BEHAVIORAL AND ELECTROPHYSIOLOGICAL CORRELATES (N400) OF LEXICAL AND PHONOLOGICAL PROCESSING IN CHILDREN WITH STUTTERING

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TABLE OF CONTENTS

Chapter 1

Introduction

Language processing in children with stuttering has been questioned and researched in the past few decades. There has been a growing interest in identifying and learning about the linguistic variables that were maybe contributing to speech production in children with stuttering (Conture, Zackheim, Anderson, &Pellowski, 2004; Kolk, Postma, Curlee, & Siegel, 1997; Ratner, 1997; Tetnowski, 1998). Many attempts have been made to establish a connection between the language (phonological, semantic, and syntactic) abilities of a child and the onset and development of stuttering in young children (Ratner, 1997; Pellowski, Anderson &Conture, 2000). Multiple reasons have been proposed to explain why it is essential to understand the links between language disturbances and their effect on fluency in children with stuttering (CWS). Some explain that the onset of the disorder has commonly been observed in 2- 4-year-old children, and this is the phase of rapid language development in children in terms of phonological, syntactic, and lexical growth, thus resulting in more and more complex utterances (Yairi & Ambrose, 2004). While others profess that since the disorder is considered multifactorial, an already inadequate speech motor system may be interacting with neural resources mediating cognition, language, and emotions (Conture et al., 2006; De Nil, 1999; Howell, Bailey & Kothari, 2010; Smith, 1999; Smith, Kelly, Curlee & Siegel, 1997).

In the current study, we have attempted to understand lexical and phonological processing in children with stuttering (CWS) and children without stuttering (CWNS) via a cross-modal primed picture naming task and a pseudo-word rhyme judgment task using behavioral and electrophysiological measures. Lexical processing in children has been studied behaviorally by many researchers using primed lexical decision and picture naming tasks. This measure is thought to allow the experimenter to approximate the time course of the participant's lexical access or encoding or other cognitive processes (Glaser 1992). This generally involves the experimenter presenting a prime such as an aurally presented word related or unrelated to the target picture, immediately before, during, or after the target's onset. Priming occurs when there is an improved response of an individual due to prior exposure to a stimulus while performing a cognitive task like naming or lexical decision (McNamara & Holbrook, 2003). Semantic priming happens when a ''target'' stimulus (auditory or visual) is processed and responded to more quickly and accurately when preceded by a "semantically related prime'' compared to exposure to an unrelated prime. "Semantic activation spreading" is the commonly used term to explain the phenomena wherein there are activations of different words in the mental lexicon during visual decoding of a picture. The words may either be related semantically or phonologically and during a naming task the representations of the speech output get engaged accordingly (Glaser, 1992; Bierwisch and Schreuder, 1992; Roelofs, 1992, 1997). This study thus used a cross-modal primed picture naming task to assess lexical processing in CWS, which used a visually presented target and aurally presented prime. The auditory prime was either semantically related, semantically unrelated or a 1000 Hz tone of 500 ms (no prime).

Pellowski and Conture (2005), in their study, used a similar paradigm of semantic priming on children with and without stuttering. Their results revealed that children without stuttering showed faster reaction times for the related condition when compared to the no prime and the unrelated condition; however, children with stuttering showed longer reaction times to the corresponding state when compared to the remaining conditions. The authors used Levelt's model (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999) to explain how lexical access and retrieval occurs during the fluent speech. Their idea was that CWS is slow at selecting the right lexical items from the mental lexicon during speech-language planning and production. Therefore it was speculated that due to weak connections between the lexemes (items) in the brain, selecting the relevant word or phrase occurs at a slower pace resulting in longer speech reaction times for the related condition. They also speculate that inappropriate mapping of the word for production after retrieval results in several dysfluencies in children with stuttering.

Research in the field of stuttering has been extended to assessing linguistic processing in children with stuttering in the past few decades (Holcomg, Coffey & Neville, 1992; Chauncey, Holcomb & Grainger; 2009). During the acquisition and development of speech and language, the motor/linguistic operation is subject to constant adjustments to the formation of efficient interactive maps (constant and determined). This intrinsic link between motor processing of speech and language processing has been researched in developmental stuttering, especially in the pediatric population. Studies show that CWS poorly on standardised language/ vocabulary tests compared to CWNS and behavioral tests conducted on these children show vulnerability to lexical and phonological processing (Anderson &Conture, 2004; Anderson et al., 2005; Pellowski&Conture, 2005; Wagovich& Bernstein Ratner, 2007). The Demands Capacity model (Adams 1990; Starkweather&Gotwald, 1990) has been popularly used to understand how the internal and external demands for fluency exceed a child's capacities during language development resulting in breakdowns in speech. Psycholinguistic theories have pointed out that faults in children's phonological encoding mechanism might be a causal factor of developing stuttering (Wingate, 1988; Howell, 2004). Another theory gaining popularity is concerning the intactness of individuals' speech motor system with stuttering. According to this concept, CWS shows more significant coordinative variability in speech production than fluent children (MacPherson & Smith, 2013). Thus, the authors suggest that with linguistic complexity and growth, these children tend to show greater variations in the coordinative ability to produce fluent speech.

Lexical Processing and ERP’s

With advances in technology, newer methods of identifying processes mediating speech and language perception and production have been discovered. In the recent past, electrophysiological studies have gained importance as an approach to understand the underlying neural processes related to speech and language processing. Electrophysiological evidence helps bridge behavioral studies results by objectifying the language processes occurring in CWS and CWNS. Since it is perceived to be an immediate recording of the underlying brain activity, it provides a link to identify precisely where the deficit might be as event-related potentials give a direct insight via these potentials' amplitude and latency. Linguistic processes in CWS have been studied by Weber- Fox, Wray, and Arnold in 2013 where they focused on Event-related potentials (ERP) obtained during syntactic and semantic processing in children who do and do not stutter. Natural sentences with or without syntactic and semantic violations were used as stimuli wherein children listened to the sentences while watching a cartoon. ERP’s were recorded for the same, and their results revealed longer N400 latencies in CWS compared to CWNS, indicating slower semantic/syntactic processing. However, the number of ERP studies done on children is very few. A large corpus of ERP studies exists on adults with stuttering (Cuadrado& Weber-Fox, 2003; Weber-Fox & Hampton, 2008; Weber-Fox, 2001). All these studies report that adults who stutter show atypical language processing compared to those who do not stutter. It was also stated that adults with stuttering exhibit N400 and P600 for both semantically/ syntactically congruent and incongruent sentences respectively whereas normally these two potentials occur only for incongruent stimuli (Friederici& Frisch, 2000; Kemmerer, Weber-Fox, Price, Zdanczyk, & Way, 2007).

Deficits in phonological skills are quite common in children with stuttering. It has been extensively studied using priming, rhyme judgment, and non-word repetition (Byrd, Conture & Ohde, 2007; Mohan & Weber, 2015). Studies show that CWS exhibits lower accuracy at non-word repetition and poor scores in rhyme judgments on behavioral tests (Coch, Grossi, Skendzel& Neville, 2005; Hakim & Bernstein, 2007). Despite all the research done in this area, there has been no establishment of whether phonological skills deficits have a relationship with stuttering (Gregg &Yairi, 2007). The authors attempt to find links between stuttering and phonological skills because these skills typically develop between 2- 4 years of age, and stuttering also first presents itself within the same time frame. Thus attempts have been made to study school-aged children who show persistent stuttering to establish relationships between a developing phonological ability and dysfluent speech (Paden, Yairi & Ambrose 1999). Several surveys initially focused on the phonological/ articulation skills as it was observed that CWS exhibited errors in speech production (articulatory errors), showed deviances in phonological processes during the child's development and results on standardized tests revealed poorer scores in CWS (Arndt & Healey, 2001; Blood, Ridenour , Qualls & Hammer, 2003). Prevalence studies indicate that at least 16 to 30 % of non-fluent children exhibit articulation and phonological deficits compared to the 6 to 8 % prevalence of articulation deficits in the general population (Blood, Ridenour, Qualls & Hammer, 2003; Louko, Edwards &Conture, 1990). Age inappropriate deviations in the phonological process have also been commonly examined in CWS, and the trend has now progressed towards research in the deficits related to phonological processing/ encoding as against deficits in production.

Phonological encoding and stuttering

Phonological encoding involves the generation of sounds, syllables, and their subsequent combinations during speech production. For an individual to speak fluently and effortlessly, it is vital to possess self-monitoring to correct oneself during the erroneous speech. To monitor one's speech, access to the subunits of language such as rhymes and phonemes are essential and an integral part of phonological processing during the speech.

This skill is a necessary pre-requisite for fluent speech production and planning (Blackmer & Mitton, 1991; Levelt, 1989; Levelt, Roeloffs, & Meyer, 1999).

Attempts have been made to explain how or why phonological encoding deficits may be responsible for breakdowns in fluency. Wingate (1988) proposed the fault-line hypothesis. He attributed stuttering to a delay in retrieving and encoding syllable rhyme during speech production, resulting in a fault line created at the point of integration of the syllable onset with its rhyme. Perkins, Kent and Curlee (1991) proposed he "neuropsycholinguistic theory" where they outlined two factors as crucial elements contributing to stuttering (1) temporal asynchrony between linguistic (i.e., lexical and phonological, and supra-linguistic planning) and(2) time pressure. On the other hand, Postma and Kolk (1993) proposed the "covert repair hypothesis" suggesting that stuttering's primary symptoms occur overtly due to internal corrections of errors present in the speaker's speech motor plan covertly delays the phonological encoding of phonemes. Another theory was the "EXPLAN theory" hypothesized that fluency failures occur due to temporal asynchronies between speech planning (PLAN) and execution (EX) (Howell, 2004). Such asynchronies are caused by difficulties associated with the planning of complex linguistic segments and fast speech rate and the resulting coping strategies adopted by the speaker. These theories have motivated considerable interest in the role of phonological encoding in stuttering.

Some of the pioneers in stuttering research have repeatedly made use of behavioral measures to identify differences in phonological encoding between CWS and CWNS. These studies compare the reaction time and accuracy of responses between the two groups of children during priming, rhyme judgment, and non word repetition tasks. Melnick, Conture and Ohde (2003) used a phonological priming paradigm on CWS and CWNS where the prime was either no prime, phonologically related prime (initial consonant vowel [CV] or CCV of picture name, e.g., bed–bell), and phonologically unrelated prime (different initial

CV or CCV, e.g., cat–bell). They found comparable results between both groups however, more significant variability in responses was observed in the CWS group. Behavioral studies have contributed to the cluster of studies on phonological processing in CWS. However, studies done using priming paradigms have not been successful at indicating great differences between the fluent and nonfluent groups in both children and adults. Few authors have reported some facilitatory effects of priming, whereas others have said very minimal effects of this condition across both groups. Authors thus caution researchers to interpret the results of such a study with careful observations due to this paradigm's sensitivity and concerning the modality of stimulus presentation, i.e., visual or auditory. They also suggest that it is important to exercise control over the intervals between the prime- target presentations during the task itself to successfully obtain the priming effect.

Due to contradicting results obtained using priming paradigms, the focus shifted towards using a rhyme judgment task to study phonological processing in CWS and AWS. Rhyme judgment of a word pair involves segmentation of the initial word in the pair into its constituent onset and rhyme, followed by holding this information in short-term memory and then comparing it with that of the target word (e.g., mouse–house). A behavioral and event-related brain potential (ERP) study done on CWS and CWNS utilized a rhyme judgment task wherein two components of the waveforms obtained during the task was studied. First, the “rhyming effect” and second, the contingent negative variation, which is a negative deflection indicating brain activity during the retention of the two words in memory and comparing them (Grossi et al., 2001). The study revealed that CWS was more inaccurate in their responses when compared to CWNS. ERP data showed that the waveforms elicited by the prime and target words had peak latency over the right hemisphere in CWS compared with CNS. The groups were comparable in the rhyming effect waveform. Still, differences were observed in the peak amplitude of the contingent negative variation elicited by the prime words (first word in the rhyming pair). The findings were interpreted to suggest that the cognitive processes mediating rhyme judgment are typical in CWS, and working memory and silent rehearsal processes may be delayed in this group.

Behavioral evidence indicates more significant delays in phonological development for young children who exhibited persistent stuttering compared to those who recovered from stuttering (Paden, Yairi& Ambrose, 1999). Also, it has been suggested that phonological disorders occur at a higher rate among CWS, (e.g., as high as 30–40%) compared to the incidence in the general population (2–6%) (Beitchman, Nair, Clegg, & Patel, 1986; Conture, Louko, & Edwards, 1993; Louko, 1995; Melnick & Conture, 2000; Ratner, 1995; Wolk, 1998). The rates of co-occurrence of stuttering and phonological disorders vary considerably across studies. These differences may be due to methodological differences among studies, including varied criteria for identifying phonological disorders (Nippold, 2001; 2002). Nonetheless, there continues to be a consensus that phonological disorders and subclinical differences in phonological processing co-occur with fluency disorders in

children.

Phonological processing and ERP’s

A rise in ERP studies has been observed in the past few decades, and rhyming paradigms have been commonly used to detect and trace developmental trends in accuracy, reaction time, and underlying neural activity for phonological process in typically developing individuals from their childhood through their adulthood (Coch, Grossi, Coffey-Corina, Holcomb, & Neville, 2002; Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001; Kramer &Donchin, 1987; Polich, McCarthy, Wang, &Donchin, 1983; Rugg, 1984; Rugg& Barrett, 1987; Weber- Fox, Spencer, Cuadrado, & Smith, 2003). Most of these researchers observed a consistent pattern in the ERP responses for the rhyming/ non-rhyming experiments. The majority of the studies reflected an evident ERP characterized by an increase in the negative peak amplitude of approximately 350–400 ms post-stimulus onset for non-rhyming target words compared to rhyming targets. This ERP index has been found to be specific to the rhyming judgment task because it was not elicited by any other matching or comparison task using identical stimuli (Polich et al., 1983). The difference between the non-rhyme and rhyme elicited waveforms (formed by subtracting the waveforms produced by rhyming conditions from the non-rhyming conditions) has been called the "rhyming effect (RE)" (Grossi et al., 2001). The RE is a broadly distributed negative component that peaks around 400 ms and is considered a member of the family of N400-like potentials that have been shown to be sensitive to contextual information (Grossi et al., 2001; Rugg & Barrett, 1987). It has been hypothesized that the RE reflects cognitive processes mediating the comparisons of the phonological representations of words, that is, the processes that underlie the ability to determine whether words rhyme or not (Grossi et al., 2001). A stable, adult-like RE was observed in the ERPs of typically developing children as young as 7 years of age performing a rhyming task (Coch et al., 2002; Grossi et al., 2001; Weber-Fox et al., 2003). However, orthographic-phonological interference produced greater peak latency delays in the REs elicited in school-age children (aged 9–10) compared to young adults (Weber-Fox et al., 2003).

To obtain a better understanding of how these skills are linked to speech production tasks such as non-word repetition, phonological priming, phoneme monitoring, and rhyme judgment have been used. This study has thus attempted to identify the phonological processes in children with stuttering using a pseudo-word rhyme judgement task via a behavioural and electrophysiological measures providing information on reaction time/ accuracy and latency/ amplitude respectively. The participant was exposed to rhyme judgment task presented aurally where they were expected to judge the rhyming or non-rhyming nature of the word pair. (eg: /dagi/ - /pagi/ ; /nija/ - /resi/). Behavioral studies have been continuously used in an attempt to identify deficits in various processes thought to have an impact on fluency. Typically, they measure reaction time and accuracy of responses using different tasks such as picture naming and rhyme judgment. However, they pose several shortcomings such as variability in responses, difficulty in interpreting results, and effects of external factors leading to variations in task performance. To overcome these shortcomings and establish a stronger link between the underlying connections related to the condition, event-related potentials (ERP) have been in greater demand. They represent the underlying brain activity and hold a more foolproof methodology that can be interpreted in a reliable manner. Since language processing (lexical and phonological) in this population of children has always been questioned, it has been deemed necessary to research how it may or may not be contributing to dysfluent speech.

Need for the Current Study

Stuttering in children has been viewed with increasing interest as it has been viewed as a multifactorial disorder. It is thus important to understand what factors may be contributing to the onset and development of stuttering especially in young children. Thus, the present study attempts to explore the linguistic processing at lexical and phonological level in children who stutter. Many studies have employed behavioral measures to understand lexical access and phonological access in individuals who stutter using reaction time and accuracy of responses; however the behavioural measures are subject to variability as they are prone to speculation related factors, reducing the objectivity of the behavioural measures. Hence these measures have to be cross-verified by employing electrophysiological measures. A majority of studies have been done on adults with stuttering, and very few use electrophysiological tests. It has also been observed that research in this field has been done in very few languages like Spanish, and a vast number if studies have been done in English.

No evidence of linguistic processing in Indian languages has been found till date. Hence further studies are necessary for other languages with more objective measures. Also, most of the studies involving research in this area have been done on adults, and they include tests of syntactic and semantic processing.

Due to a dearth in ERP research in stuttering, the underlying neurophysiological correlates of stuttering in children have not been established to date. It is essential to identify the correlates of both lexical and phonological processes in CWS to confirm the possible deficits in language processing CWS, and thus both behavioural and electrophysiological measures were employed in this study. The present study aims to investigate the difference in lexical access and phonological access in Kannada speaking children who stutter and who do not stutter. To evaluate the behavioural and electrophysiological evidence of lexical access and phonological access, a cross modal primed lexical decision task and a pseudo-word rhyme judgement task were used. Overt picture naming has been avoided in ERP investigations to eliminate manual responses during articulation, which may corrupt the ERP responses. However, authors have suggested using covert naming or delayed naming to avoid motor responses hampering EEG recording, which has been adopted in this study (Chauncey, Holcomb & Grainger, 2009).

To summarize, the present study was designed to investigate the behavioural and electrophysiological correlates of lexical processing through a cross modal primed picture naming task, and phonological processing through rhyme judgment task, wherein the behavioural and electrophysiological correlates language and phonological processing were identified in children who stutter and who do not stutter.

Research Questions and Hypotheses

The research questions of the current study are as follows:

i) Can we identify any differences in behavioural and electrophysiological measures of lexical processing between CWS and CWNS on a cross modal primed picture naming task which included semantically related, semantically unrelated and no prime conditions?

ii) Can we identify any differences in behavioral and electrophysiological measures of phonological processing between CWS and CWNS on a pseudo word rhyme judgement task?

The hypotheses of the current study include the following:

i) CWS will perform less accurately in the picture naming task than their age and gender matched fluent peers, in both behavioral and electrophysiological measures. A delay, reflected by longer reaction times, in the processing of semantically unrelated, words when compared to the semantically related, and no prime condition is also predicted.

ii) CWS will perform less accurately and exhibit greater reaction times in the rhyme judgement task, for the non rhyming pairs, when compared to CWNS in both behavioral and electrophysiological measures.

If the first predictions are proved to be correct, then the current study would add to existing evidence suggesting that children with stuttering exhibit deficits in language processing (Conture, Zackheim, Anderson, & Pellowski, 2004; Kolk et al., 1997; Ratner, 1997; Tetnowski, 1998). The current study would help support the various theories of stuttering, which have helped lay the basis of understanding the contribution of linguistic variables as a causative factor in developmental stuttering. If the second hypothesis is proved to be correct, then it would help confirming that children with stuttering exhibit difficulties in phonological processing as evidenced by previous researchers (Byrd, Conture&Ohde, 2007; Mohan & Weber, 2015).

Chapter 2

Review of Literature

One of the topics gaining interest in the field of stuttering is whether children with stuttering have dissociations in linguistic abilities when compared to those who do not (Ratner, 1997). Many studies done in this area have however shown very inconsistent results and thus haven't been able to establish the link between language abilities and stuttering.

