at capturing subtle differences and changes in language processing patterns than behavioral measures alone. This finding supports the importance of utilizing both behavioral and electrophysiological outcome measures to obtain a more holistic view of language development in young children.

4.2.2 Relationships Between Nonverbal IQ and Semantic Processing

Regression analyses were performed to evaluate relationships between changes in behavior and change in neural processes for semantic condition at pre- to post-test. A significant relationship between change in non-verbal IQ and semantic processing was identified in the late time window over posterior electrode sites. When the two groups were separated, this effect was strongest for children participating in PCMC-A, while there was no significant correlation in the Head Start Alone group. This correlation revealed that a bigger improvement nonverbal IQ performance over time was associated with a more negative change in N400 amplitude over time. The increased N400 with better nonverbal IQ performance is different than what might be expected. One possible explanation for this relationship is perhaps children in PCMC-A who had lower IQ scores at the beginning of the study were attending more to the violation condition after direct training in attention, which may result in more negative N400 neural responses at post-test. Children with better nonverbal IQ scores at pre-test did not appear to exhibit this same effect of attention training.

4.3 Syntactic Processing

Across both groups, the ERPs elicited by syntactic violations were not significantly different from those elicited by canonical sentences, either in the early 400-700 ms time window or the late 850-1550 ms time window. Studies in older children have reported a significantly later P600 in children (upwards of 750 ms post stimulus onset) than in adults, (Hahne & Friederici, 1999) and previous studies of higher SES children have reported a P600 in preschool-age children using the same paradigm as the current study (Weber-Fox et al., 2013; Hampton Wray, Pakulak, Yamada, Weber, & Neville, 2016). However, the current findings of no significant condition effects in this sample of children from lower SES backgrounds suggests that, despite language skills within normal limits, children from lower SES backgrounds may exhibit less mature syntactic processing patterns than children from higher SES backgrounds. One possible reason for this finding may be that the later development of syntactic and morphological skills compared to semantic skills (Brown, 1973) results in a longer time period to develop and become organized in children from lower SES backgrounds. Since children from lower SES households often exhibit slower rates of language development, the formation and maturation of language networks responsible for higher-level language processing, like syntax, may also take more time. This slower maturation of syntactic processing then results in the minimal differentiation between violation and canonical sentences observed in the current study.

4.3.1 No Differences in Syntactic Processing Between Groups

No differences between groups were observed in the early time window for syntactic processing. This finding may result from the less mature syntactic processing system in lower SES children, as discussed above. It may also be that attention training and parent training for 8-weeks with PCMC-A may not be long enough to elicit change at the neural level, especially given the likely starting point of weaker abilities in neural processes for syntax in children from lower SES background.

However, a difference between groups from pre- to post-test was observed in the late time window. This difference appeared to be largely driven by pre-test differences in the Head-Start Alone group. Despite random assignment of all participants into groups, unexpected pre-test differences in syntactic processing were observed. The differences at pre-test were a larger posterior positivity elicited by syntactic violations in the Head Start Alone compared to the

PCMC-A group. No differences were observed between groups at post-test. Therefore, the change observed from pre-to post-test appears to result from pre-test differences in ERP patterns for syntactic processing in the HS-Alone group. The reasons for this pre-test difference are unclear. Despite random assignment, children in the HS-Alone group may have had slightly higher nonverbal IQ and receptive language scores, as well as higher household SES values compared to children randomly assigned to PCMC-A. As ERPs have been found to differ with small changes in skill level, including nonverbal IQ, receptive language, and SES (Hampton Wray & Weber-Fox, 2013), the accumulation of multiple small increases in these measurements may have contributed to a significant difference between groups at pre-test.