On one hand, some literature reviews and empirical studies have determined that CWS may have less developed phonology, vocabulary, or overall language abilities than their normally-fluent peers (Anderson &Conture, 2000, 2004; Byrd & Cooper, 1989; Louko, Conture, & Edwards, 1999; Paden, Yairi, & Ambrose, 1999; Pellowski, Conture, Anderson, &Ohde, 2001; Silverman & Ratner, 2002). On the other hand, some other studies have found no confirmation to suggest that the speech or language abilities of CWS are less developed than those of CWNS (Nippold, 2002). Howell, Davis, and Au-Yeung (2003) reported that CWS and CWNS (aged 2–10 years) showed comparable performance on the "Reception of Syntax test" which is a test to assess syntactic development. Other empirical studies have indicated that CWS also show language skills far more advanced than their age related developmental expectations. (Watkins &Yairi, 1997; Watkins, Yairi, & Ambrose, 1999).

Scholars have been intrigued by the possibility of a connection between stuttering and language ability in children and the implications that such a link may hold for treatment and assessment of fluency disorders. It also helps expand the already existing knowledge base regarding the nature, causes, and treatment of stuttering (Anderson &Conture, 2000; Ratner, 1997; Berry, 1938; Bloodstein, 2006; Byrd & Cooper, 1989; Johnson, 1955; McDowell, 1928; Nippold, 1990; Ryan, 1992; Silverman & Williams, 1967; Watkins, 2005; Watkins

&Johnson, 2004; Watkins, Yairi, & Ambrose, 1999; Westby, 1974; Yaruss, LaSalle, &Conture, 1998).

Models of Dysfluent Speech

A child's language ability and stuttering has been linked by several authors and several factors have been thought to contribute to the same. The most striking factor is that stuttering typically begins between the ages of 2 and 4 years (Yairi, 2004), which has been considered a time of rapid progress in syntactic, morphologic, and lexical skills when children are acquiring the ability to produce increasingly complex utterances (Owens, 2012). Some of the explanations and theories regarding stuttering are provided below:

Demands and Capacities Model

According to Starkweather (1987) stuttering occurs "when intrinsically self-imposed and environmental demands exceed the speaker's capacities for speech production". The motoric, linguistic, cognitive and socio-emotional demands could lead to stuttering. The linguistic demand would include any load on semantic, syntactic, phonologic and pragmatic aspects of language processing. Capacities refer to inherent strengths or weakness to speak fluently. The supportive environment including the parents and teachers also play a major role in reducing the development of stuttering behaviours.

As stated above in the Demands–Capacities (DC) model of stuttering (Adams, 1990; Starkweather & Gottwald, 1990), when internal or external demands for fluent speech begins to exceed the child's capacities during his/ her developmental years, in one or more areas of development (e.g., linguistic, cognitive, motoric, emotional), it is most likely for stuttering to occur. Therefore it is a strong indication that the presence of a language disorder in a young child could make him vulnerable to stuttering (Bajaj, 2007; Bernstein Ratner, 1997; Blood, Ridenour, Qualls, & Hammer, 2003).

Dynamic Multifactorial Model

This is one of the recent models which consider the heterogenic causes of stuttering. According to this model, a single factor cannot be accounted for development of stuttering (Smith & Kelly, 1997). Stuttering is the results of interaction of multiple factors (motoric, linguistic, cognitive, social and emotional) none linearly, and proposes a dynamic way of change over time.

Packman & Attanasio 3 factor causal model

This is a newly proposed model incorporating physical and linguistic elements to explain the development of stuttering. According to this model the first causal factor of stuttering is genetic predisposition of "impaired neural processing" (Packman, 2012). The structural and functional deficiencies in the brain will cause instability in the systems of person who stutter. The second factor being increased linguistic demand such as linguistic complexity or variable stress or altered speed and rhythm. The third factor is the physiological arousal or the readiness of the body to react to external stimuli.

Covert Repair Hypothesis

Kolk et al., in 1997 proposed the cover repair hypothesis (CRH) which explains that all disfluent speech is caused by 'covert repairs' of phonological encoding errors that speakers detect before they are expressed overtly (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999). According to CRH, errors in speech production can be detected at the phonological level before they are overtly spoken, resulting in an innate repairs of errors. A covert repair is said to occur when an erred word or sound is detected and is internally rectified rather than an external rectification It is also assumed that any pre-motor planning errors while assigning of specific phonetic features to the syllabic frame can cause stuttering (Perkins et al., 1991). Deficits in phonological encoding could cause discord in linguistic planning and its subsequent motor execution has been proved by several researchers (Howell & Au-Yeung, 2002; Wingate, 1988). Considering there is a deficit in phonological decoding in individuals who stutter; the reason for these deficits could be the inefficient semantic activation or the problem with the phonological encoding system itself (Postma & Kolk, 1993).

EXPLAN theory

An alternative theory about stuttering is the EXPLAN model (derived from 'EX', the speech execution mechanism, and 'PLAN', the parallel language planning mechanism). The development and evidence in favor of EXPLAN are reviewed by Howell (2002, 2004) and Howell and Au-Yeung (2002). These authors argue that language planning and execution are parallel independent processes with neither process being monitored for errors. Consequently, they reject the notion of covert repairs, and instead propose that disfluent speech reflects a mismatch between the timing of planning and the timing of execution. Specifically, whilst someone is executing speech, they can plan upcoming speech. Disfluency occurs if a speaker speaks fast and finishes executing one segment before the plan for the next segment is ready. Consistent with this view, evidence has been published that shows planning difficulty (Dworzynski & Howell, 2004; Howell, Au-Yeung, Yaruss, & Eldridge, 2006) and local increases in speech rate (Howell, Au Yeung, & Pilgrim, 1999; Howell & Sackin, 2000) affect fluency.

Linguistic Variables Related to Fluency

Findings suggest that the linguistic characteristics of dysfluencies are fairly predictable, and evidence point out that CWS may have less developed linguistic skills than CWNS. This has prompted researchers to speculate that CWS may have dissociations or asynchrony within or between subcomponents of their linguistic formulation processes. The stuttering events most commonly exhibited by CWS tend to occur on (a) low frequency words (Anderson, 2005; Soderberg, 1966; Palen & Peterson, 1982), (b) first three words of an utterance (Ratner, 1981; Howell & Au-Yeung, 1995; Wall, Starkweather, & Cairns, 1981),

(c) function words (Bernstein, 1981; Bloodstein & Grossman, 1981;Howell, Au-Yeung, & Sackin, 1999), and (d) longer or more syntactically complex utterances (Ratner & Sih, 1987; Howell & Au-Yeung, 1995; Kadi-Hanifi & Howell, 1992; Logan &Conture, 1995, 1997; Melnick & Conture, 2000; Yaruss, 1999). These linguistic factors have also been shown to influence the fluency with which words are produced in adolescents and adults who stutter (Bergmann, 1986; Brown, 1945; Danzger & Halpern, 1973; Hubbard & Prins, 1994; Klouda &Cooper, 1988; Natke, Grosser, Sandrieser, & Kalveram, 2002; Prins, Hubbard, & Krause, 1991; Ronson, 1976; Wingate, 1984). However, it has also been found that when young CWS, older children and adults are compared, younger CWS tend to stutter more on content words than function words (Brown, 1938a, b; Dayalu, Kalinowski, Stuart, Holbert, & Rastatter, 2002; Howell et al., 1999). Thus, an overall analysis indicates that the consistency of association between certain utterance characteristics and the loci of stuttering goes to show that there may be an interaction between linguistic processing and dysfluencies observed in stuttering.

Another factor, which can be linked to the previously discussed DC model, is that stuttering has been observed to drastically increase as children attempt to produce long and grammatically complex utterances (Ratner &Sih, 1987; Logan &Conture, 1995; Melnick&Conture, 2000; Weiss &Zebrowski, 1992). This suggests that the presence of a language disorder could make it especially difficult for a child to manage stuttering during the effort to express complex thoughts (Arndt & Healey, 2001).

Studies Related to Vocabulary and Language Skills in CWS

Ntourou, Conture and Lipsey (2011) conducted a meta analytical review compiling all the studies done on linguistic abilities in children who stutter. They included studies ranging from those involving the administration of standardized language tests on children with stuttering to tests employing the use of advanced paradigms to assess their language abilities. Their review showed that children who stutter score significantly lower on norm referenced standardized tests when compared to those who do not. These results were consistent for measures such as receptive language, expressive vocabulary and the mean length of utterance. One of the earliest studies include one done by Murray and Reed (1977) where they attempted to determine whether preschool CWS show delays in language skills when compared to their fluent peers. They included seven preschool CWS and CWNS. The children were subjected to the PPVT and Northwestern syntax screening test spanned across multiple sessions. Various dimensions of language such as comprehension of complex language, verbal abilities, and aspects of vocabulary among many others were recorded. They concluded from their results that CWS scored much lower than the CWNS on the verbal and overall language quotients in the standardized tests mentioned above. The authors thus concluded that these results were in compliance with the hypothesis that dysfluent children show associated problems in language skills.

Growing research in the field has made it evident that the use of multiple research methodologies is a key aspect of identifying the issue regarding the language abilities of pre-school children with stuttering. (e.g., Murray & Reed, 1977; Ryan, 1992; St. Louis & Hinzman, 1988; Westby, 1974). This thought arises from the fact that several studies have reported that various language abilities of young dysfluent children are lower than those of their fluent peers (e.g., Anderson &Conture, 2000; Bernstein Ratner & Silverman, 2000; Murray & Reed, 1977; Westby, 1974). However contradictions arise where others have reported no significant differences between the two groups (Ratner & Sih, 1987; Bonelli, Dixon, Ratner, & Onslow, 2000; Nippold, Schwarz, & Jescheniak,1991), while some others suggest that CWS have sufficient but not advanced language abilities (Brosch, Häge &Johannsen, 2001; Reilly et al., 2009; Watkins, 2005). The use of norm referenced standardized tests was used in the earliest research strategies where the tools focused on the nature of the deficit (e.g., Peabody Picture Vocabulary Test— Revised [PPVT–R]; Dunn & Dunn, 1981), whereas others employed language tests that more broadly assess aspects of both receptive and expressive language (e.g., Test of Early Language Development, Second Edition [TELD–2]; Hresko, Reid, & Hamill, 1991). Authors have also used spontaneous language samples to measure mean length of utterance (Kadi-Hanifi & Howell, 1992) and developmental sentence scoring (Westby, 1974). Finally, others have employed experimental measures to study the speech-language performance in CWS (e.g., lexical priming, as in Pellowski & Conture, 2005; Savage & Howell, 2008)It is also relevant to note other differences among these various studies.

The focus of most investigations associated with language production in CWS has been on phonological processes/ skills, a handful of studies on lexical processing have also been conducted in the recent past. Some studies on semantic priming paradigms have been used to study lexical encoding in adults with typical (McNamara & Healy, 1988) as well as atypical (Baum, 1997; Del Toro, 2000) speech-language production abilities. Studies on CWS and the use of lexical priming tasks have gained importance in the recent past. To name a few, the initial study done on lexical processing on a non fluent group of children was where authors, Pellowski and Conture (2005) used a semantic priming paradigm, in which speech reaction time for naming pictures was measured. The pictures were preceded by either a semantic (related and unrelated) primes, to examine lexical processing in preschool CWS and CWNS. They found that CWS named pictures significantly slower and showed lesser benefit from related primes than CWNS. CWNS also exhibited a significant, negative relationship between receptive vocabulary and speech reaction time in two conditions, whereas CWS did not. The authors revealed that their results suggest that the lexical processing abilities of CWS may not be as developed or organized as those of their normally-fluent peers which was in accordance with Melnick et al. (2003), A more recent study by Hartfield and Conture (2006) made use of conceptual and physical primes to examine how they affect speed and accuracy of picture naming in CWS. Their results revealed that CWS performed much slower when compared to CWNS, but they also showed quicker responses to functionally related primes than physically related primes. The authors suggested that the lexicons of CWS may be more conceptually organized (i.e., words are organized by their functional attributes) than their normally fluent peers, an organizational scheme that tends to be more prominent in early lexical development.

Anderson and Conture (2004) attempted to study syntactic processing abilities of sixteen CWS and CWNS who were aged between 3.3 and 5.5 years. They were subjected to a sentence structure priming task wherein black on white line drawings of children, adults and animals performing simple activities were depicted on a screen and the aim was to elicit a description of the activity from the children. Speech reaction time was measured in the presence and absence of priming sentences. Their results indicated that dysfluent children showed slower reaction times in the absence of priming conditions and greater syntactic priming effects than fluent children.

Savage and Howell (2008) compared how priming of function versus content words in a short sentence will affect fluency in CWS and a control group. They included twelve children in each group aged 3.10 to 8.11 years who were subjected to a task wherein they first heard an auditory prime that was either a function word ("he/she is) or content word ("waving") followed by a visual presentation of a cartoon which they had to describe (e.g.: "He is (functional word) or "waving" (content word). Their results indicated that both groups demonstrated improved fluency with function word priming than content word priming and the effect was more pronounced in CWS than CWNS. They also discovered that CWS group produced content words with significantly longer durations when compared to children in the control group. From this study the authors attempted to find the underlying nature of the process involved in dysfluent speech production and provided explanations in sync with the EXPLAN theory.

A study attempted to quantify the presence of language dissociations in childhood stuttering by examining differences in performance between speech and language measures in CWS and CWNS (Anderson &Conture, 2000). In particular the authors found that CWS, when compared to CWNS, exhibit a significantly greater difference between standardized measures of receptive/expressive language and receptive vocabulary, with receptive/expressive language being better developed than receptive vocabulary. On average, CWS scored almost 30 percentile points higher on the receptive/expressive language measure than on the receptive vocabulary measure. Likewise, CWNS exhibited the same relative trend of lexical development lagging that of syntactic development, but there was only an average of a 13 percentile point difference between the two measures.

Ratner, Newman and Strekas (2009) investigated the effects of word frequency, neighborhood frequency, and density on a group of fifteen CWS in the age ranges of 4; 10 to 16; 2 and 15 age- and sex-matched CNS. They made use of a confrontation picture naming task for the same and the results revealed that CWS and CNS were comparable in accuracy. Significant difference for word frequency, neighborhood frequency, or density was not observed between both groups. The authors interpreted the findings to suggest that the organization of the phonological lexicon was comparable in CWS and CNS.

In 2014, Alvarez, Jaramillo and Cabrera used a lexical decision task in Spanish children with and without stuttering, as it is considered to be an appropriate method of investigating the lexical access without involving articulation. They studied the effect of first syllable frequency and word frequency on the responses and suggested that if stuttering is related to deficits in the oral production mechanism there should be no change in reaction time and accuracy, as the task does not involve any overt responses. Their results revealed that CWS were slower in responding to correct answers and they also exhibited more inaccurate responses when compared to CWNS. The authors thus attributed this change to the deficit at the level of processing/ access, especially due to the fact that these children were not made to respond outwardly.

Event Related Potentials and Language Processing in Stuttering

Picture naming has long been used to tap the processes involved in language productions, such as, activation, selection, and phonological encoding of words conveying target concepts. It has been used effectively to test the time course of these processes (Glaser, 1992). In picture naming, visual feature processing of a pictured object leads to the activation of concepts (Collins & Loftus, 1975). The commonly understood concept is that when a picture is visually processed it leads to the spread of activation from the concept to the lemmas holding syntactic information about words and rapid processing of semantic and phonological information facilitates fluent speech production (Levelt, 1989). These processes have been related to semantic encoding. Processes in semantic and phonological encoding appear to have multiple steps however they occur within just hundreds of milliseconds (Schmitt, Münte, & Kutas, 2000; Van Turennout, Hagoort, & Brown, 1997, 1998)

ERPs reflect the electrophysiological responses during overtly experienced events. Previous studies have reported language processing being atypical in persons with stuttering based on the difference in underlying neural activities and structure from electrophysiological studies. Some studies related to ERP's have been reported in the recent years in persons who stutter (Cuadrado & Weber-Fox,2003; Weber-Fox & Hampton, 2008; Weber- Fox, Hampton

Wray, & Arnold,2013 ;Weber-Fox et al.,2004). It involves the recording of electrical responses elicited due to firing of neurons while processing any information.

Weber-Fox (2001) investigated the role of neurolinguistic factors in stuttering using Event-related potentials in nine adults who stutter and control group in the age range of 17 to 34 years. Participants were asked to read sentences silently which were presented on the computer screen and had to respond by pressing the button to judge whether sentence made any sense or not. ERP's elicited for adults who stutter for closed-class, open-class and semantic anomalies were characterized by reduced negative amplitude compared to the control group. Results showed that there were alterations in linguistic processing for adults who stutter were related to neural functions that are common to word classes and perhaps involve shared, underlying processes for lexical access. Cuadrado and Weber-Fox (2003) studied the syntactic processing using the behavioral and ERPs while the IWS and NS made judgments about the subject-verb agreement violations in simple and more syntactically complex sentences. The behavioral responses were obtained in both off-line and online tasks. The judgment accuracy for IWS was lower than the NS more so for syntactically more complex sentences. Further, the amplitudes of the P600 responses for IWS were reduced when compared to NS. Weber-Fox et al. (2004) investigated the phonological processing in AWS. They recorded behavioral and ERPs from AWS and NS while the participants did a phonological rhyme judgment task. Although RTs, accuracy of responses and ERPs were similar between AWS and NS, topographic pattern for ERPs were different between two groups of individuals. Weber-Fox & Hampton (2008) studied neural processing of semantic and syntactic constraints as indexed by N400 and P600 responses in AWS and AWNS. They reported significantly differences in AWS when compared to AWNS. In Weber-Fox, Spruill, Spencer, and Smith (2008) study, ERPs were recorded while CWS and CWNS did a visual rhyming task. Results suggested N400 responses with respect to phonological rehearsal and target word anticipation was atypical in CWS. Further, there was also atypical processing with hemispheric contribution towards the linguistic integration stage of processing. Weber-

Blomgren, McCormick, and Gneiting (2002) conducted an electrophysiological study which revealed longer latencies of auditory P300 on linguistic stimuli compared to non linguistic stimuli in adults who stutter compared to adults who do not stutter. This is one of the earlier electrophysiological studies in stuttering literature suggesting a delay in linguistic processing in stuttering population. Further, researchers have investigated linguistic processing in individuals who stutter using N400 and P600. N400 which reflects the semantic processing and P600 which reflects the syntactic processing have been found atypical in persons with stuttering.

Weber-Fox et al. (2013) studied CWS and CWNS while the participants listened to sentences which had either semantically or syntactic (phrase structure) violations. There were differences in both the N400 and P600 amplitudes for both semantic and syntactic violations. Usler and Weber-Fox (2015) studied neural processing of syntactic and semantic structures in, persistent, and recovered 6-7 year old CWS. Their responses were also compared to age and gender matched normal children. ERPs were recorded while these children listened to sentences which had semantic and syntactic violations in English and Jabberwocky sentences. Results suggested neural processing of syntactic structures may be less well developed in 6-7 year old children with persistent development stuttering.

Huffman (2009) studied the lexical semantic activation in PWS and PWNS using a picture naming task. They looked for the effect of semantic and phonological priming on picture naming using behavioral and ERP (N400) measure. The results revealed that N400 priming for semantically related stimuli was not operational in PWS compared to PWNS.

Whereas N400 effects of phonological priming task did not differentiate the two groups. The results implied impaired semantic network activation in persons who stutter.