4.3.2 Relationships Between Nonverbal IQ and Syntactic Processing

A relationship was identified between change in nonverbal IQ performance and syntactic processing in the late time window over anterior electrode sites. This correlation was strongest in the PCMC-A group, with no significant relationship in the Head Start Alone group. This finding indicates that greater change in nonverbal IQ scores were correlated with increased negativity over anterior electrode sides over time. The negativity recorded in this time window may be a precursor to the Left Anterior Negativity, or LAN, which has previously been reported in adults (Neville, Nicol, Barss, Forster, & Garrett, 1991; Friederici, Hahne, & Mecklinger, 1996) and older children (Hahne et al.). As discussed in Methods, the LAN is considered an index of syntactic processing (Friederici, 2002, 2003; Batterink & Neville, 2013). In addition to sensitivity to morphosyntactic errors in predicted syntactic structures during online sentence processing, the LAN has also been reported to be sensitive to linguistic load placed on working memory systems during syntactic parsing tasks. (Kluender & Kutas, 1993). Therefore, these results suggest children with better nonverbal IQ performance over time may be showing the emergence of a precursor to the LAN component at post-test, which was not present at pre-test.

One possible explanation for this relationship may be due to the skill areas assessed by behavioral tests at pre- and post-test in the current study. Subtests measuring aspects of nonverbal IQ included a strong working memory requirement, so that better performance on this task reflects, at least in part, better working memory skills. Previous research suggests working memory plays a primary role in the acquisition of syntax, as syntax is essentially the ability to mentally sequence words into a logical, and grammatically acceptable word order (Ellis, 2010; Ellis & Sinclair, 1996). Syntactic processing highly engages areas of the brain responsible for the storage, retrieval, and sequencing of phonological, morphological, and grammatical information, and direct training in attention has been shown to mediate syntactic processing skills (Neville et al., 2013). Additionally, attention skills have also been discussed as a facilitator of working memory abilities (Posner & Peterson, 1990). As the standardized assessment used in the current study to assess nonverbal IQ involved working memory tasks, it is possible that better performance on the nonverbal IQ task indicated better working memory skills, and possibly also better attention skills, however, the potential relationships between these factors are purely speculative. However, there is a literature showing better skill in working memory is associated with more mature syntactic processing (Fiebach, Schlesewsky, & Friederici, 2001; Pakulak & Neville, 2010; Hampton Wray & Weber-Fox, 2013).

4.3.3 Relationships Between Receptive Language and Syntactic Processing

Finally, regression analyses between changes in behavior and syntactic processing revealed a relationship between change in receptive language performance and increased negativity in neural responses to syntactic violations over anterior electrode sites in the earlier time window. As with the change observed in the semantic condition, this correlation was stronger for the PCMC-A group and not significant for the Head Start Alone group. These findings indicate that children who exhibited greater change in receptive language performance over time also exhibited a less negative response to syntactic violations in the early time window. As can be seen in the ERP waveforms, the PCMC-A group had slight negativity over anterior electrode sites in the early time window at pre-test elicited by syntactic violations; this early difference became less negative at post-test. One potential reason for this change may be that young children from lower SES backgrounds exhibit a greater reliance on semantic processing networks to process syntactic information than observed in higher SES peers, indexed by the small negativity in the early time window present at pre-test. Overtime, children participating in PCMC-A may be transitioning to more reliance on less developed networks for syntax to process syntactic information, which is indicated by the lack of an early negativity elicited by syntactic violations at post-test. Therefore, children who show more growth in language skills during the eight-week time period also exhibit greater amplitude reduction in the early negativity. Similarly, those children who had greater negativity at pre-test may have begun the study with less mature language processing skills and therefore would have to experience a greater reduction in negativity to make the transition to language processing with syntactic networks. Conversely, children who started with higher language skills may have had smaller negativities at pre-test and thus did not make as large of a transition from reliance on semantic to syntactic networks in order to process syntactic violations, which is illustrated by less change in syntactic processing patterns over time.

CHAPTER 5: LIMITATIONS AND FUTURE DIRECTIONS

Dual-generation intervention research investigating language processing in preschool children with neurobiological outcome measures is currently in its infancy. One limitation of this study involved the pre-test differences present in the syntactic condition within the Head Start Alone group. While this may have limited the conclusions that could be made based upon group comparisons in the current study, future research may benefit from employing additional analyses that specifically match a subset of participants between groups at pre-test to control for unpredictable pre-existing differences between groups. Another future direction is to employ more complex statistical procedures in order to control for pre-test differences to evaluate changes following intervention. Importantly, it will be critical to understand whether these pre-test differences between groups are meaningful, for example, if they reflect other subtle differences in skills, and if so, how might those differences impact neural processes and also response to intervention.