Maxfield et al. (2012) aimed to understand how the performance of adults with stuttering varies with semantic and phonological priming on picture word naming task compared to typically fluent adults using Event Related Potentials(N400). The results revealed that the priming effect was greater in typical fluent speakers and AWS exhibited reduced semantic priming effects and increased phonological priming which reflected atypical semantic and phonologic processing in AWS. Maxfield, Morris, Frisch, Morphew, and Constantine (2015) made use of a naming task to assess cognitive/language processing across AWS and typically fluent adults. The target pictures were followed by prime words and both prime and target was either mismatched /identical. The effect of priming in naming and the performance was correlated with the vocabulary knowledge. They found that reaction time and accuracy improved with priming in both groups with longer reaction time in AWS. The longer reaction time in AWS was in positive correlation with the receptive vocabulary in TFA. Electrophysiological results revealed that posterior-P1 amplitude negatively correlated with expressive vocabulary in TFA versus receptive vocabulary in AWS. Frontal/temporal-P1 amplitude correlated positively with expressive vocabulary in AWS. Results suggest that poorer expressive vocabulary in AWS indicates greater suppression of conceptual information which is irrelevant. Topographically restricted N400 indicates weaker connections for lemma in AWS. In conclusion the study indicates difference in underlying cognitive/language processing during picture naming in AWS than TFA. Maxfield, Huffman, Frisch, and Hinckley (2010) have also looked for semantic activation spreading on picture naming in AWS using ERP measures on picture word priming task. An unattended probe word was presented aurally prior to the presentation of the picture, which was either semantically related or semantically/phonologically unrelated to picture names for which

ERP’s were recorded.ERP results revealed that posterior N400 amplitude was enhanced for both semantically related and unrelated probes in TFA than in AWS.N400 results suggests that while picture naming there is a strategic inhibitory effect on semantic activation spreading in AWS. The authors report that the difference in N400 amplitude as suggestive of difference in attention allocation in AWS compared to TFA. In general, ERP studies evidence the atypical neural processing during language related tasks in persons with stuttering.

To summarize, literature has revealed several deficits in language processing in CWS. It needs to be explored further using a variety of methodologies. As the use of electrophysiological studies has been gaining popularity it is also warranted in current research trends in order to validate behaviourally obtained results.

Phonological Processing and Stuttering

Since it has long been hypothesized that one of the causes of stuttering in young children may be deficits in phonological encoding, it has been an area of interest for most researchers. Several explanations regarding the underlying cause of the disorder have been explored and a lot of attention has been shifted towards dysfunctions in motor execution of speech. The inability to temporally coordinate respiratory, phonatory, and articulatory movement during speaking has been one of the presumed causes (Perkins Rudas, Johnson, and Bell, 1976; Caruso, 1991). However, a few problems have been identified in this explanation. Firstly it needs to be identified that the in-coordination is onto genetically prior to stuttering (Wijnen & Boers, 1994). It has been observed through research that 75% of the dysfluencies tend to appear in children between the ages of 2 to 7 years and there appears to be no evidence of motor in-coordination in children as young as 2 years through their childhood (Andrews and Harris, 1964). Alternate explanations not related to motor theories are those related to functioning at the central level that is related to ‘speech planning’ occurring before the execution of speech movements.

Research on normal speech production and on phenomenon such as “slip of the tongue” and also on individuals with aphasia, help understand that the preparation before the execution of an utterance can be divided into three main components: (1) message generation; (2) formulating; and (3) articulating (Levelt, 1989) (Figure 1). The formulating component encloses the central linguistic processes of syntactic and phonological encoding. Syntactic encoding is the creation of sentence structure on the basis of abstract representations of word meanings, so-called “lemmata”. Phonological encoding comprises the creation of a fully specified articulatory program, which incorporates three sub processes: (1) selection of the segments for a (string of) word(s); (2) sequencing these segments within syllable frames; and (3) the fixation of intonational and temporal parameters of syllables. This only results in a motor plan which is much like a layout which is not entirely ready to be executed.

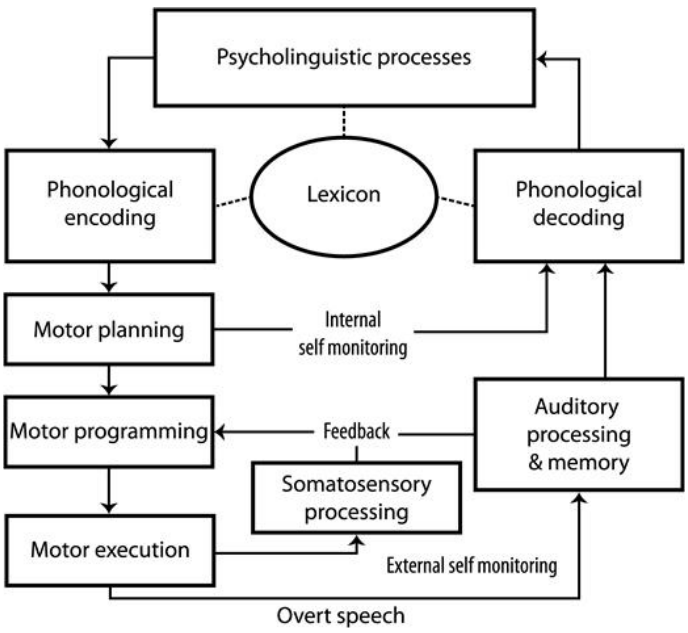

Figure 1.1: Schematic representation of Levelt’s model showing the processes involved in planning and execution of speech motor plan.

This only enables to system to be prepared for the coordinated patterns of movement in the speech-related muscle systems to be developed. One of the important aspects of Levelt's model is the use of auditory feedback. Much evidence has been acquired to show that speakers are able to monitor the articulatory plan before its execution (Baars, Motley, and MacKay, 1975; Garnsey and Dell,1984).There are some indications that phonological encoding may be crucially involved in stuttering. Quite commonly research shows that individuals who stutter have longer speech initiation times than fluent speakers in various tasks (Starkweather, 1987). Even in silent reading it has been shown that individuals with stuttering are slower than those without stuttering, which implies that the problem cannot be restricted to motor execution, but most probably involves phonological encoding (Bosshardt, 1990; Postma, Kolk, and Povel, 1990a). Moreover, many studies point out that patterns if speech production often observed in stuttering are usually similar to those of accidental sound errors (slips of the tongue), which have been convincingly argued to arise during phonological encoding (Levelt, 1989). This has been explained in terms of the types of dysfluencies seen during stuttered speech, especially repetitions and prolongations. These dysfluencies in individuals who stutter and segmental errors show a tendency to occur on the word initial positions; unstressed syllables and function words are least commonly affected. Further, the frequency of speech errors and of stutter events appears to be affected by the same factors, such as sentence length and complexity, the recurrence of identical or similar phonemes (e.g., tongue twisters) (Postma, 1991).

Brown (1945) has been identified as a pioneer in discovering a link between the phonological factors contributing to stuttering namely: "phonetic difficulty, grammatical difficulty, word position, and word length". In order to obtain a clearer understanding of how phonology and stuttering maybe connected most of the authors who began research in this field followed in Brown's footsteps. Howell and Au-Yeung (1955) took into consideration, the effect of the phonological complexity of an utterance on the severity of stuttering on children based on Brown's assumption regarding phonological complexity being one of the factors. They tested this assumption by categorizing the utterances of 31 CWS and 48 CNS ranging from 3 to12 years of age into eight phonological categories(not phonologically difficult; complex shape; multisyllables; late emerging consonant; complex shape and multisyllables; complex shape and late emerging consonants; multisyllables and late emerging consonants; complex shape, multisyllables, and late emerging consonants). They were trying to create a link between the severity of stuttering and the phonological categories and identify whether they had any contribution to increase or decrease in severity. The authors found positive results and concluded that it was possible that severity was directly related to extent of phonological development in children. These studies done in the initial years of stuttering research has paved the way for authors to shift focus onto the use of a variety of paradigms to test the effect of phonological encoding on stuttering.

Phonological encoding has been thought of a process involving the retrieval or building a phonetic or articulatory plan from each lemma which is the conceptual representation in the mind of a words meaning and grammatical structure. It has been thought of as being made of three of the following processes: (1) generation of segments that constitute words; (2) integration of sound segments within the structure of words; and (3) assignment of appropriate syllable stress (Levelt, 1989).These processes are imagined to be like a bridge between the lexical/ phonological processing and the execution of speech movements (Levelt, 1989, 1999). The neuropsycholinguistic theory (Wingate, 1988), fault line hypothesis (Perkins, Kent & Curlee, 1991) , covert repair hypothesis (Postma & Kolk, 1993) and the EXPLAN theory (Howell, 2004) have all led to considerable interest in exploring the links between language processing and production in individuals with stuttering. As mentioned earlier the most commonly used methodologies to test this link have been priming, non word repetition, phoneme and rhyme monitoring (Sasisekaran, 2013). Given below is an overview of the various studies done on children and adults with stuttering to understand the role of phonology in the disorder.

Priming studies

Priming has been long used as an experimental paradigm in various studies. It is explained by researchers who study the effects of priming it works in a facilitatory manner by increasing the activation level of the involved phonological segments. This in turn boosts the articulation plan already processed in the system, e.g. : the segment ‘bur’ may activate all words sharing this string of syllables such as “burglar”, “bury”, “burn” etc. Thus for all these words sharing the string of syllables the speech onset time will be faster (Wijnen & Boers, 1994). Brooks and Macwhinney (2000) conducted a study on fluent children aged five to twelve years, using phonological priming in picture naming which included the use of phonologically related, unrelated and neutral/ identical word primes. The study revealed that the children named the pictures faster when they were preceded by a related string of syllables than when preceded by an unrelated one. One of the earlier studies done by Melnick et.al, (2003) on three to five year old children with and without stuttering also indicated longer speech reaction times for dysfluent children when compared to the fluent peers and he also noted a negative correlation between the mastery of articulation and reaction time for speech. Byrd, Conture and Ohde (2007) explored the holistic and segmental processing in a picture naming auditory priming experiment on twenty six children with stuttering aged three to five years. They also used three priming conditions, neutral (tone), holistic (which involved an entire target word without the initial CV component) and the segmental prime (which included only the initial CV combination and not the whole word). The analysis of their results revealed that the children performed faster in the holistic priming condition when compared to the segmental priming conditions. They also showed that group differences in the type of priming conditions were present i.e., the 5 year old CWNS were faster in the holistic condition whereas CWS were faster in the segmental condition. They concluded that CWS show delays in segmental encoding or decoding (related to segments of speech) when compared to CWNS.

A greater number of studies have been done on adults with stuttering (AWS). An implicit priming task was used by Wijnen and Boers (1994) where 20 – 35 year old adults with stuttering participated in their study. The participants were instructed to utter one word as fast as possible, from a set of five words which were visually presented. Prior to the presentation of the five words a cue/ prime was presented which was either a homogenous i.e.; the cue word being phonemically similar to the target, or heterogeneous wherein the cue word was unrelated to the target. Their results revealed that AWS showed more errors and slower speech onset times than AWNS. However both groups performed better in the homogenous condition when compared to the heterogeneous condition.

Although there have been many researchers whose results suggest that phonology may have a role to play in stuttering some others have refuted this claim as well. Burger & Wijnen (1999) used a similar paradigm on 15 – 40 year old adults with stuttering. Both groups were reported to show comparable performance and the results did not particularly prove the involvement of any phonological deficits. Another study by Vincent, Grela and Gilbert (2012) also reported significantly longer speech onset times in AWS in all priming conditions with no significant changes in frequency of stuttering across the conditions. They concluded that phonological encoding may not have a major role to play in dysfluent speech production in AWS.

Phoneme monitoring studies

Phoneme monitoring in silent naming has been one of the widely used experimental tasks, apart from priming, in typically developing and disordered population (Sasisekaran, 2013). Wheeldon and Lahiri (2002) explain that a phoneme monitoring task expects the participant to encode single segments of sounds constituting a name of a picture in order to be able to respond accurately. An investigation of the segmentation and rhyme abilities of CWS was conducted by Sasisekaran and Byrd (2013). Participants performed two verbal monitoring tasks, phoneme and rhyme monitoring, in silent naming. Performances in the verbal monitoring tasks were compared with a neutral, nonverbal tone monitoring task. Additionally, the complexity of the phoneme monitoring task was varied such that participants had to monitor for singleton versus consonant clusters. Analysis of the response time data did not reveal significant differences between the groups in the three monitoring tasks. Analysis of the complexity data revealed a trend for slower monitoring consonant clusters in the CWS group compared with the CNS. The latter finding offered a preliminary suggestion of segmentation difficulties with increasing phonemic complexity in CWS. The author followed up the previous experiment to find the time course of phonological encoding in CWS and CWNS. Participants were required to monitor the target phonemes situated at syllable onsets and offsets of bisyllabic words. An auditory tone monitoring task was also paired with the phoneme monitoring task and the data revealed that CWS progressively performed slower in monitoring subsequent phonemes within the bisyllabic words; while differences were not seen in the auditory tone monitoring task. Error percentages between both groups and tasks were compared and no marked differences were observed between the phoneme monitoring and auditory tone monitoring. The CWS group was also significantly slower in a picture-naming task compared with the CNS. The findings suggested that CWS experience temporal asynchronies in one or more processes, including phonemic encoding and/or motor planning, leading up to phoneme monitoring during silent naming.

Similarly, AWS have also shown differences in monitoring tasks and segmentation tasks. The performance of an experimental group and control group was compared on a phoneme monitoring task, picture naming and simple motor task. Results revealed a significantly slower response times in AWS when compared to the fluent group especially in the phoneme monitoring whereas they performed equivalently in the other two tasks. Thus they elaborated that the results reflect possible delays in the phonological encoding/ monitoring of speech segments during silent naming (Sasisekaran, De Nil, Smyth & Johnson (2006). Sasisekaran and De Nil (2006) confirmed earlier findings and reported significant group differences between 10 AWS and 12 control participants in a phoneme monitoring task performed during silent naming, and only marginal differences were observed in phoneme monitoring during perception.70 These findings, however, need to be interpreted with caution, as the phoneme monitoring task involves several sub processes including speed of lexical retrieval, phonological encoding, general monitoring skills, and motor responses.

A study conducted on AWS revealed contradictory results on a phoneme monitoring task. Brocklehurst and Corley (2011) studied the ability to monitor errors in speech during overt and covert production of tongue twisters. Their study included 32 AWS and 32 control participants to. Their aim was to assess the stability of the covert repair hypothesis because it had been suggested that persons with stuttering exhibit a greater number of errors. They found that compared with the control participants, AWS produced more word onset and word order errors. This finding indicated that when rate is held constant, AWS make, and therefore detect, more errors of phonological encoding. However, these authors failed to find a significant correlation between the number of errors in overly produced speech and stuttering severity scores. Based on experimenter and self-ratings, they also found that AWS were not more aware of the errors they make. Therefore these authors concluded that although individuals who stutter tend to make more errors, their dysfluencies may not be a result of errors in phonological encoding.

Non-word repetition

Gathercole (2006) helped understand the underlying processes involved in non word repetition and highlighted the importance of intact auditory processing (when the nonwords are presented aurally), encoding of the acoustic information into phonological representations, holding the representation in working memory, motor planning and execution of the response which are all step by step processes occurring during such a task. It has gained some popularity in research studies due to the involvement of so many processes which can be assessed using a single task. Non-word production can be thought of as a direct link to segmental/phonological encoding with negligible lexical access including semantic and syntactic encoding. Thus, authors have explained that differences in task performance can be attributed to differences in phonological encoding abilities. Hakim and Ratner (2004) investigated nonword repetition in eight CWS and CWNS aged between 4 and 8 years. Their results indicated that CWS produced more segmental errors, such as omissions and deletions, than CNS, and this difference was significant at the three-syllable length level, and both the groups had a higher percentage of errors across four- and five-syllable nonwords. They suggested that the findings supported the hypothesized link between stuttering and a linguistic processing deficit at the phonological level of speech production. In accordance with the previous study Anderson, Wagowich and Hall (2006) also found similar differences in 12 CWS and 12 CNS between 3 and 5 years. However caution must be exercised by researchers when using this task as it involves multiple underlying processes. Thus isolating any one process to identify the functioning level which has the deficit becomes a challenge.

As always research leads to a variety of results as shown by a study done on twelve Iranian CWS aged 5 to 7 years (Bakhtiar, Abad &Panahi, 2007). They reported comparable nonword repetition performance between CWS and age matched CWNS. These authors also compared reaction times for nonword repetition between the two groups and found no difference. They interpreted the findings as support against the covert repair hypothesis, 4 which attributes slowed and/or erroneous phonological encoding in CWS. Smith and colleagues (2012) in their study using the same paradigm, revealed that majority of the CWS had language and/or phonological disorders and produced significantly more errors in the nonword repetition task compared with the CWNS. Although, it was observed that those children without any errors in speech showed comparable results with the fluent group. In contrast to some of the earlier studies, these authors have shown that children who stutter do not differ from those who do not when it comes to accuracy of their performance.

In a 2013 study by Sasisekaran and Byrd, fourteen CWS and CWNS were subjected to a nonword repetition and phoneme elision task. The phoneme elision task requires the repetition of a nonword with the omission of a target sound (Wagner, Torgesen & Rashotte, 1999). Statistical analysis of their data revealed that the CWS showed significantly lower scores in percent of correct phonemes on the non word repetition task when compared with the CWNS. In phoneme elision, the younger CWS showed a significantly lower accuracy rate than the older CWS, although similar differences were not evident between the younger versus older CWNS. Group differences in speech initiation times were not evident in either of the tasks. The findings were interpreted to support the presence of a phonological encoding/working memory deficit.

Rhyme Judgment

Studies on phonological encoding have employed several tasks and experimental paradigms to tap into how it affects speech production. Among these some studies have used rhyme judgment to study phonological processing in both CWS and AWS. Rhyme judgment of a word pair involves knowledge of the segments in a word, followed by the segmentation of the initial word in the pair into its constituent onset (initial segment) and rhyme (final segment). The information then needs to be held in short-term memory and compared to the segments in the target word (e.g., mouse–house).As stated in an earlier study, the rhyme abilities of children with and without stuttering aged 7 to 13 years, was assessed using a segmentation and rhyme monitoring task by Sasisekaran and Byrd (2013). The children were asked to make a judgment of whether the non-word they hear and the name of the picture they're visually presented with are rhyming or not. Results revealed that both groups performed well in the task with minimal errors and the non-word they heard prior to the picture helped prime their system for the segments in the target picture, thus enabling their responses to improve.

Event related potentials and phonological processing

A review of literature on electrophysiological research related to phonological encoding shows studies dating back to early 21st century. In 2003, Hanson & Rugg employed a rhyme judgement task on normal adult males. The ERP waveforms showed evidence of a prominent late negativity in the non rhyming conditions when compared to the rhyming condition. They also observed that the negativity was focused more towards the midline and right hemisphere. A rhyme judgement task and its effects on the electrophysiological measures were investigated by Weber- Fox, Spruill, Spencer and Smith (2008) on CWS aged 9 to 14 years. They primarily measure peak latency and amplitude of the N400 and revealed that the latency of the N400 was slightly earlier over the left hemisphere when compared the right hemisphere for children who do not stutter. However the latencies were somewhat equal over both hemispheres for the stuttering group.

Weber-Fox, Wray and Arnold (2013) tested behavioural (percent errors) and event related brain potential (ERP) responses in 10CWS between 9;4 and 13;9 and an equal number of age-matched CNS in a rhyme judgment task.23 Two components of the ERP waveforms elicited during rhyme judgment—rhyming effect (defined as the cognitive neural activity associated with the rhyme decision) and contingent negative variation (defined as brain activity associated with the processes involved in holding and comparing two words for rhyme)—were studied. The researchers found that the CWS made more errors in the task. ERP data revealed that the waveforms elicited by the prime and target words had peak latency over the right hemisphere in CWS compared with CNS. The groups were comparable in the rhyming effect waveform, but differences were observed in the peak amplitude of the contingent negative variation that was elicited by the prime words (first word in the rhyming pair). The findings were interpreted to suggest that the cognitive processes mediating rhyme judgment are typical in CWS and working memory and silent rehearsal processes may be delayed in this group.

Much research using rhyme judgement hasn't been conducted on this population to be able to validate the results across groups. Further research is warranted in this field and the sensitivity of the task also needs to be probed. There have been no documented studies on Indian children with stuttering and also in Dravidian languages. Hence it is important to conduct research to identify whether these processes need further investigation in children and adults with stuttering.