Another potential limitation of the current study were the behavioral assessments used to evaluate receptive language skills and nonverbal IQ. While correlations emerged between nonverbal IQ, receptive language, and language processing, more sensitive behavioral assessments may have enhanced the ability of this study to better characterized behavioral changes as indexed at the neural level. Standardized assessments are typically designed to broadly evaluate and identify developmental areas that may be deficient, therefore, future studies may benefit from employing a more diverse battery of standardized assessments to evaluate specific aspects of language proficiency and cognition, such as selective attention, verbal reasoning, phonological awareness, and vocabulary knowledge. Future studies may also benefit from using language and nonverbal IQ assessments that do not tax working memory skills as heavily, in order to more accurately assess specific mechanisms underlying each child's individual abilities at pre-test and at post-test.

A final limitation of the current study is the sample of participants with highly controlled variables. All children involved in this study were right-handed monolingual speakers of English with typically developing nonverbal IQ and receptive language scores and no pre-existing language or neurological impairments. The majority of participants self-reported as being White/Caucasian and all children and families were living at or below the poverty threshold in the state of Oregon. Taken together, these demographic factors may limit the generalizability of this population to other populations in the United States and elsewhere, which are often more racially, culturally, linguistically, and medically diverse. While the results of the current study provide valuable insight into the neural mechanisms mediating language with exposure to a novel, dual-generation intervention, future studies would benefit from recruiting a more diverse and representative spectrum of children and families, such as bilingual families, or those from culturally diverse households. Additional insight could also be gleaned from lengthening the intervention phase from 8 weeks to 10 or 12 weeks, as well as following children after participation in intervention to determine if language processing patterns persist over time.

CHAPTER 6: CONCLUSIONS

This study investigated the impact of a novel, dual-generation intervention on the development of neural mechanisms underlying language processing in preschool children from lower SES backgrounds. The findings of this study provide evidence that within a relatively short time frame of eight-weeks, children participating in PCMC-A displayed different neural processing patterns for semantics than those seen in children participating in Head Start alone, as indexed by ERPs. These results highlight the benefit of the enhancement of neural processes for language for an attention-focused intervention program, which directly targets improving school readiness and developmental outcomes for children and their families. Although changes may be small, these findings reveal that PCMC-A, designed to targeted attention, positivity impacts language processing in preschool children.

Over the history of childhood interventions, extensive resources have been allocated to designing programs that facilitate cognitive and language growth in children in an attempt to ameliorate the detrimental effects of poverty. Therefore, it is significant not only that PCMC-A has been shown to facilitate enhancement of multiple skill areas – language and attention – as indexed by empirical change in neural function, but PCMC-A provides enriching experiences for families from lower SES backgrounds. Given the effectiveness of the PCMC-A intervention, principles and application of this program may have the potential to provide enriching and long-lasting experiences to future generations of children and families.

REFERENCES

REFERENCES

Batterink, L., & Neville, H. J. (2013). The human brain processes syntax in the absence of conscious awareness. *The Journal of Neuroscience, 33*(19), 8528-8533. doi:10.1523/JNEUROSCI.0618-13.2013

Blair, C., & Raver, C. C. (2012). Child development in the context of adversity: Experiential canalization of brain and behavior. *American Psychological Association, 67*(4), 309-318. doi: 10.1037/a0027493

Blakemore, S. J. (2012). Imaging brain development: the adolescent brain. *NeuroImage, 61*(2), 397–406. doi:10.1016/j.neuroimage. 2011.11.080.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53,* 371–399. doi:10.1146/ annurev.psych.53.100901.135233

Brown, R. W. (1973; 1976). *A first language: The early stages*. Cambridge, Mass: Harvard University Press.