Chapter 3

Method

Participants

Two groups of participants, a clinical group and a control group were recruited for the study. The clinical group consisted of 18 Kannada-speaking CWS aged between 6 and 12 years (Mean age= 8.98; SD= 1.77). Whereas the control group consisted of 20 age and gender-matched CWNS. Both CWS and CWNS were recruited through a convenient purposive sampling technique. As this is an explorative study, we did not estimate the sample size of both the clinical and control groups of children. CWS were recruited from Department of Clinical Services, All India Institute of Speech and Hearing, Mysore. CWNS were recruited by contacting nearby schools in Mysore city. The CWS were recruited for the study only after a confirmed diagnosis of stuttering by a qualified Speech-language Pathologist. The diagnosis was based on their performance in Stuttering Severity Index (Riley, 2004). The severity of stuttering was determined by calculating the frequency of dysfluencies, duration of the longest block and the physical concomitants. The severity of stuttering in the participants of this study ranged from mild to severe degree. The parents of CWS provided informed written consent to allow the participation of the child in the study. They also filled a questionnaire regarding the child's onset of stuttering, history of rehabilitation, sibling history, and other demographic details. As reported, the CWS had no history of audiological, psychological, and neurological problems and no history of therapy taken. The demographic information of the participants is provided in Table-3.1.

Table 3.1: *Demographic details of the participants in the experimental group*

Participants	Age (years)/ Gender	Severity of Stuttering	SSI score	Handedness	History of treatment

S1	10/Male	Mild	15	Right	Yes
S2	9/Male	Mild	11	Right	Yes
S3	11/Male	Severe	30	Right	No
S4	7/Male	Mild-Moderate	20	Right	No
S5	11/Male	Mild	12	Right	Yes
S6	7/Male	Moderate	23	Right	No
S7	9/Male	Mild	11	Right	No
S8	12/Male	Moderate	25	Right	No
S9	9/Female	Moderate	25	Right	No
S10	9/Male	Moderate	22	Right	No
S11	7/Male	Moderate	26	Right	No
S12	6.8/Female	Moderate	25	Right	No
S13	11yrs/Male	Mild	20	Right	No
S14	8yrs/Male	Mild	16	Right	No
S15	12yrs/Male	Mild	19	Right	No
S16	7 yrs/Female	Moderate	24	Right	No
S17	10yrs/Male	Moderate	26	Right	No
S18	7yrs/Male	Severe	31	Right	No

Stimuli for lexical decision task

One hundred and fifty black and white line drawings of common objects relevant to our study were collected based on Snodgrass and Vanderwart's (1980) standardized set of 260 pictures. The line drawings were rated on a 5-point rating scale by three special educators and three speech-language pathologists on four parameters: name agreement, familiarity, visual complexity, and image agreement. Based on the ratings, 120 pictures with a rating of greater than 3 were finalized for the study (Figure 3.1). These pictures were randomly divided into the three priming conditions; semantically related, semantically unrelated and no prime conditions with forty target pictures in each condition. Each target was assigned with a prime based on the condition to which it belonged. A male Kannada speaker was made to read the prime words which were recorded using the CSL 4500 software at a sample rate of 44000Hz. Each word was then edited using Praat software to remove pauses, and extraneous noise, and the duration of the words ranged from 450-600 ms.

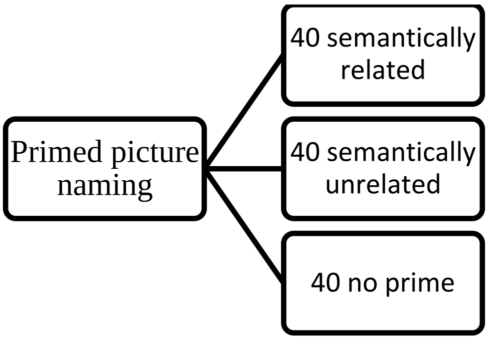

Figure 3.1: Diagram representing the final list of words after ratings by SLP's.

All the children were subjected a two-part testing procedure, which included the behavioural test (30-40 minutes) and the electrophysiological test (2 hours). The two tests were spaced apart by a minimum of two days. The cross-modal primed picture naming task was used to assess lexical processing. It was based on a cross-modal priming paradigm wherein the prime was presented as an auditory stimulus, and the target was a black and white line drawing (visual). The primes were presented in three conditions, the semantically related condition wherein the auditory prime was semantically related to the target (e.g.,/mane/- /ba:gIlU/), unrelated to the target (/sa:gara/- /IrUve/ and the no prime condition wherein a 1000 Hz tone of 500 ms was presented before the appearance of the picture.

Stimuli for rhyme judgment task

A pseudo-word rhyme judgement task in Kannada was used to assess the phonological processing in both groups of children. One hundred and fifty meaningful bisyllabic, non- geminate Kannada words were transformed into pseudowords by transposing the phonemes within the word (e.g.: /na:ji/ = /nija:/) (Shylaja & Swapna, 2010). The words were then rated by three speech-language pathologists to judge for familiarity on a 4 point rating scale, 0 being unfamiliar and 4 being very familiar. The word pairs that were rated greater than 2 we not included in the final list of words. A total of 100 pseudowords (50 rhyming and 50 non-rhyming pairs) (Figure 3.2) were included in the stimuli for the rhyme judgement task. The first word of the pair was the prime, and the second word, the target. The pairs were read out by a male Kannada speaker who was recorded using the CSL 4500 at a sampling rate of 44000Hz. The recording was then edited using PRAAT software to remove extraneous noise and pauses.

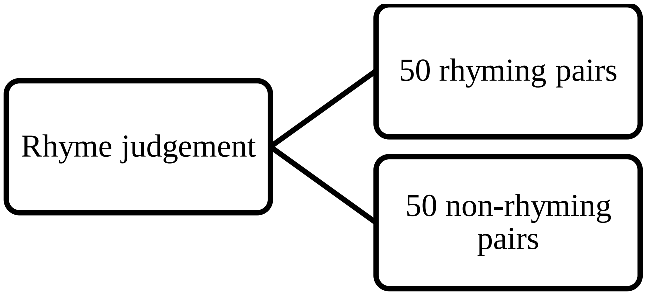

Figure 3.2: Diagram representing the number of stimuli for the task after SLP ratings.

Behavioural Experiment

Procedure for lexical decision task

The behavioural task was administered using the DMDX software as it enables recording of vocal responses. A Sony VAIO laptop was used to present the stimulus and it was placed 15 inches from the participant. The stimulus presentation was as follows: an auditory prime was presented for 700 ms, followed by a target picture after 500 ms. The picture lasted on the screen for 2000 ms, and the next prime-target pair appeared after 1000 ms. The auditory prime was presented through headphones at 60-70 dB SPL. The participants were instructed: “You will first hear a word or a beep sound after which a picture will appear. You have to name the picture as soon as it appears on the screen”. Ten prime-target pairs were used as practice items and the 120 test items were divided into 5 blocks. The participants were given a break after two blocks where they were allowed to play a game or do an activity of their choice for a few minutes.

Procedure for rhyme judgment task

The stimuli for the task were loaded into E-Prime 2.0 software to measure reaction time and accuracy. The rhyme judgement task included a hundred prime- target pairs presented using a set of creative headphones at 60-70 dB SPL. The participant was instructed: “You will hear two words one after the other, listen to the pairs whether they rhyme or not and press 1 if rhyming and 2 if non-rhyming.” Ten pairs were presented as practice items, and a hundred rhyming & non-rhyming pairs were presented in 4 blocks of 25 items each. The prime was presented for 700 ms followed by a fixation for 500 ms and the target was presented for 700 ms followed by a fixation for 2000 ms. Thus the next pair was given after duration of 2000 ms.

Behavioural Responses

The behavioral responses were measured in terms of reaction time and accuracy. Reaction time is defined as the interval of time between presenting a stimulus and the onset of an immediate response to it (Batra, Vyas, Gupta, Gupta, & Hada, 2014). The participants’ naming responses were recorded as . WAV files were analyzed using Check vocal software. To measure reaction time, the .WAV files were opened in the software and the cursor was placed at the onset of the response waveform. The responses were considered inaccurate if the answer was preceded by a hesitation/interjection, revised, misnamed and if the participant was unresponsive. For the rhyme judgment task also behavioral responses of reaction time and accuracy were measured using the E-Data aid module of E-Prime 2.0 software.

Electrophysiological Experiment

Procedure for lexical decision task

The participants were subjected to electrophysiological experiments only after the behavioral investigation. The minimum gap of two days was given after the behavioral experiment. The stimulus items were the same as those used for the behavioral experiment, and they were programmed on E-Prime 2.0. However, the stimulus blocks were repeated twice such that the items appeared twice in random order. The pictures used in the picture naming task appeared on a VIEWPixx monitor, a specifically designed display toolbox with 1920 (Height) x 1220 (Width) pixels. The black and white line drawings appeared on a white background. The auditory prime was presented at 60-70 dB SPL using ER 3A insert earphones.

The stimulus presentation for the ERP experiment followed the same pattern as that behavioral experiment. However, in the ERP paradigm, an additional pre and post fixation (a cross and a question mark respectively) of 500 ms and 1000 ms was included. The auditory prime was presented for 700 ms followed by fixation for 500 ms, and the target picture appeared for 1000 ms followed by a post-fixation for 2000 ms during which the participant was asked to name the picture. After the fixation disappeared, a blank screen was presented for 1000 ms. The next prime appeared after a total duration of 3000 ms. An outline of the presentation for both behavioral and electrophysiological experiments is provided in Figure 3.3.

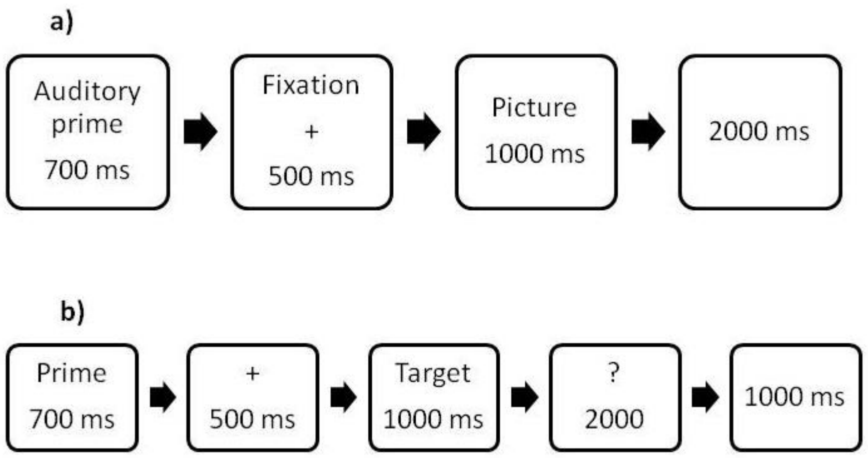

Figure 3.3: a) presentation of stimuli in the behavioural experiment; b) presentation of stimuli in the electrophysiological experiment.

The participant was seated comfortably on a reclining chair, and the continuous EEG was acquired using an elastic cap (Quik cap by Compumedics Neuroscan) comprising 64 silver chloride electrodes. Twenty-nine scalp electrodes were placed in the following positions based on the 10-10 system: FP1, FPz, FP2, Fz, F3, F4, F7, F8, T7, T8 Cz, C3, C4, CP1, CP2, CP5, CP6, FC1, FC2, FC5, FC6, Pz, P3, P4, P7, P8, Oz, O1, O2, and Oz (Figure 3.4). Bipolar electrodes were placed over the left and right outer canthi to monitor horizontal eye movements (HEOG) and over the left inferior and superior orbital ridge to monitor vertical eye movements (VEOG). The linked mastoid served as a reference/ active electrode during recording. Signa gel was used as conduction material. It was injected into the electrodes using a syringe to obtain contact between the scalp and electrode surface. The impedance at all the electrode sites was below 20 kΩ. Continuous EEG recording was obtained using the Compumedics Neuroscan instrument with SynAmps^2 amplifier, and the test lasted for two hours, including participant preparation and the data collection for two tasks.

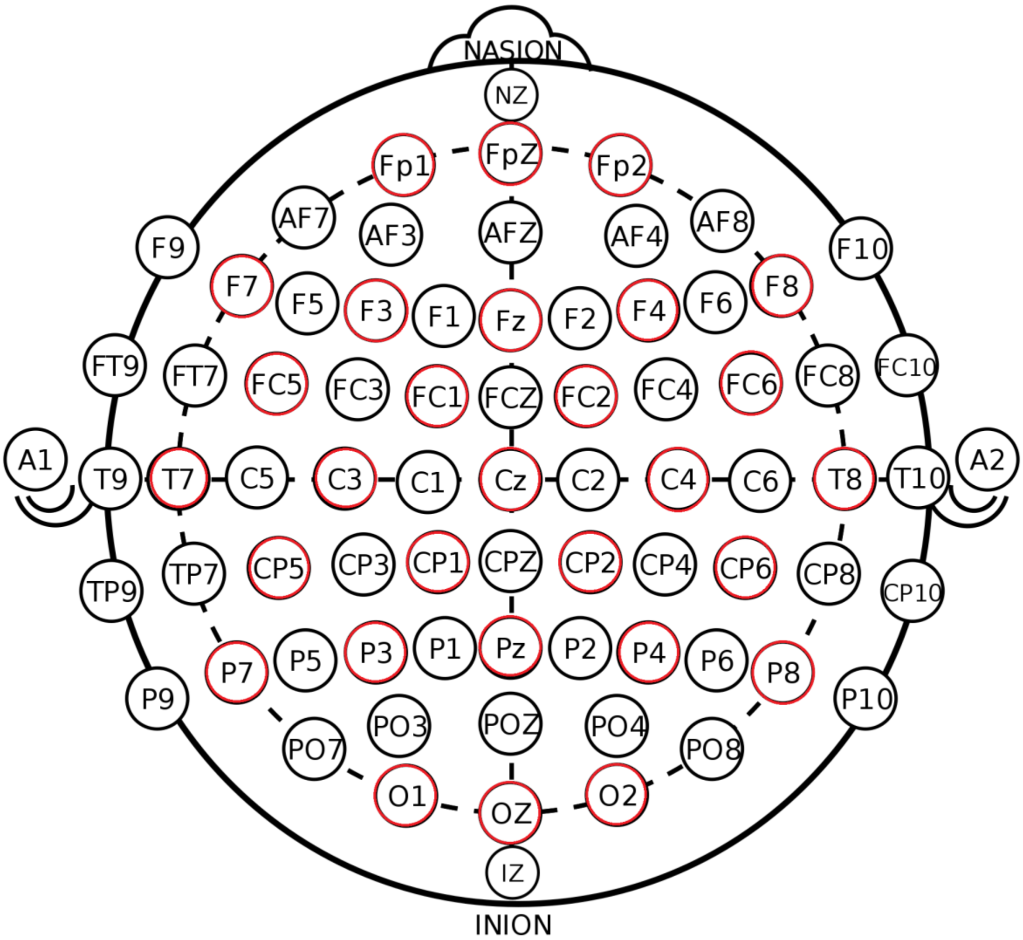

Figure 3.4: Diagram representing the electrode montage for recording of EEG waveforms using Quik cap.

Offline Analysis of ERP Recording

During offline processing, the continuous EEG data were DC offset corrected and the DC corrected waveforms were bandpass filtered from 0.5 to 30 Hz with a 48 dB roll-off to eliminate the high-frequency noise component. The ocular artifacts were removed from the EEG signal. The continuous filtered EEG waveform was epoched from -200 to 1500 ms. Any trials with remaining artifacts exceeding 25 µV for the VEOG and HEOG channels for the remaining channels were automatically detected and these epochs were removed from further analysis. Responses were epoched from -200 to 1500ms to obtain the responses for each condition. A voltage-dependent artifact rejection was carried out to remove any artifacts arising due to other unwarranted responses. The remaining trials were averaged by condition for semantically related, unrelated and no prime conditions for each participant (Weber-Fox, Wray & Arnold, 2013; ERPLAB; Lopez-Calderon & Luck, 2010). The amplitude and latency measures of N400, an ERP that signifies the semantic processing in an individual, were considered for further analysis. For the analysis purpose, N400 was defined as a negative going deflection which peaks around 400 milliseconds post stimulus onset, although it can extend from 250-500 milliseconds (Holcomb, Coffey, & Neville, 1992). In the current study, the amplitude and latency of the N400 were measures to compare between CWS and CWNS to understand the neurological correlates during a lexical processing task involving three different priming conditions.

Procedure for rhyme judgement task

The ERP experiment for the rhyme judgement task was counterbalanced with the primed picture naming task. The same set of stimuli was included for the ERP recording. Four blocks of 25 items each were presented and the last block was repeated twice such that the items appeared twice in a random order. The participant was instructed as follows: "You will hear two words one after the other. They may sound similar or different. Listen to the word pairs and press 1 if you find them to be same and 2 if different. Press the correct button when the question mark appears on the screen". The pairs' rime was presented for 700 ms followed by a fixation for 500 ms, after which the target word was presented for 700 ms followed by a post fixation for 2000 ms during which the participant was asked to press the appropriate button. The post fixation was provided in order to avoid motor responses during the task. The next pair of words was presented after 3000 ms. Electrode sites were retained the same as those used in the primed picture naming task along with the VEOG, HEOG and reference electrodes (Figure 3.5). A continuous EEG recording was obtained for the same. The EEG recording for both experiments lasted for 2 hours, including preparing the participant and the two tasks.

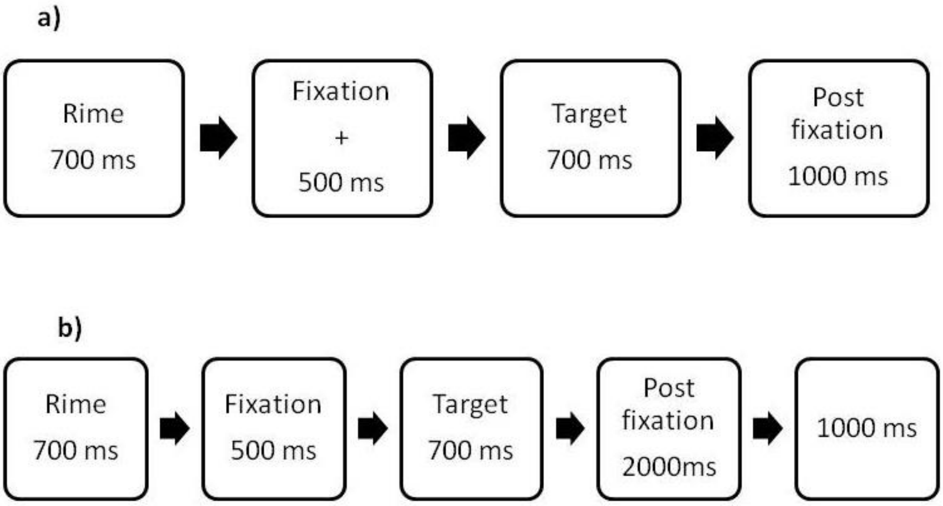

Figure 3.5: Schematic representation of the presentation of stimuli for the rhyme judgement task (4a) for behavioural and ERP experiment (4b).