Bryck, R., & Fisher, P. (2012;2011;). Training the brain practical applications of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science. *American Psychologist, 67*(2), 87-100. doi:10.1037/a0024657

Bradley, R., & Corwyn, R. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53*, 371-399.

Bruce, J., McDermott, J. M., Fisher, P. A., & Fox, N. A. (2009). Using behavioral and electrophysiological measures to assess the effects of a preventive intervention: A preliminary study with preschool-aged foster children. *Prevention Science,10*(2), 129-140. doi:10.1007/s11121-008-0115-8

Burger, K. (2010). How does early childhood care and education affect cognitive development? An international review of the effects of early interventions for children from different social backgrounds. *Early Childhood Research Quarterly, 25*, 140–165. doi:10.1016/j.ecresq.2009.11.001

Campbell, F. A., Ramey, C. T., Pungello, E., Sparling, J., & Miller-Johnson, S. (2002). Early childhood education: Young adult outcomes from the abecedarian project. *Applied Developmental Science, 6*(1), 42-57. doi:10.1207/S1532480XADS0601_05

Colantuoni, C., Lipska, B. K., Ye, T., Hyde, T. M., Tao, R., Leek, J. T., et al. (2011). Temporal dynamics and genetic control of transcription in the human prefrontal cortex. *Nature, 478*(7370), 519–523. doi: 10.1038/nature10524.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods 134*, 9–21.

Diamond, A., & Lee, K. (2011). Interventions shown to Aid Executive Function Development in Children 4–12 Years Old. *Science (New York, N.Y.)*, *333*(6045), 959–964. http://doi.org/10.1126/science.1204529

Douet, V., Chang, L., Cloak, C., & Ernst, T. (2014). Genetic influences on brain developmental trajectories on neuroimaging studies: From infancy to young adulthood. *Brain Imaging and Behavior, 8*(2), 234-250. doi:10.1007/s11682-013-9260-1

Early Childhood Research Institute on Measuring Growth and Development. (1998). Technical report No. 4: Research and development of individual growth and development indicators for children between birth to age eight. *Center for Early Education and Development*, Minneapolis, MN: University of Minnesota.

Ellis, N. C. (2010). Construction learning as category learning. In M. Putz and L. Sicola (Eds.) *Cognitive processing second language acquisition: Inside the learner's mind*. Amsterdam: John Benjamins.

Ellis, N. C., & Sinclair, S. (1996). Working memory in the acquisition of vocabulary and syntax: putting language in good order. *Quarterly Journal of Experimental Psychology, 49A*, 234-250.

Evans, G. W., Gonnella, C., Marcynyszyn, L. A., Gentile, L., & Salpekar, N. (2005). The role of chaos in poverty and children's socioemotional adjustment. *Psychological Science, 16*(7), 560-565. doi:10.1111/j.0956-7976.2005.01575.x

Evans, G. W., & Kim, P. (2013). Childhood poverty, chronic stress, self-regulation, and coping. *Child Development Perspectives, 7*(1), 43-48. doi:10.1111/cdep.12013

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L.. . Hurt, H. (2006). Childhood poverty: Specific associations with neurocognitive development.*Brain Research, 1110*(1), 166-174. doi:10.1016/j.brainres.2006.06.072

Fenson, L., Marchman, V. A., Thal, D. J., Dale, P. S., Reznick, J. S., & Bates, E. (2007). *MacArthur-Bates Communicative Development Inventories: User's guide and technical manual* (2nd ed.). Baltimore, MD: Brookes.

Fernald, A., Marchman, V. A., & Weisleder, A. (2013). SES differences in language processing skill and vocabulary are evident at 18 months. *Developmental Science, 16*(2), 234-248. doi:10.1111/desc.12019

Fiebach, C.J., Schlesewsky, M. & Friederici, A.D. (2001). Syntactic Working Memory and the Establishment of Filler-Gap Dependencies: Insights from ERPs and fMRI. *Journal* *of Psycholinguistic Research, 30*, 321-338. doi:10.1023/A:1010447102554

Fishbein, D. (2000). The importance of neurobiological research to the prevention of psychopathology. *Prevention Science, 1*(2), 89-106. doi:10.1023/A:1010090114858