Offline analysis of ERP recording:

During offline processing, the continuous EEG data were DC offset corrected and DC corrected waveforms were bandpass filtered at 0.5-30 Hz with a 48 dB roll-off to eliminate the high frequency noise component. The ocular artifacts were removed from the EEG signal. The continuous filtered EEG waveform was epoched from -200 to 1500 msec. Any trials with remaining artifacts exceeding 10 µV for the VEOG and HEOG channels for the remaining channels were automatically detected and these epochs were removed from further analysis. Responses were epoched from -200 to 1500 to obtain the responses for each condition. A voltage dependant artifact rejection was carried out to remove any artifacts arising due to other unwarranted responses. The remaining trials were averaged by condition for rhyming and non-rhyming words for each participant (Weber-Fox, Wray & Arnold, 2013; ERPLAB; Lopez-Calderon & Luck, 2010). Mohan and Weber (2015) reported that ERP studies had indicated increased amplitude of the negative peak at around 400-ms post-stimulus onset (N400) for non-rhyming words compared to rhyming words across several rhyming studies done in English. The difference between the N400 elicited by the non-rhyming and rhyming words is called the “rhyme effect”. The N400 is a negative-going deflection that peaks around 400 milliseconds post-stimulus onset, although it can extend from 250-500 milliseconds (Holcomb, Coffey, & Neville, 1992). The amplitude, latency, and topographical distribution could vary according to the priming conditions, semantic relatedness, and also for congruent and incongruent words (Holcomb & Neville, 1991; Kutas, Lindamood, &Hillyard, 1984). In the current study, the amplitude and latency of the N400 are compared between CWS and CWNS to understand the neurological correlates during a phonological processing task using a rhyme judgment task in Kannada.

Statistical Analysis

All data obtained in the study were analyzed using IBM Statistical Package for the Social Sciences (SPSS) software package (Version 20.0). The normality of the data was checked with The Shapiro-Wilks test (Field, 2005), and the results revealed that the data were found to be normally distributed ($P > 0.05$). Hence, repeated measures ANOVA were used to analyze the data. Further, the effect size was estimated with partial eta square. The results of the study are as follows:

Chapter 4

Results

The aims of this study were to

I. Identify any differences between CWS and CWNS in the behavioural (reaction time and accuracy) and electrophysiological measures (latency and amplitude) of lexical processing using a cross modal primed picture naming task involving three priming conditions; semantically related (SR) , unrelated (UR) and no prime (NP).

II. Identify any differences between behavioural (reaction time and accuracy) and electrophysiological measures (latency and amplitude) of phonological processing using a pseudo-word rhyme judgement task

Behavioural results for lexical decision task

The behavioural results were analyzed in terms of reaction time and accuracy. The results of the same are provided in Figure 4.1 and 4.2 respectively. To assess whether the data were normally distributed, the data were subjected to measures of normality using the Shapiro-Wilks test (Field, 2005). As normality measures were closer to 1, the data were considered to be normally distributed and they were subjected to parametric tests. Repeated measures ANOVA was done to analyze the effect of priming conditions on reaction time and accuracy of responses.

The mean reaction time of CWS more than that of CWNS in all the priming conditions. However, the mean reaction times across the three conditions within each group were comparable. Results of ANOVA (Table 4.1) showed a significant main effect of group on mean reaction time ($p < 0.05$) with large effect size ($\eta_p^2 = \mathbf{0.28}$). Effect size values were considered as small if they are around 0.02, medium if they are around 0.13 and large if they are around 0.2 (Field, 2005). However, there was no significant main effect of condition and conditions*group interaction effect on reaction time ($p<0.05$). Subsequent condition-wise comparison of mean reaction time between CWS and CWNS groups using independent t-test showed statistically significant difference ($p<0.05$) between the two groups in all the three conditions (Table 4.2).

The mean accuracy scores (Figure 4.2) were comparable between groups in the all the conditions while it differed across the conditions within each group. In the CWS group, the maximum mean accuracy was seen NP condition followed by SR and then UR condition. On the contrary, in the CWNS group the maximum mean accuracy was seen NP condition followed by UR and then SR condition. The results of repeated measures ANOVA showed a significant main effect of priming condition on the mean accuracy scores ($p<0.05$) with large effect size ($\eta_p^2 = \mathbf{0.254}$) (Table 4.1). The conditions*group interaction effect and the group effect on mean accuracy scores were not statistically significant.

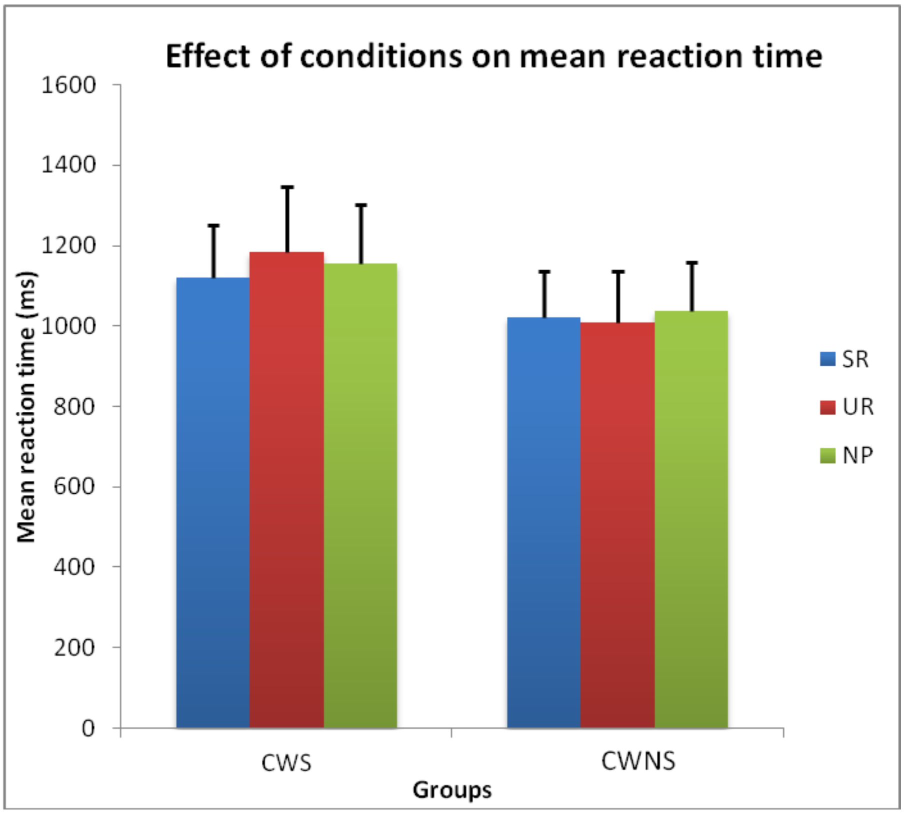

Figure 4.1: Mean reaction time of the CWS and CWNS groups in the three priming conditions (SR, UR, and NP, CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

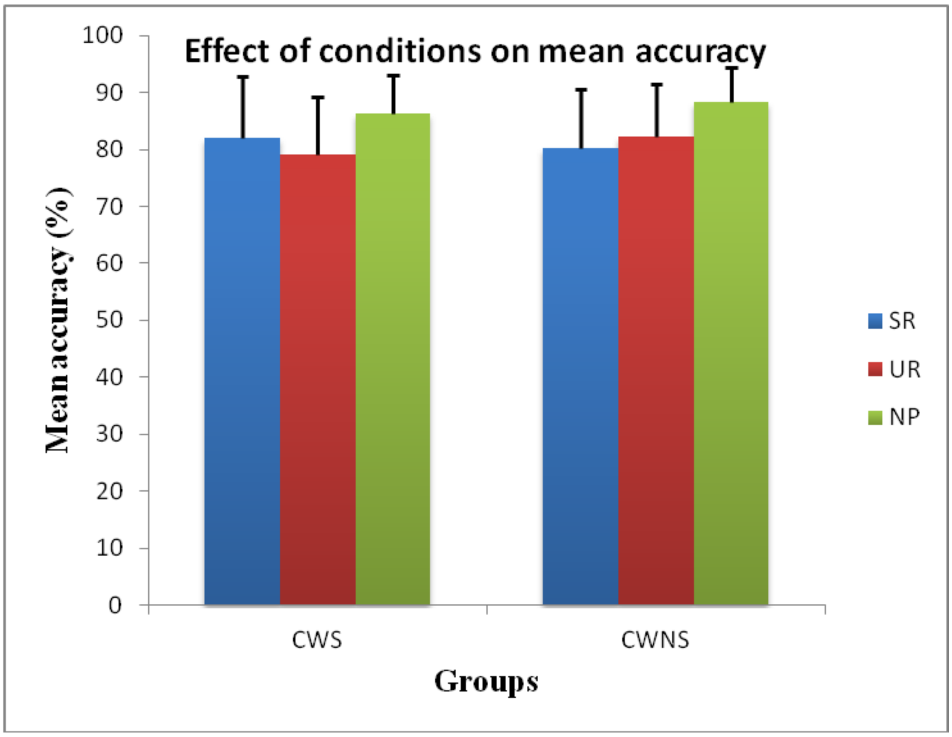

Figure 4.2: Mean accuracy score of the CWS and CWNS groups in the three priming conditions (SR, UR, and NP CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

Table 4.1: *Results of repeated measure ANOVA showing the effect of group, condition and the interaction effect on the reaction time and accuracy score obtained in the behavioral experiment*

Behavioural Measure	**Factors**	**df, F**	**p**	**η^2p**	**Observed power**
Reaction time	Conditions	F(2,68)= 0.713	0.494	-	-
	Conditions*group	F(2,68)= 1.322	0.273	-	-
	Group	F(1,34)= 13.215	0.001*	0.280	0.942
Accuracy	Conditions	F(2,68)= 11.585	0.000*	0.254	0.992
	Conditions*group	F(2,68)= 1.483	0.234	-	-
	Group	F(1,34)=0.223	0.640	-	-

Table 4.2: *Results of independent t-test comparing reaction time of CWS and CWNS groups in the three conditions of primed picture naming task*

Conditions	t value	Sig.
Semantically related	t(34)=2.466	0.019*
Semantically unrelated	t(34)=3.564	0.001*
No prime	t(34)=2.608	0.013*

Behavioural results for rhyme judgment task

Analysis of the behavioural data was done on two measures: reaction time (ms) and accuracy scores (%). The mean reaction time was compared between the stuttering group and the fluent group. Both groups performed comparatively with no significant differences, and descriptive statistics revealed a slightly better performance in the CWS group when compared to the CWNS group in both conditions and also showed slightly quicker responses for the non-rhyming conditions than the rhyming condition (Figure 4.3). Mean accuracy scores obtained from descriptive statistics revealed that CWNS exhibited fewer errors than CWS although they failed to be significant between the two groups (Figure 4.4). Repeated measures ANOVA revealed no significant effect of group or condition on mean reaction time and accuracy was not present (table 4.3). Similarly significant interaction effect between group* condition was not observed for both measures.

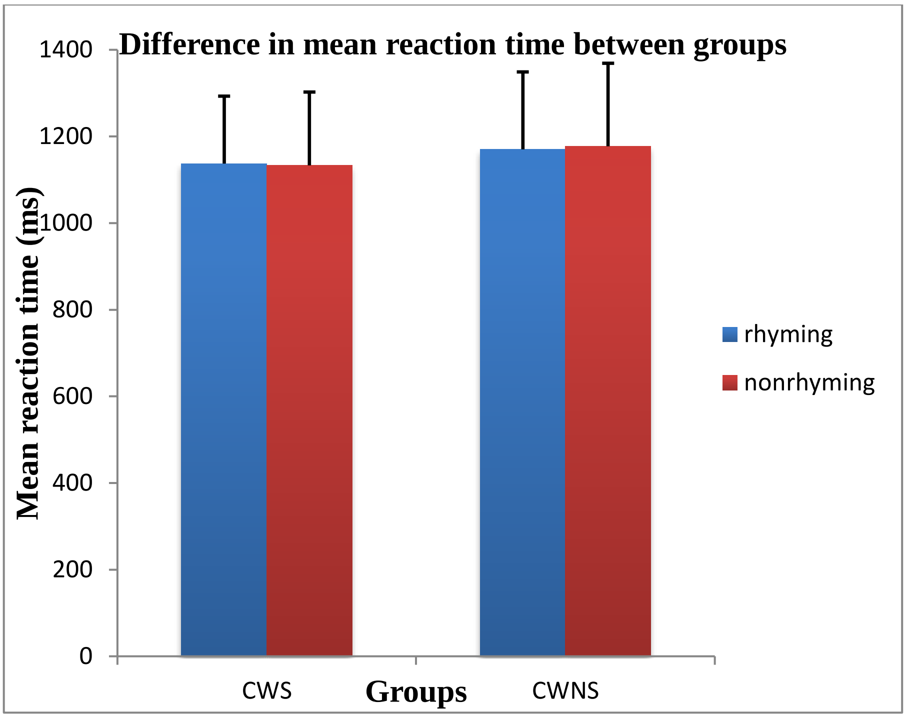

Figure 4.3: Effect of conditions on the mean reaction time (ms) between CWS and CWNS (CWS- children who stutter, CWNS-children who do not stutter).

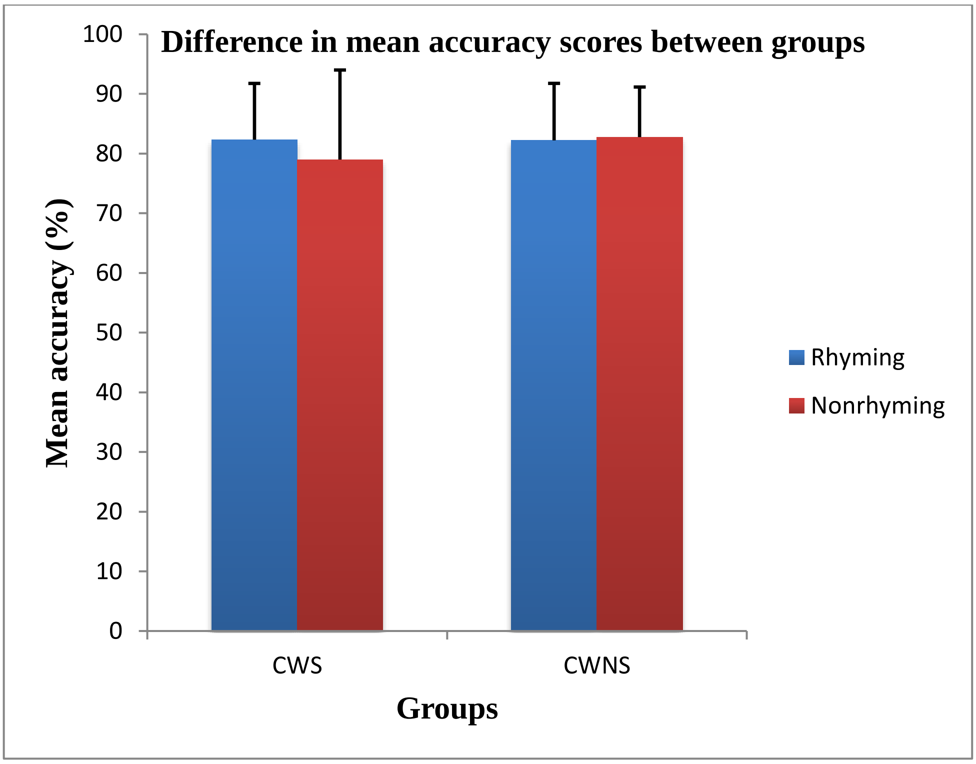

Figure 4.4: Effect of conditions on the mean accuracy scores (%) between CWS and CWNS (CWS- children who stutter, CWNS-children who do not stutter).

Table 4.3: *Within group effect comparison of dependant variables using repeated measure ANOVA for rhyme judgement task on Mean reaction time and Mean accuracy measures*

Behavioural Measures	**Factors**	**df, F**	**Sig.**
Reaction time	Conditions	F(1,34)= 0.005	0.944
	Conditions*group	F(1,34)= 0.069	0.794
	Group	F(1,34)= 0.507	0.481
Accuracy	Conditions	F(1,34)= 1.415	0.242
	Conditions*group	F(1,34)= 2.114	0.155
	Group	F(1,34)=0.255	0.617

Results of N400 for lexical decision task

To begin with, the ERP data were obtained and analyzed based on two measures, namely, amplitude of the N400 peak and latency of the N400 across all electrode sites. Statistical analysis of the data for both variables (latency and amplitude) was done according to three regions of interest, namely: left (FP1, F3, FC1, CP1, P3 and O1), central (FPz, Fz, Cz, Pz and Oz), and right (FP2, F4, FC2, CP2, P4 and O2). Descriptive statistics revealed that the amplitude and latency of N400 was greater in the children with stuttering than the control group in all three conditions (Figure 4.5, 4.6, and 4.7). Repeated measures ANOVA indicated no main effect of conditions and region of interest (ROI) and no interaction effects of conditions*group, ROI*group and conditions*ROI*group on amplitude. However, for amplitude of N400, ANOVA revealed statistically significant effect of group with large effect size ($\eta_p^2 = \mathbf{0.259}$). Results also revealed interaction effect of ROI*group and ROI*conditions*group on mean latency of N400 but no main effect was identified (Table 4.4).

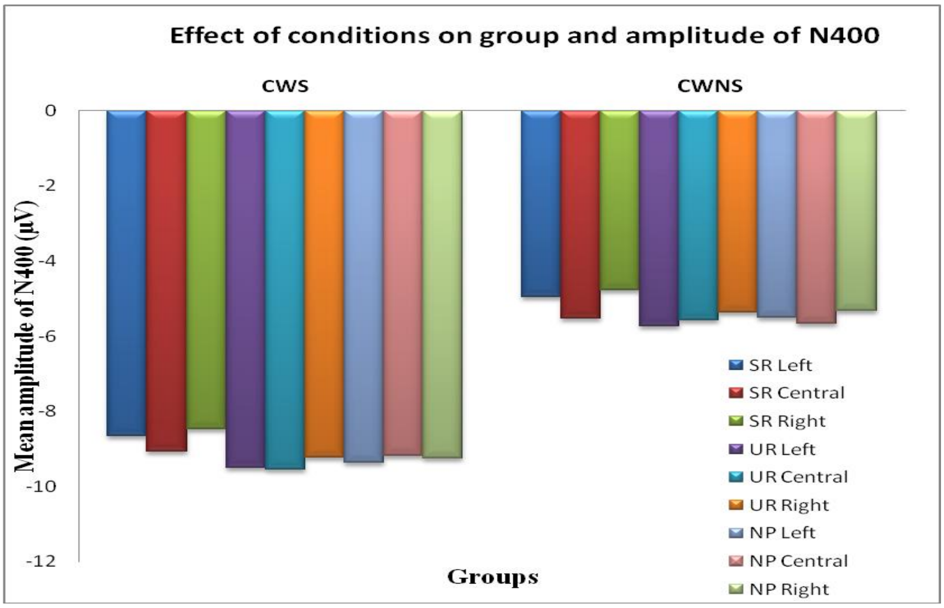

Figure 4.5: Effect of conditions (SR, UR, and NP) across three regions of interest, on mean N400 amplitude for CWS and CWNS (CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

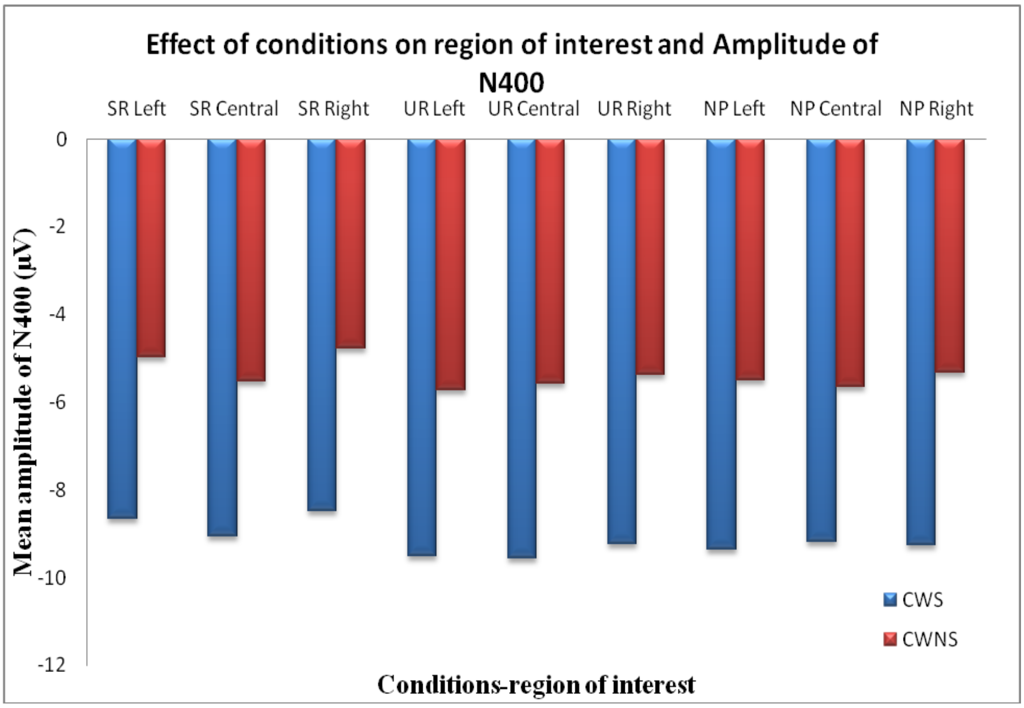

Figure 4.6: The effect of priming conditions on the mean amplitude of N400 for CWS and CWNS(CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

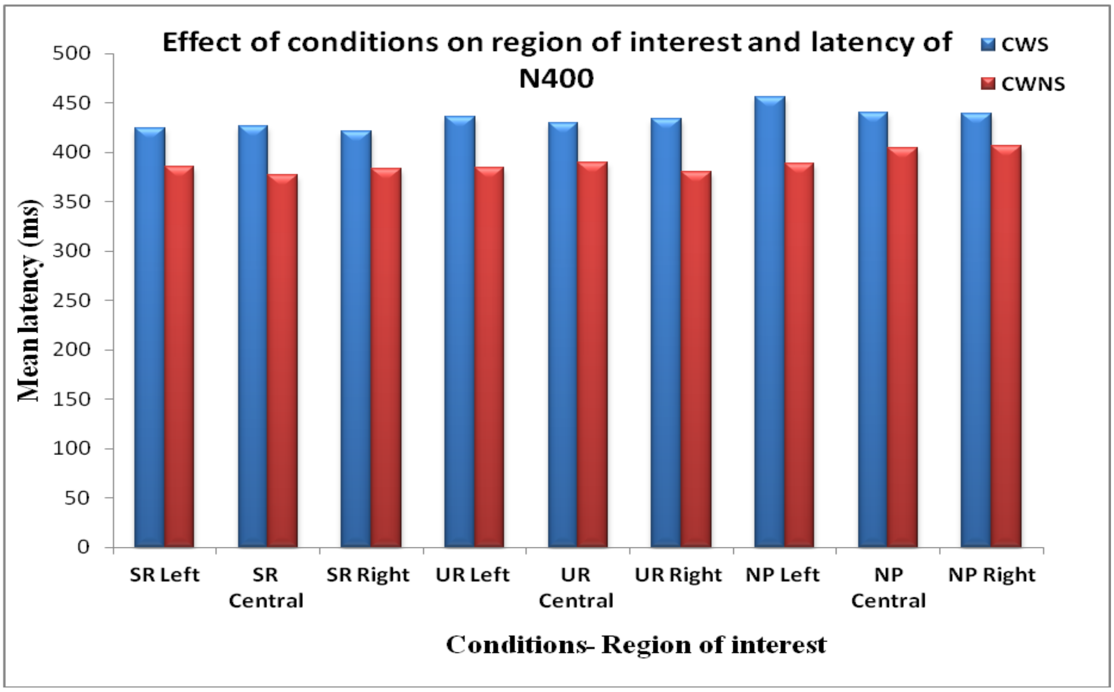

Figure 4.7: The effect of priming conditions on the mean latency of N400 for CWS and CWNS(CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime)).

Table 4.4: *Within group effect comparison of dependant variables on repeated measure ANOVA for primed lexical decision task on Mean amplitude and Mean latency of N400*

Measures	**Factors**	**df, F**	**Sig.**	**η^2p**	**Observed power**
Amplitude	Conditions	F(2,44)= 1.040	0.362	-	-
	Conditions*group	F(2,44)= 0.036	0.965	-	-
	ROI	F(2,44)= 0.972	0.386	-	-
	ROI*group	F(2,44)=0.045	0.956	-	-
	Conditions*ROI	F(4,88)=1.83	0.120	-	-
	Conditions*ROI*groups	F(4,88)=0.420	0.794	-	-
	Group	F(1,22)=7.671	0.011*	0.259	0.754
Latency	Conditions	F(2,44)= 4.164	0.022*	0.159	0.704
	Conditions*group	F(2,44)=0.081	0.923	-	-
	ROI	F(2,44)=0.223	0.801	-	-
	ROI*group	F(2,44)=3.048	0.05*	0.122	0.560

	Conditions*ROI	F(4,88)=0.102	0.981	-	-
	Conditions*ROI*group	F(4,88)=3.529	0.010*	0.138	0.849
	Group	F(1,22)=18.743	0.000*	0.460	0.985

As the data were normally distributed, Independent two samples t test was used assess the effect of group on mean amplitude of N400. The results indicated statistically significant difference across ROI*conditions between the two groups (Table 4.5). Figures (4.8, 4.9, 4.10, 4.11, and 4.12) show the scalp distribution of N400 waveforms.

Table 4.5: *Between group effect comparisons of dependant variables with independent two sample t test for primed picture naming task on Mean amplitude of N400*

Measure	**Conditions**	**ROI**	**t value**	**Sig.**
		Left	t(22)= -2.451	0.023*
	SR	Central	t(22)= -2.277	0.023*
		Right	t(22)= -2.554	0.033*
		Left	t(22)= -2.507	0.020*
Amplitude	UR	Central	t(22)= -2.561	0.018*
		Right	t(22)= -2.357	0.028*
		Left	t(22)= -2.796	0.011*
	NP	Central	t(22)= -2.305	0.020*
		Right	t(22)= -2.852	0.009*

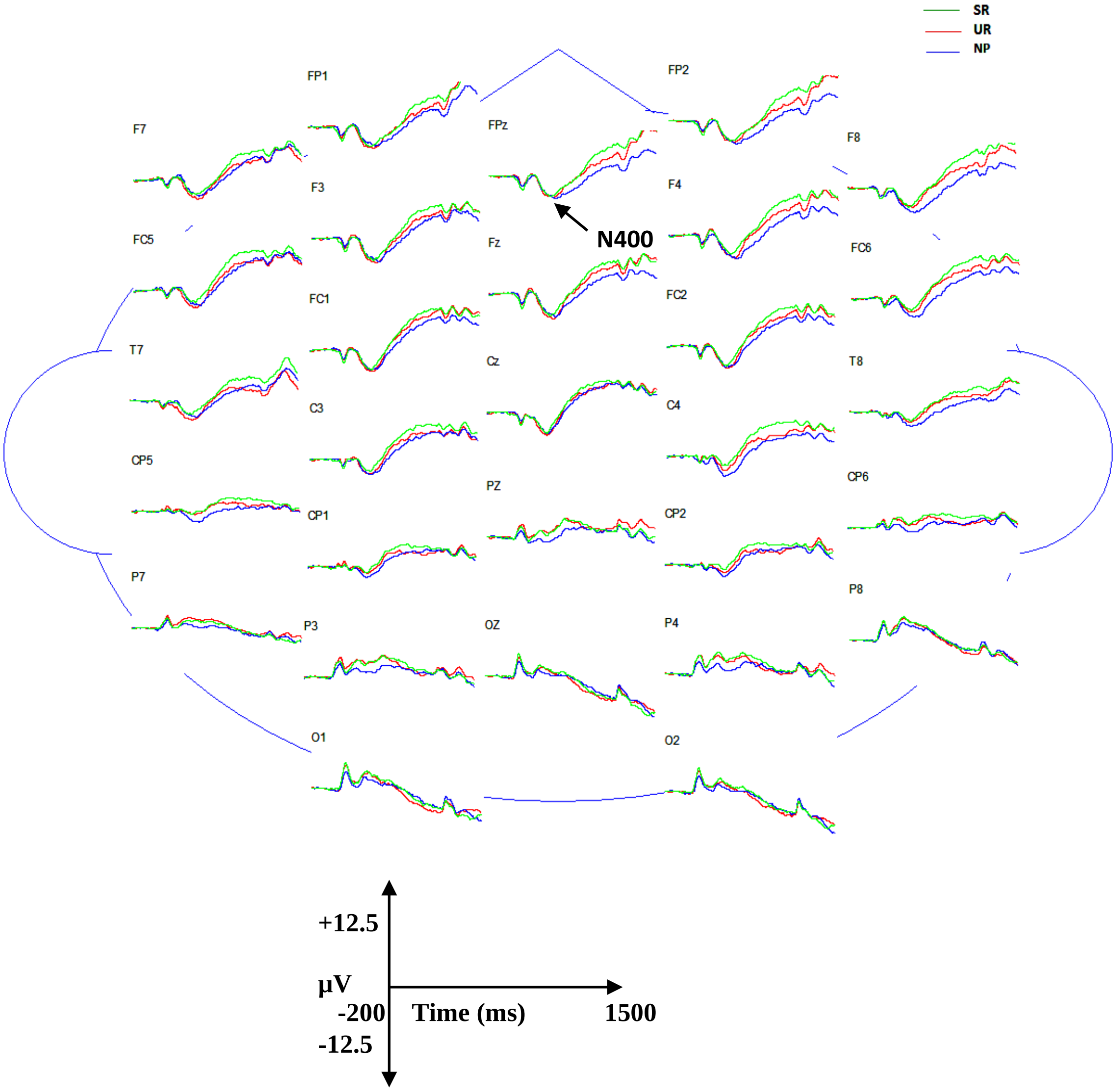

Figure 4.8: Comparison of grand average ERPs at all electrode sites, across three conditions (SR- green, UR- red and NP- blue) in CWS group (CWS- children who stutter, CWNS- children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

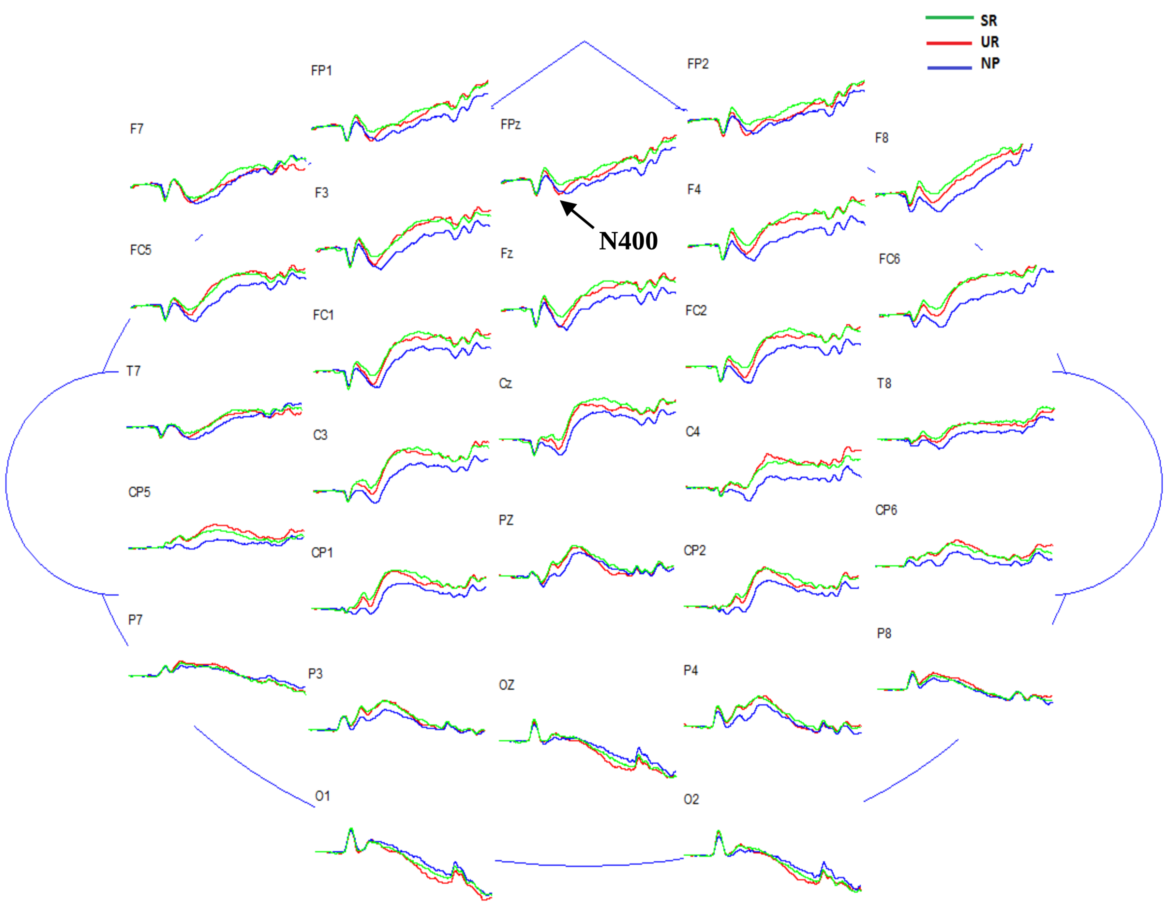

Figure 4.9: Comparison of grand average ERPs at all electrode sites, across three conditions (SR- green, UR- red and NP- blue) in CWNS group (CWS- children who stutter, CWNS- children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

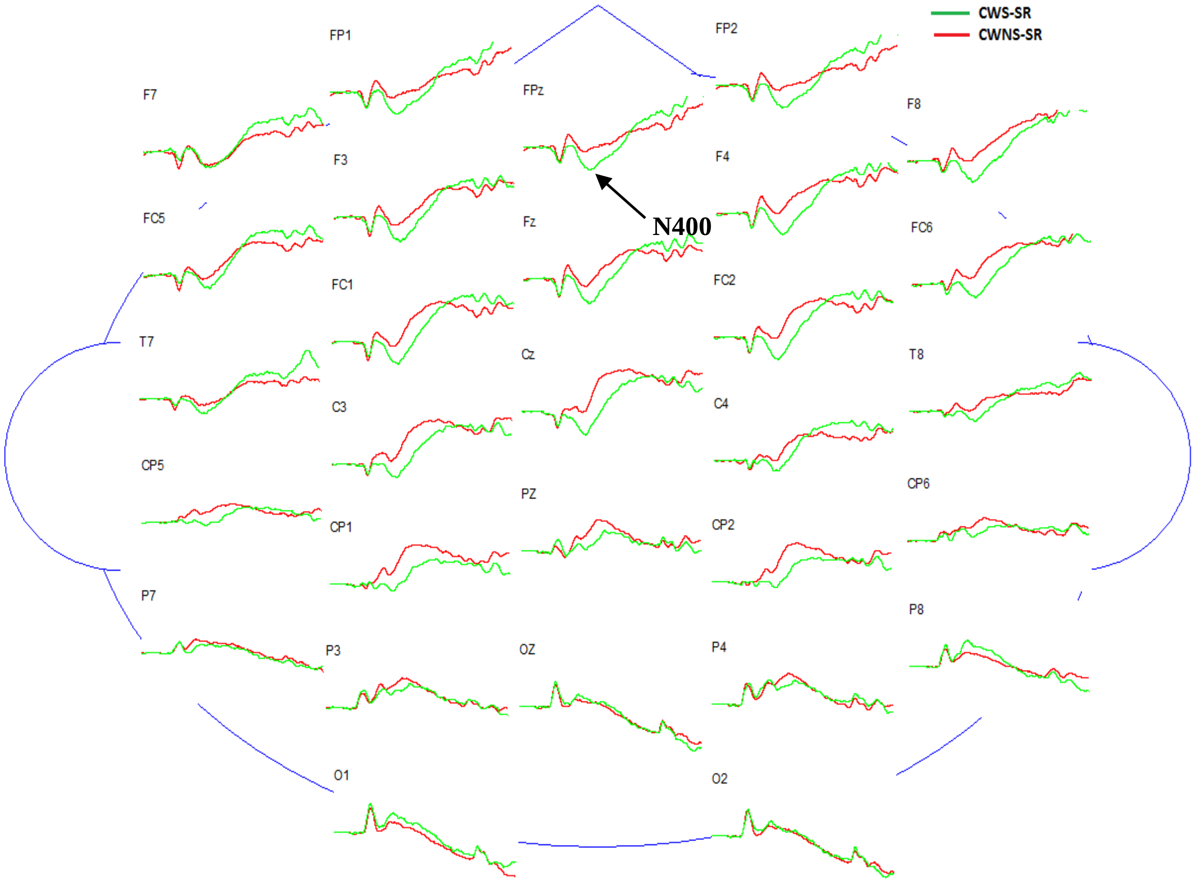

Figure 4.10: Between group comparisons in semantically related condition indicating greater amplitude and latency of N400 in CWS group (green) compared to CWNS group (red) (CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime)

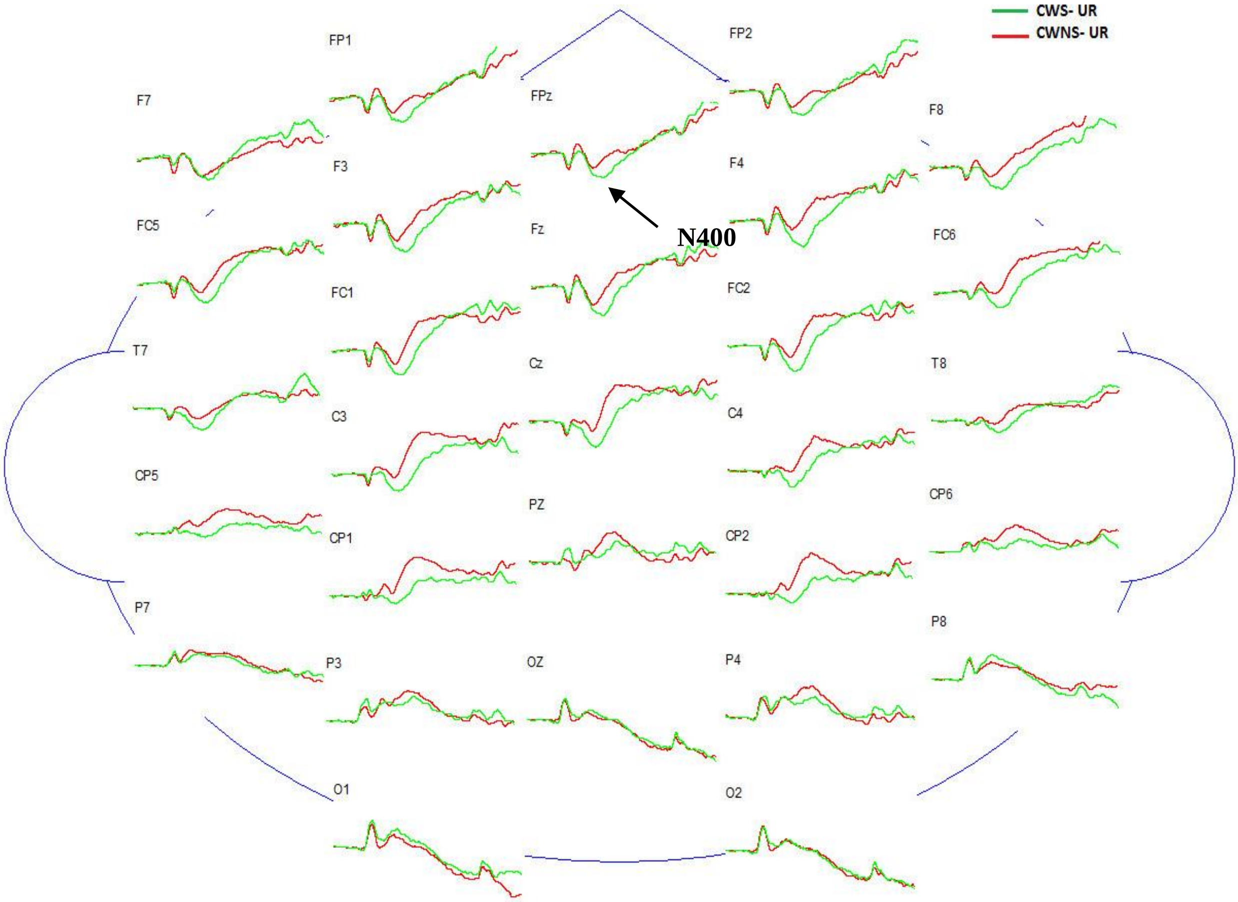

Figure 4.11: Between group comparisons in semantically unrelated condition indicating greater amplitude and latency of N400 in CWS group (green) compared to CWNS group (red) (CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