Fox, S. E., Levitt, P., & Nelson III, C. A. (2010). How the timing and quality of early experiences
influence the development of brain architecture. *Child Development, 81*(1), 28-40. doi:10.1111/j.1467-8624.2009.01380.x

Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews, 91*(4), 1357-1392. doi:10.1152/physrev.00006.2011

Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Science, 6*(2), 78-84. doi:10.1016/S1364-6613(00)01839-8

Friederici, A. D. (1983). Aphasics' perception of words in sentential context: Some real-time processing evidence.*Neuropsychologia, 21*(4), 351-358. doi:10.1016/0028-3932(83)90021-0

Friedrich, M., & Friederici, A. D. (2006). Early N400 development and later language acquisition.*Psychophysiology, 43*(1), 1-12. doi:10.1111/j.1469-8986.2006.00381.x

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research, 1,* 183–192.

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). The temporal structure of syntactic parsing: Early vs. late effects elicited by syntactic anomalies. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1219-1248.

Goodman, E., McEwen, B., Huang, B., Dolan, L., & Adler, N. (2005). Social inequalities in biomarkers of cardiovascular risk in adolescence. *Psychosomatic Medicine, 67*(1), 9-15. doi:10.1097/01.psy.0000149254.36133.

Gouvea, A. C., Phillips, C., Kazanina, N., & Poeppel, D. (2010). The linguistic processes underlying the P600. *Language and Cognitive Processes, 25*(2), 149-188. doi:10.1080/01690960902965951

Greenough, W., Black, J., & Wallace, C. (1987). Experience and brain development. *Child Development*, *58*, 539– 559.

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech: Semantic ERP effects. *Neuropsychologia, 38*(11), 1518-1530. doi: 10.1016/s0028-3932(00)00052-X

Hagoort, P., Brown, C. M., & Groothusen, J. (1993). The Syntactic Positive Shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8*, 439-484.

Hahne, A., Eckstein, K., & Friederici, A. D. (2004). Brain signatures of syntactic and semantic processes during children's language development. *Journal of Cognitive Neuroscience, 16*(7), 1302-1318. doi:10.1162/0898929041920504

Hahne, A., & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience, 11,* 193–204.

Hampton Wray, A., Pakulak, E., Yamada, Y., Weber, C., & Neville, H. (2016). *Development of neural processes underlying language subsystems in young children from higher and lower socioeconomic status environments.* Poster session presented at the Cognitive Neuroscience Society Annual Meeting, New York, NY.

Hampton Wray, A & Weber-Fox, C. (2013). Specific aspects of cognitive and language proficiency account for variability in neural indices of semantic and syntactic processing in children. *Developmental Cognitive Neuroscience 5*, 149–171. doi: 10.1016/j.dcn.2013.03.002

Hart, B., & Risley, T. R. (2003). The early catastrophe: The 30 million word gap. *American Educator, 27*(1), 4.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Paul H. Brookes Publishing Company.

Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Review of Psychology, 34*, 33-61.

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development, 74*(5), 1368-1378. doi:10.1111/1467-8624.00612

Holcomb, P. J., Coffey, S. A., & Neville, H. J. (1992). Visual and auditory sentence processing: a developmental analysis using event-related brain potentials. *Developmental Neuropsychology, 8*(2-3), 203-241. doi: 10.1080/87565649209540525

Hollingshead, A. A. (1975). *Four-factor index of social status*. Unpublished manuscript, Yale University, New Haven, CT.

Huston, A. C., McLoyd, V. C., & Garcia Coll, C. (1994). Children and poverty: Issues in contemporary research. *Child Development, 65*(2), 275-282. doi:10.1111/j.1467-8624.1994.tb00750.x

Huttenlocher, P. R. (1979). Synaptic density in human frontal cortex - developmental changes and effects of aging. *Brain Research, 163*(2), 195–205. doi:10.1016/0006-8993(79)90349-4

Huttenlocher, P., & Dabholkar, A. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology, 387*(2), 167-178. doi:10.1002/(SICI)1096-9861(19971020)387:2<167::AID-CNE1>3.0.CO;2-Z

Juottonen, K., Revonsuo, A., Lang, H., 1996. Dissimilar age influences on two ERP wave- forms (LPC and N400) reflecting semantic context effects. Brain Research. Cognitive Brain Research 4, 99–107.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes, 15*(2), 159–201

Kluender, R. & Kutas, M. (1993). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. Journal of Cognitive Neuroscience, 5, 196-214.