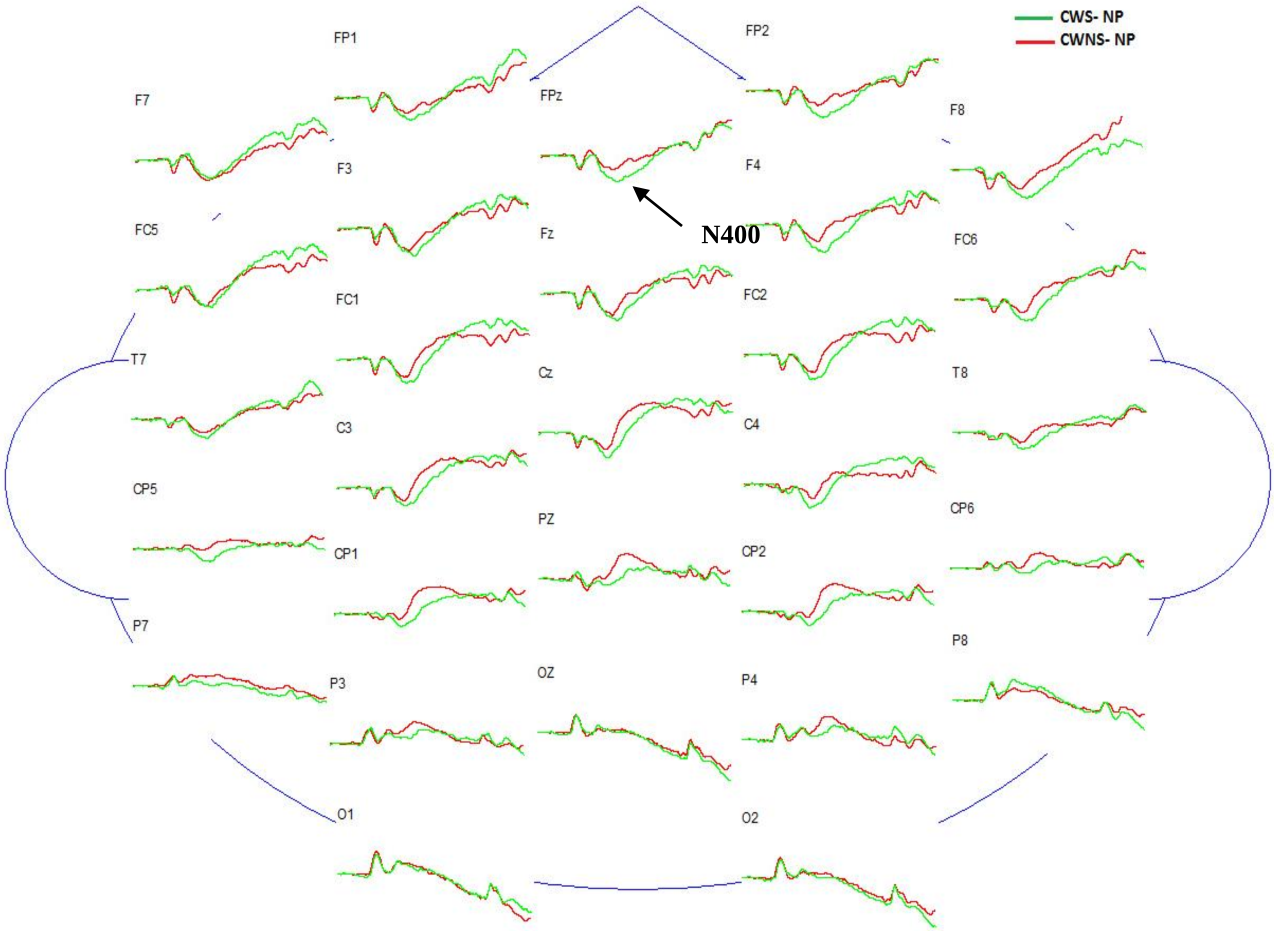

Figure 4.12: Between group comparisons in no prime condition indicating greater amplitude and latency of N400 in CWS group (green) compared to CWNS group (red) (CWS- children who stutter, CWNS-children who do not stutter, SR- semantically related, UR- semantically unrelated, NP-no prime).

Results of N400 for rhyme judgment task

The electrophysiological data were obtained by analyzing the N400 waveforms to obtain peak amplitude (µV) and latency (ms). Statistical analysis of the data for both variables (latency and amplitude) was done according to three regions of interest, namely: left (FP1, F3, FC1, CP1, P3 and O1), central (FPz, Fz, Cz, Pz and Oz), and right (FP2, F4, FC2, CP2, P4 and O2). As the data were normally distributed parametric tests were done and the results are as follows. On observation the CWS group exhibited slightly greater amplitude and latency of the N400 peak when compared to CWNS; however it was not a very marked difference (Figure 4.13 and 4.14). Table 4.6 highlights the results of repeated measures ANOVA for the ERP data. It indicated significant effect of region on mean amplitude ($p<0.05$) but no significant main effect of group or condition was obtained. Also, there was no interaction effects of condition*group, ROI*group and conditions*group*ROI on mean amplitude and latency according to the statistical analysis. There was found to be no significant main or interaction effects on mean latency of N400 across groups. Figures (4.15 to 4.18) show the scalp distribution of N400 waveforms.

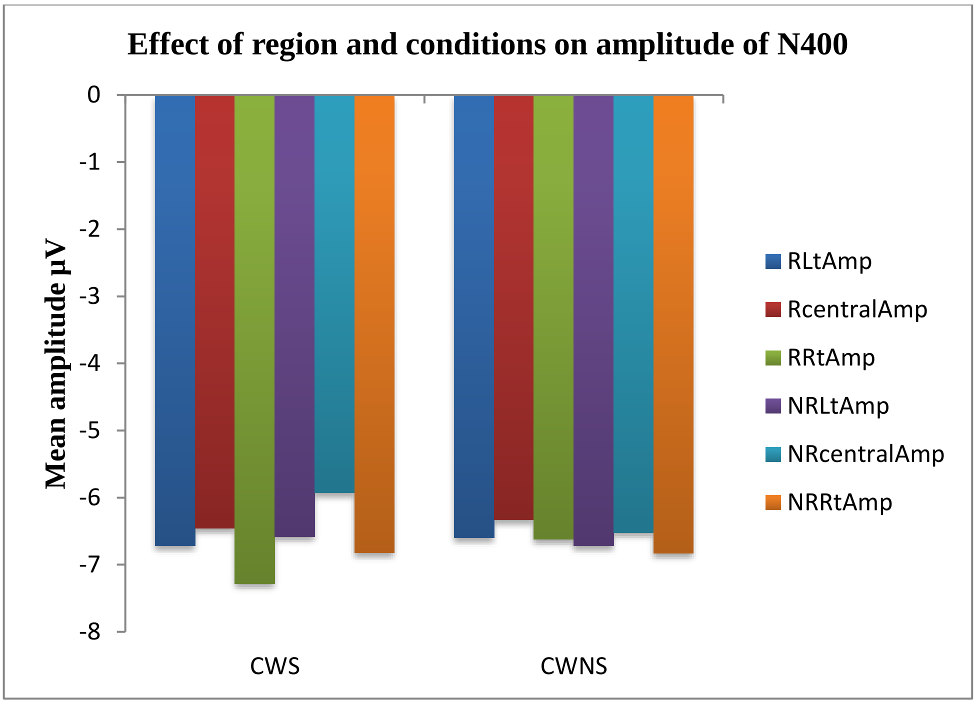

Figure 4.13: Effect of conditions on the mean amplitude of N400 between both groups across regions (CWS- children who stutter, CWNS-children who do not stutter, RLtAmp- rhyming left amplitude, RcentralAmp- rhyming central amplitude, RRAmp-rhyming right amplitude, NRLtAmp-nonrhyming left amplitude, NRcentralAmp- nonrhyming central amplitude, NRRtAmp-nonrhyming right amplitude).

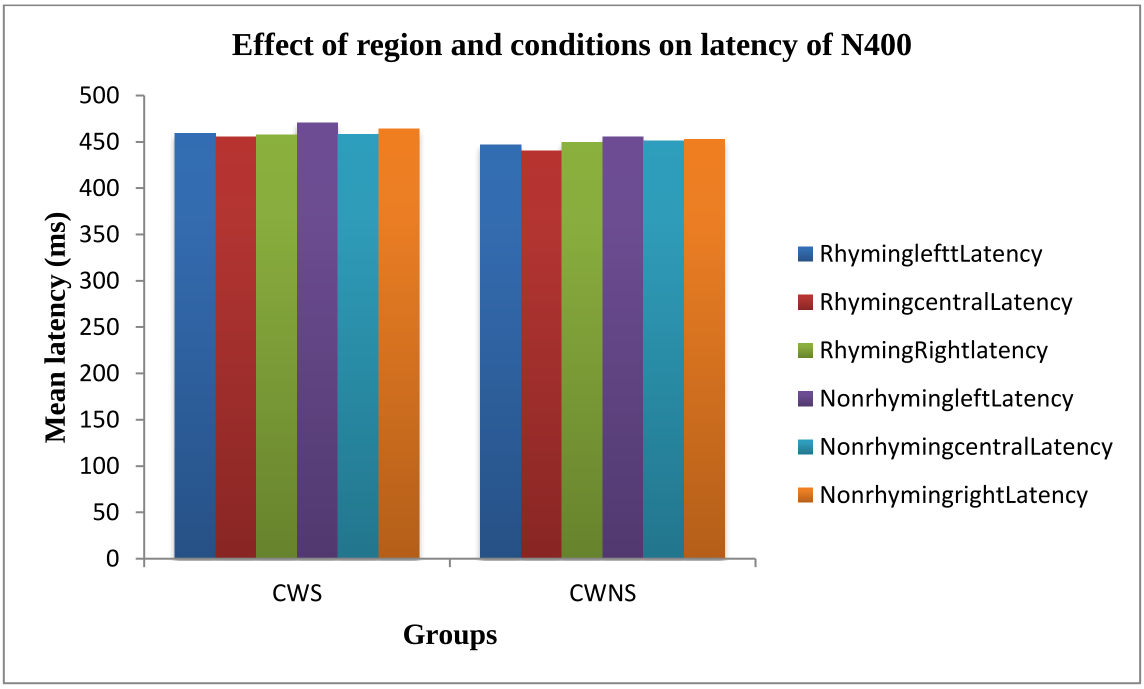

Figure 4.14: Effect of conditions on the mean latency of N400 between both groups across regions (CWS- children who stutter, CWNS-children who do not stutter).

Table 4.6: *Within group effect comparison of dependant variables on repeated measure ANOVA for rhyme judgement task on Mean amplitude and Mean latency of N400*

Measures	**Factors**	**df, F**	**Sig.**	**η^2**	**Observed power**
Amplitude	Conditions	F(1,22)= 0.034	0.856	-	-
	Conditions*group	F(1,22)=0.242	0.628	-	-
	ROI	F(2,44)= 7.198	0.002*	0.247	0.917
	ROI*group	F(2,44)=1.671	0.200	-	-
	Conditions*ROI	F(2,44)=0.190	0.827	-	-
	Conditions*ROI*groups	F(2,44)= 0.433	0.651	-	-
	Group	F(1,22)=0.001	0.980	-	-
Latency	Conditions	F(1,22)= 1.291	0.268	-	-
	Conditions*group	F(1,22)=0.004	0.950	-	-
	ROI	F(2,44)=1.832	0.171	-	-
	ROI*group	F(2,44)=0.150	0.861	-	-
	Conditions*ROI	F(2,44)=0.378	0.687	-	-
	Conditions*ROI*group	F(2,44)=0.635	0.535	-	-
	Group	F(1,22)=0.648	0.429	-	-

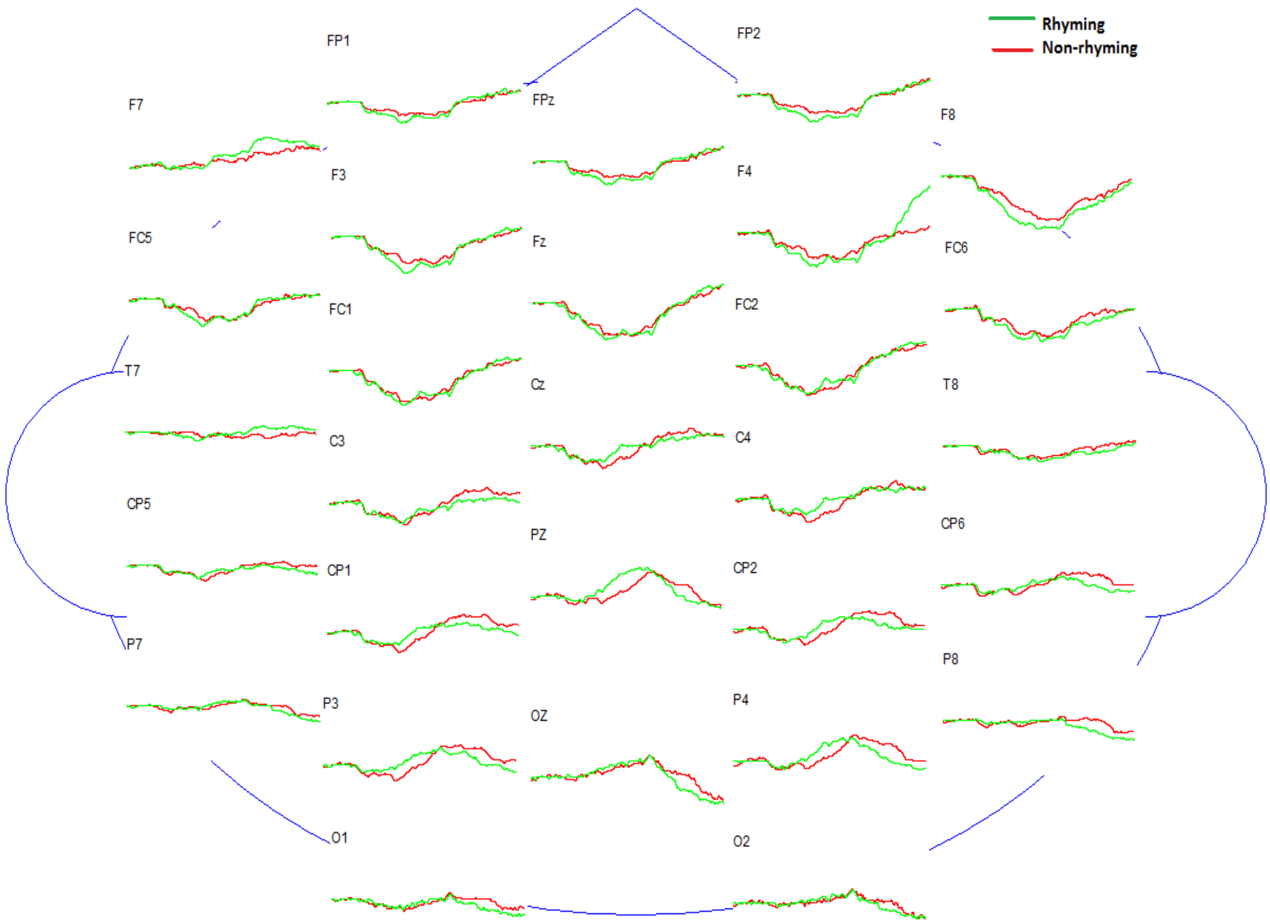

Figure 4.15: Comparison of the grand averages of the two conditions (rhyming and non-rhyming) at all electrode sites in the CWS group (CWS-children who stutter).

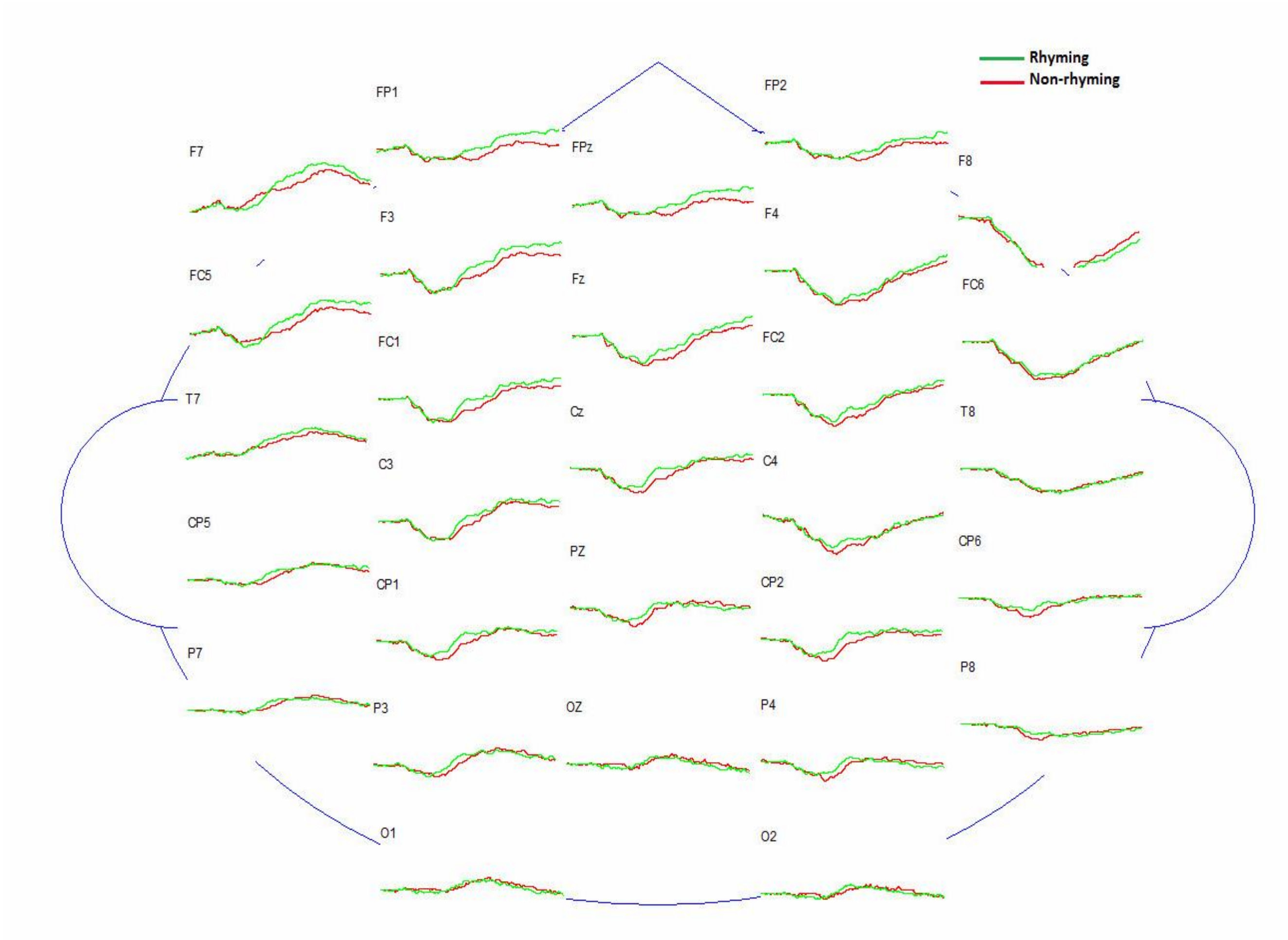

Figure 4.16: Comparison of the grand averages of the two conditions (rhyming and non-rhyming) at all electrode sites in the CWNS group (CWNS-children who do not stutter).

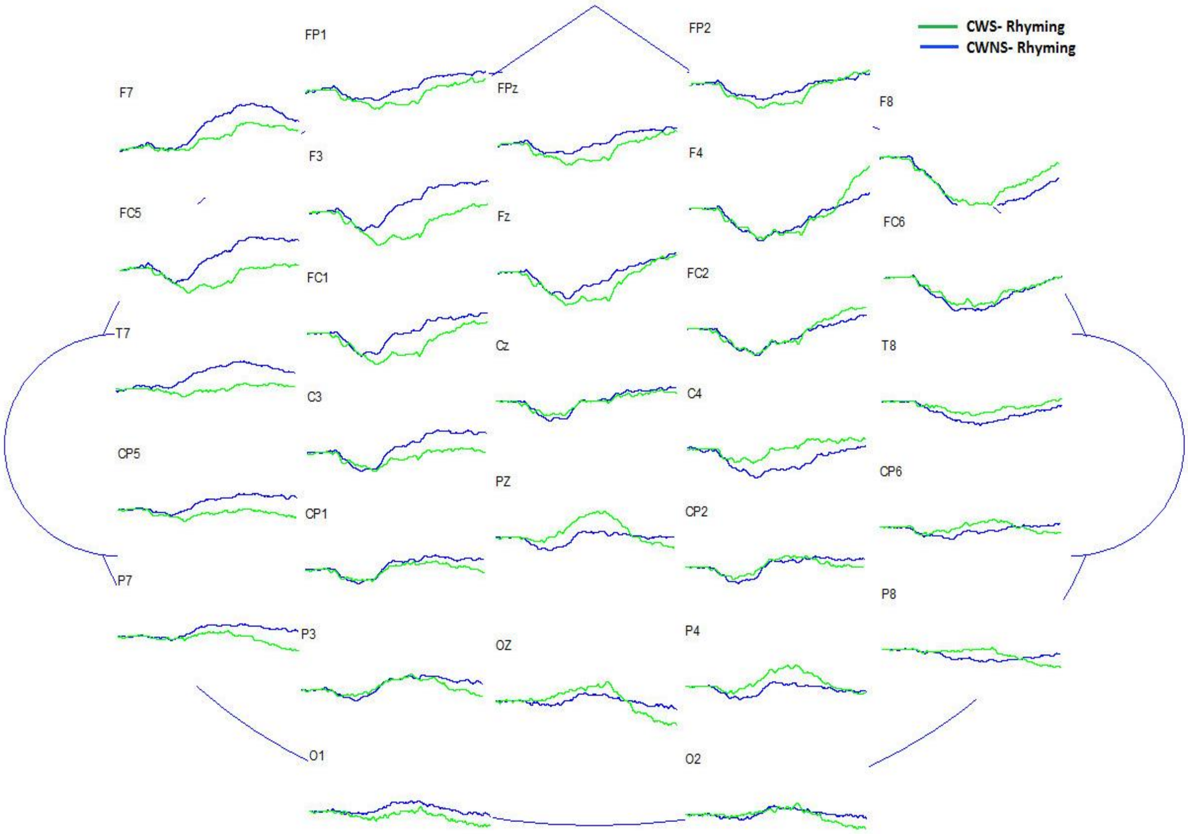

Figure 4.17: Comparison of the ERP grand averages of the two groups (CWS= green, CWNS= blue) in the rhyming condition (CWS-children who stutter, CWNS-children who do not stutter).

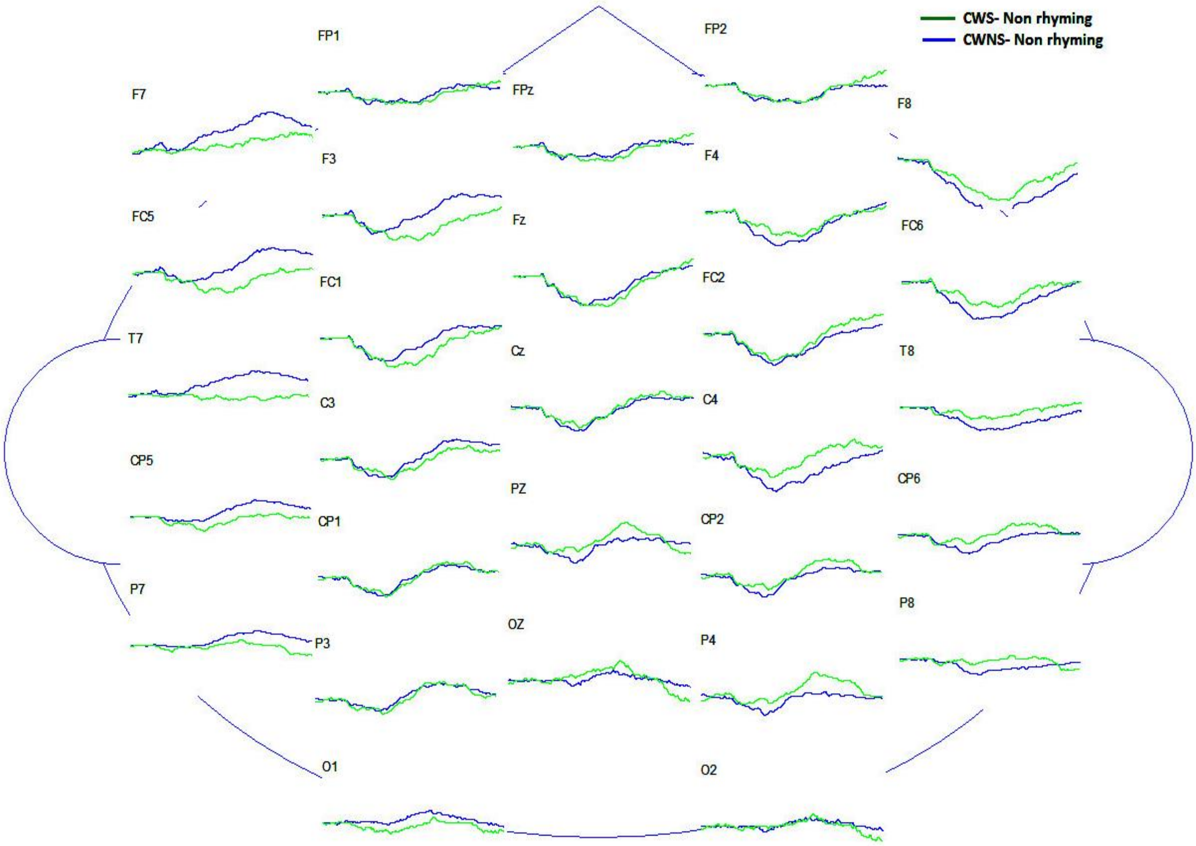

Figure 4.18: Comparison of the ERP grand averages of the two groups (CWS= green, CWNS= blue) in the non- rhyming condition (CWS-children who stutter, CWNS-children who do not stutter).

Chapter 5

Discussion

The current study aimed at finding differences between behavioural and electrophysiological (N400) correlates of lexical and phonological processing in children with and without stuttering. These differences were explored and documented using a cross-modal primed picture naming task, which involved the use of a semantic priming paradigm. The semantic priming task consists of semantically related, unrelated, and no prime (500 Hz tone) conditions that allow us to understand lexical access/ processing as a related prime helps activate words faster than an unrelated prime or tone. This is justified by the semantic spreading activation theory, which states that auditory or visual priming of concepts beforehand results in quicker responses such as naming or lexical decisions of words and non-words (Collins & Loftus, 1975; Meyer, 1973; Meyer & Schvaneveldt, 1971; 1976; Neely, 1977). Reaction time and accuracy was documented from the task and the data revealed interesting results that corroborate previous findings. The results showed that CWS named pictures slower than CWNS in all three conditions, exhibited by significant differences in reaction time during the behavioral task. In CWS, the unrelated condition showed longer reaction times than the related and no prime conditions. However, accuracy measures between both groups and across conditions were comparable, and significant differences were not observed. Thus, the results suggest that lexical processing, although intact, maybe slightly slower in CWS compared to their fluent peers.

Explanations regarding variable reaction time between fluent and non-fluent groups have revolved around the fact that it may result from failures in the temporalization of speech. A look into the processing timeline indicates that the time taken for lexical processing or activation of semantic information is longer in CWS than in CWNS (Conture, Zackheim, Anderson, Pellowski, 2004). However, longer reaction times need not imply that there are deficits in processing, but it may be an indicator of delayed or slow processing in children who stutter. As a result, CWS showed observable differences in reaction times in related versus unrelated and no prime conditions showing that the facilitation effect is intact in these children.

A large corpus of studies is related to speech reaction time in adults instead of studies done on children. Various experimental paradigms used by multiple authors have resulted in slower speech reaction times in children who stutter when compared with children who do not stutter. Bishop, Williams and Cooper (1991) and Melnick, Conture and Ohde (2003) used picture naming tasks to examine speech reaction times in children as young as 3 years of age. The findings from this study also support the results obtained by Bishop and colleagues (1991), who reported that 3–10-year-old children who stutter exhibited slower speech reaction times than children who do not stutter during three vocal tasks of increasing linguistic complexity.

Semantic Priming Effect

An important finding from this study is that children who stutter were significantly slower in response to across all the priming conditions, whereas children who do not stutter were substantially faster. Fluent children seem to speed up their processing time in the presence of primes as opposed to dysfluent children. As expected, for children who do not stutter, these findings support previous studies that have demonstrated a significant priming effect when utilizing semantic primes (e.g., Anderson et al., 2001; Nation & Snowling, 1999). The most befitting explanation for this phenomenon is the spreading activation theory (Collins & Loftus, 1975; Collins & Quillian, 1969). The authors explain that each word can be imagined to be a node where the words related to these nodes i.e., the semantically related nodes, are all stored in the same vicinity in semantic memory, which is broadly knows as the mental lexicon. Activating one of the words/ nodes representing the prime word presumably spreads its activation to nodes of semantically related targets, thus minimizing the required time to activate related targets to their required recognition threshold (Neely, 1991). So it is presumed that on hearing or seeing a prime word, the activation spreads through the network to activate all the words that are semantically related to the primed node which in turn facilitates the processing of the target when prime and target are semantically related. Another similar explanation along the same lines as the spreading activation theory is Levelt's model (Levelt et al., 1999). Within Levelt's model, the nodes are represented as lemmas and the spreading activation and selection of these lemmas are thought to account for the priming effects. Therefore this study has based its assumptions and interpretation of these results on the Levelt's model to some extent. Considering the spreading activation occurring in both the above-mentioned theories, the results related to slower speech reaction time in CWS may be suggesting that the time taken by these children to activate the appropriate nodes maybe longer for any of the priming conditions because the network with the mental lexicon itself maybe weak (Pellowski & Conture, 2005). The trouble may thus be at the level of encoding the nodes that fail to occur during the priming conditions or at the lexicon level having weak interconnected nodes. This may also result in the activation of wrong targets that are covertly corrected before selecting the right target, resulting in longer response time.

McGregor (1997) explained word-finding difficulties in pre-school children, and his discussion combined with Levelt's model (Levelt, 1999) may help solve the questions related to delayed lexical processing/ activation in CWS (Figure 14). Since Levelt's model believes in lemmas (word meaning) and lexemes (word meanings), the concept is that CWS may have difficulty in linking the semantic meaning (lemma) of a word to its structural representations (lexeme), and this gap between the two results in delayed word retrieval. Thus, compared to the fluent children, the mapping of the words seems to take longer than required even when primes are provided to facilitate activation of target words in the neighborhood.

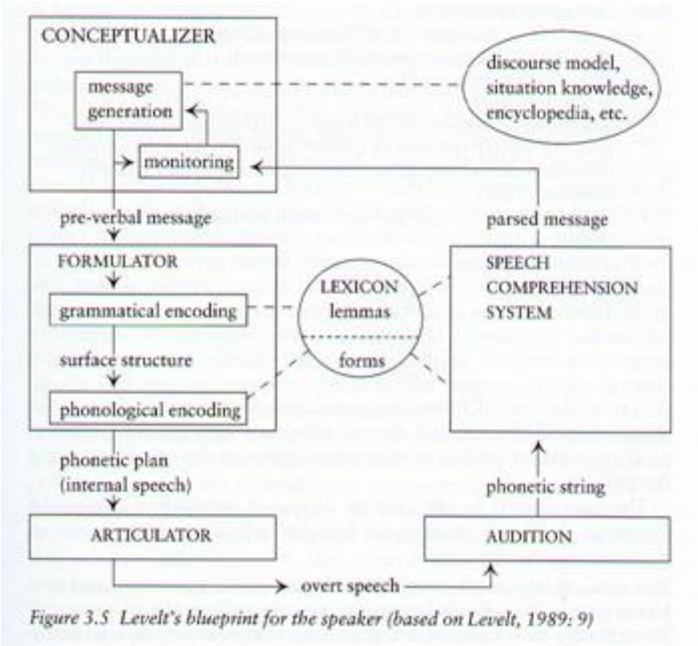

Figure 5.1: A schematic representation of the Levelt's model of speech production

In McGregor's words he explains difficulties in word retrieval as ''a possible developmental immaturity in retrieval mechanisms'' (McGregor, 1997). Hence, a suggestion that helps understand the process in a simpler way is that children who stutter are innately slower to retrieve words from their mental lexicons, even for those words which have complete or strong semantic representations or those with stronger networks Frequent hesitations and delayed word productions maybe a result of slow word retrieval or their attempts to retrieve the correct word despite multiple inaccurate activations within the system. The delays may also be attributed to the fact that the children were expected to name the pictures as quickly as possible and the time pressure to speak at a fast rate lead to an imbalance in the already weak system (Pellowski & Conture, 2005).

Lexical processing and Event Related Potentials

Weber Fox and Hampton (2001) were among the earliest researchers to use ERP's in experiments related to adults with stuttering. Their study explores how neural activations for AWS may differ for a linguistic task that does not require preparation for overt articulation and engage the articulatory system for covert speech. Their results revealed similar performances between experimental and control groups in identifying verb-agreement violations and semantic anomalies. Still, ERPs elicited by syntactic and semantic constraints indicated atypical neural functions for AWS. A typically reduced N400 was obtained as expected for reduced semantic expectations and a typical P600 for verb-agreement violations in the fluent group. In contrast, both N400s and P600s for the semantic and verb-agreement conditions were observed in the ERPs of the AWS. The same priming paradigm was adopted during the electrophysiological experiment and the ERP results obtained from the current study are in correlation with the study's behavioral findings. As part of the study, the focus was the N400, an ERP component defined by negative-going activity that peaks in amplitude at ~ 400 to 550 ms after the onset of a stimulus, usually a word (Fischler, 1990). The amplitude of the N400 component has been shown to be inversely related to the strength of activation that emerges from a priming context (Van Petten & Kutas, 1991; Rosler & Hahne, 1992). That is, a word whose activation has been primed by a preceding stimulus will elicit N400 activity that is smaller in amplitude than when the same word has not been primed by a preceding stimulus (Pizon-Moore, 2010). A significant and focal N400 was observed in both groups across conditions. A delay in the activation/ processing in CWS is reflected in the longer latencies on N400 in the CWS group than the CWNS. This was observed across all priming conditions and across the three ROI's as well (left, central, and right). An interesting finding from the study was that the amplitude of the N400 was much more significant in the stuttering group when compared to the non-stuttering group. Another interesting result is that larger N400's were elicited by the unrelated condition as compared to the related and no prime condition in both groups. There were no hemispheric lateralization effects of the paradigm according to the statistical analysis, however on observation, robust activity was observed in the anterior- superior regions, namely the fontal and frontoparietal channels in left, right and central channels.

Several theories revolve around understanding how activation of words for speech production occurs at the neurological level. A psycholinguistic model explains that a psycholinguistic breakdown occurs in AWS because there is a failure to activate at least one target from the corpus of words does (Postma & Kolk, 1993), resulting in the above mentioned deficits. At some point during psycholinguistic planning, the system triggers, i.e., forces, the retrieval of phonemes for the word with greatest activation strength (Kolk et al., 1997). If there are multiple words competing for activation, those words that reach highest activation may be retrieving irrespective of it being accurate or inaccurate, resulting in erroneous productions. An internal monitor, which checks the surface structure of psycholinguistic plans for accuracy (Levelt, 1983), may then detect the presence of ill-retrieved phonemes and signal the speaker to halt speaking and initiate a repair; potentially disrupting fluency (Dell, 1986; Kolk, &Postma 1993, 1997).

Maxfield, Huffman, Frisch, and Hinkley (2010) helped understand this phenomenon better by providing three interpretations. First, explained that the mental lexicons of AWS are poorly organized, resulting in weak activation of a target picture than its semantically-related neighbors. The second interpretation of the N400 patterns seen in AWS was that "too many" semantically-related words become activated on the path to naming due to the tendency for AWS to use word substitutions and circumlocutions, again requiring an inhibitory mechanism to allow the target label to emerge. A third interpretation was that, because at least some individuals have reduced phonological working memory capacity (Bajaj, 2007), holding a picture label in mind while a semantically-related probe word is presented might be distracting enough to require semantic inhibition. However these explanations have all been provided with AWS in mind and some caution may have to be exercised when interpreting the same with CWS.

Speculation associated with the Neuropsycholinguistic Theory of Stuttering (Perkins, Kent, &Curlee, 1991) suggests that people who stutter experience asynchrony between linguistic and paralinguistic processing components as a result of linguistic uncertainty or inefficient neural resources. This asynchrony induces dysfluencies that are transformed into stuttering events under conditions of time pressure; the speaker is required to initiate and accelerate the disrupted utterance and experiences loss of control in the process. More generally, this theory suggests that stuttering occurs as a function of reduced efficiency in one or more processing systems (linguistic, paralinguistic, integrative, and segmental), resulting in an imbalance in the production of language “as different components arrive at a central language integrator at different times and thus have a mistimed impact on the motor production of speech” (Tetnowski, 1998)

To conclude, the current study provided both behavioural and electrophysiological evidence indicating differences in lexical processing between CWS and CWNS. This conclusion was made from the longer mean reaction time in the behavioural task and greater amplitude and longer latencies of N400 in CWS when compared to CWNS.

Rhyme judgement task

This experiment's main objective was to compare the behavioral and neural correlations of phonological processing in children who stutter and children who do not stutter. To study phonological processing rhyme judgment task was used. Behavioral measures included reaction time and accuracy of responses. Electrophysiological measures included N400 latency and amplitude measures.

Overall results suggested no significant difference between children who stutter and children who do not stutter for both behavioral and electrophysiological measures. There were no statistically significant results or trends toward statistical significance, for the Group main effect. Thus, based on the methods used here, the stuttering and nonstuttering children were indistinguishable in terms of overall behavioral reaction time and accuracy (Group analysis) and neural responses (Group by conditions and Group by conditions by ROI analyses).

We recognize that rhyme judgment task may provide only limited information about phonological processing compared to other phonological processing tasks such as nonword repetition and phonological working memory task. Further, the reliability of the behavioral measures was not done in the current study. Hence, this can be one of the limitations of the study. Therefore, further studies need to be done to corroborate the present findings.

Clinical applications

1. The findings of the study may aid the detailed assessment of language abilities in children who stutter
2. Further, the findings of the current study may guide the clinicians in the detailed assessment of phonological assessment at the time of pre-therapy abilities in children who stutter.

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