Knudsen, E. I. (2004). Sensitive periods in the development of the brain and behavior. *Journal of Cognitive Neuroscience, 16*(8), 1412-1425. doi:10.1162/0898929042304796

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621-647, 621-647. doi:10.1146/annurev.psych.093008.131123

Kutas, M. & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic anomaly. *Science, 207*, 203-205.

Kutas, M. & Van Petten, C. (1994). Psycholinguistics electrified: Event-related brain potential investigations. In M. A. Gernsbacher (ed.), *Handbook of Psycholinguistics*, 83-143. New York: Academic Press.

Lewis, M. D. (2005). Self-organizing individual differences in brain development. *Developmental Review, 25*(3), 252-277. doi:10.1016/j.dr.2005.10.006

Li, M., Cui, Z., Niu, Y., Liu, B., Fan, W., Yu, D., & Deng, J. (2010). Synaptogenesis in the developing mouse visual cortex. *Brain Research Bulletin, 81*(1), 107-113. doi:10.1016/j.brainresbull.2009.08.028

Liu, D., Diorio, J., Day, J.C., Francis, D.D., & Meaney, M.J. (2000). Maternal care, hippocampal synaptogenesis and cognitive development in rats. *Nature Neuroscience*, *3*(8), 799–806.

Lopez-Calderon, J., & Luck, S. (2010). ERPLAB Toolbox (1.1.0). Retrieved from http://erpinfo.org/erplab

Love, M. L., & Brooks-Gunn, J. (2010). Getting the most out of early head start: What has been accomplished and what needs to be done. In R. Haskins, & W. Steven Barnett (Eds.), Investing in Young Children: New Directions in Federal Preschool and Early Childhood Policy, (pp. 29-37). Washington, D.C.: Brookings & NIEER.

Luck, S.J. (2012). Event-related potentials. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf & K. J. Sher (Eds.), APA Handbook of Research Methods in Psychology: Volume 1, Foundations, Planning, Measures, and Psychometrics. Washington, DC: American Psychological Association.

Ludwig, J., & Miller, D. L. (2007). Does head start improve children's life chances? evidence from a regression discontinuity design. *The Quarterly Journal of Economics, 122*(1), 159-208. doi:10.1162/qjec.122.1.159

Lupien, S. J., King, S., Meaney, M. J., & McEwen, B. S. (2001). Can poverty get under your skin? basal cortisol levels and cognitive function in children from low and high socioeconomic status. *Development and Psychopathology, 13*(3), 653-676. doi:10.1017/S0954579401003133

Molinaro, N., Barber, H. A. & Carreiras, M. (2011). Grammatical agreement processing in reading: ERP findings and future directions. *Cortex 47*(8), 908-930. doi: 10.1016/j.cortex.2011.01.019

National Center for Children in Poverty. (2013). United States demographics of low-income children. Retrieved from: http://www.nccp.org/profiles/US_profile_6.html

Neville, H., Nicol, J., Barss, A., Forster, K. I., & Garrett, M. I. (1991). Syntactically-based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 3*, 151-165.

Neville, H. J., Stevens, C., Pakulak, E., Bell, T. A., Fanning, J., Klein, S., & Isbell, E. (2013). Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proceedings of the National Academy of Sciences of the United States of America, 110(29), 12138-12143.*

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science, 10*(4), 464-480. doi:10.1111/j.1467-7687.2007.00600.x

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8*(1), 74-87. doi:10.1111/j.1467-7687.2005.00394.x

Nunez, P. L. (1995) *Neocortical dynamics and human EEG rhythms*. New York, NY: Oxford University Press.

Osterhout, L., & Holcomb, P. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*, 785–806

Pakulak, E. & Neville, H. J. (2010). Proficiency differences in syntactic processing of monolingual native speakers indexed by event-related potentials. *Journal of Cognitive Neuroscience, 22*(12), 2728-2744. doi: 10.1162/jocn.2009.21393

Pakulak, E., Sanders, L., Paulsen, D., Neville, H. (2005). Semantic and syntactic processing in children from different familial socioeconomic status as indexed by ERPs. *Cognitive Neuroscience Society*, New York, NY.

Pan, B. A., Rowe, M. L., Singer, J. D., & Snow, C. E. (2005). Maternal correlates of growth in toddler vocabulary production in low-income families. *Child Development, 76*(4), 763-782. doi:10.1111/j.1467-8624.2005.00876.x

Pancsofar, N., Vernon-Feagans, L., & Family Life Project Investigators. (2010). Fathers' early contributions to children's language development in families from low-income rural communities. *Early Childhood Research Quarterly, 25*(4), 450-463. doi:10.1016/j.ecresq.2010.02.001

Pilgreen K.L. (1995). Physiologic, medical and cognitive correlates of electroencephalography. In: Nunez PL (Ed), 195-248. *Neocortical dynamics and human EEG rhythms*. New York: Oxford University Press.

Pinker, S. (1984). *Language learnability and language development*. Cambridge, Mass: Harvard University Press.

Posner, M. I. & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-32

Raizada, R. D. S., & Kishiyama, M. M. (2010). Effects of socioeconomic status on brain development, and how cognitive neuroscience may contribute to levelling the playing field. Frontiers in Human Neuroscience, 4(3), 1-11. doi: 10.3389/neuro.09.003.2010

Ramey, S. L., & Ramey, C. T. (2004). Early learning and school readiness: Can early intervention make a difference? *Merrill-Palmer Quarterly, 50*(4), 471-491. doi:10.1353/mpq.2004.0034

Rao, H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Korczykowski, M., Avants, B. B. … Farah, M. (2010). Early parental care is important for hippocampal maturation: Evidence from the brain morphology in humans. *Neuroimage, 49*(1), 1144-1150. doi:10.1016/j.neuroimage.2009.07.003

Reid, J. B., Eddy, J. M., Fetrow, R. A., & Stoolmiller, M. (1999). Description and immediate impacts of a preventive intervention for conduct problems. *American Journal of Community Psychology, 27*(4), 483-517.

Reid, V. M., Hoehl, S., Grigutsch, M., Groendahl, A., Parise, E., & Striano, T. (2009). The neural correlates of infant and adult goal prediction: Evidence for semantic processing systems. *Developmental Psychology, 45*, 620–629.

Roid, G. H. (2003). *Stanford-Binet Intelligence Scales: Fifth Edition*. Itasca, IL: Riverside, Publishing.

Rosenzweig, M. R. (1966). Environmental complexity, cerebral change, and behavior. American Psychologist, 21(4) 321-332. doi: 10.1037/h0023555

Schmidt-Kassow, M., Kotz, S.A. (2009). Event-related brain potentials suggest a late interaction of meter and syntax in the P600. *Journal of Cognitive Neuroscience, 21*, 1693–1708.

Sansour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinshaw, S., & Boyce, W. T. (2011). Family socioeconomic status and child executive functions: the roles of language, home environment, and single parenthood. *Journal of the International Neuropsychological Society, 17*(1), 120-132. doi: 10.1017/S1355617710001335

Schweinhart, L. J., Montie, J., Xiang, Z., Barnett, W. S., Belfield, C. R., & Nores, M. (2005). *Lifetime effects: The HighScope Perry Preschool study through age 40*. (Monographs of the HighScope Educational Research Foundation, 14). Ypsilanti, MI: HighScope Press.

Sheridan M. A., Sarsour, K., Jutte, D., D'Esposito, M., Boyce, W.T. (2012). The Impact of social disparity on prefrontal function in childhood. *PLOS ONE, 7*(4), e35744. doi:10.1371/journal.pone.0035744

Shonkoff, J. P. (2012). Leveraging the biology of adversity to address the roots of disparities in health and development. *Proceedings of the National Academy of Sciences, 109*, 17302–17307.

Shonkoff, J. P., & Fisher, P. A. (2013). Rethinking evidence-based practice and two-generation programs to create the future of early childhood policy. *Development and Psychopathology, 25*, 1635-1653.

Shonkoff, J. P., & Levitt, P. (2010). Neuroscience and the future of early childhood policy: Moving from why to what and how. *Neuron, 67*(5), 689-691. doi:10.1016/j.neuron.2010.08.032

Shonkoff, J., Richter, L., van der Gaag, J., & Bhutta, Z. (2012). An integrated scientific framework for child survival and early childhood development. *Pediatrics, 129*(2), E460-E472. doi:10.1542/peds.2011-0366

Silva-Pereyra, J., Conboy, B. T., Klarman, L., & Kuhl, P. K. (2007). Grammatical processing without semantics? an event-related brain potential study of preschoolers using jabberwocky sentences. *Journal of Cognitive Neuroscience, 19*(6), 1050-1065. doi:10.1162/jocn.2007.19.6.1050

Silva Pereyra, J. F., Klarman, L., Lin, L. J., & Kuhl, P.K. (2005). Sentence processing in 30-month-old children: An event related potential study. *Neuroreport, 16*(6), 645-648. doi: 10.1097/00001756-200504250-0026

Silva-Pereyra, J., Rivera-Gaxiola, M., & Kuhl, P. K. (2005). An event-related brain potential study of sentence comprehension in preschoolers: Semantic and morphosyntactic processing. *Cognitive Brain Research, 23*(2), 247-258. doi:10.1016/j.cogbrainres.2004.10.015

Spencer, S., Clegg, J., & Stackhouse, J. (2012). Language and disadvantage: A comparison of the language abilities of adolescents from two different socioeconomic areas.*International Journal of Language & Communication Disorders,47*(3), 274-284. doi:10.1111/j.1460-6984.2011.00104.x

Stevens, C. & Neville, H. (2013). Specificity of experiential effects in neurocognitive development. In M.S. Gazzaniga (Ed.), *The New Cognitive Neuroscience, Fifth Ed.* Cambridge, MA: The MIT Press.

Tanner, D., & Van Hell, J. G. (2014). ERPs reveal individual differences in morphosyntactic processing. *Neuropsychologia, 56*, 289-301. doi: 10.1016/j.2014.02.002

Usler, E., & Weber-Fox, C. (2015). Neurodevelopment for syntactic processing distinguishes childhood stuttering recovery versus persistence. *Journal of Neurodevelopmental Disorders, 7*(1), 1-21. doi:10.1186/1866-1955-7-4

Van Petten, C., & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology, 83*, 176–190.

Walker, D., Greenwood, C., Hart, B., & Carta, J. (1994). Prediction of school outcomes based on early language production and socioeconomic factors. *Child Development, 65*(2), 606-621. doi:10.1111/j.1467-8624.1994.tb00771.x

Weber-Fox, C. M., Hampton Wray, A., & Arnold, H. (2013). Early childhood stuttering and electrophysiological indices of language processing. *Journal of Fluency Disorders, 38*(2), 206-221. doi:10.1016/j.jfludis.2013.01.001

Wiig, E. H., Secord, W. A., & Semel, E. (2004). *Clinical evaluation of language fundamentals - Preschool (CELF-P:).* San Antonio, TX: The Psychological Corporation: Harcourt Assessment, Inc.

Yamada, Y., & Neville, H. J. (2007). An ERP study of syntactic processing in english and nonsense sentences. *Brain Research, 1130*(1), 167-180. doi:10.1016/j.brainres.2006.10.052

Zito, K., & Svoboda, K. (2002).*Activity-dependent synaptogenesis in the adult mammalian cortex*. Cambridge: Elsevier Inc. doi:10.1016/S0896-6273(02)00903-0