LEXICAL PROCESSING IN 8-10 YEAR OLD CHILDREN: EVIDENCE THROUGH BEHAVIORAL AND ERP MEASURE

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Abstract

The primary aim of the present study was to compare the behavioral with event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in typically developing children. Children in the age range of 8-10 years were investigated with both behavioral and electrophysiological measures. The behavioral response and N400 were recorded using 30 pairs of words and non-words presented auditorily. The reaction time and accuracy for words and non-words were considered along with the peak amplitude and latency of N400 peak for the analysis. The results showed a significant difference in both reaction time and accuracy for words and non-words. There was also significant difference noted in the peak amplitude and latency measure for words and non-words. When the behavioral measures were correlated with amplitude and latency of N400, the reaction time correlated very well with amplitude and latency than the accuracy measure. Thus, indicating that the peak amplitude and latency measure of N400 could serve as an important tool which reflects the integration of semantic information in children at a lexical processing level. The present study also revealed a significant difference in the performance of the children on tasks which were observed to be lateralized to channels in the left hemisphere. This indicated that for lexical decision, involves a higher level language (semantic) processing in children lateralized to the left hemisphere. The present findings explain that the behavioral and neurophysiological measures are equally important and may not provide a complete picture when each of the measure is carried out alone.

Key words*:* *Lexical decision, Reaction time, Accuracy, Event-related potential (ERP), N400*

Phonology is a structural aspect of language which involves the sounds of a language and their organization. It is well known that there is a causal connection between children's phonological skills and their acquisition of reading and spelling. Data from both normally developing and atypically developing children demonstrates that the quality of a child's phonological representations is important for their subsequent progress in literacy. This relationship has been found across all languages so far studied, for both normal readers (Bradley & Bryant, 1983; Hoien, Lundberg, Stanovich & Bjaalid, 1995; Siok & Fletcher, 2001), and children with dyslexia (Bradley & Bryant, 1983; Bruck, 1992; Landerl, Wimmer, & Frith, 1997; Porpodas, 1999). However, the focus on understanding whether these deficits are at a perceptual level, awareness level or cognitive level has been attempted through offline behavioral tasks such as metaphonological or phonological awareness tasks. Studies in the literature have investigated implicit phonological representations using different methods such as lexical gating, priming, syllable similarity tasks etc in both typically developing individuals and reading-impaired populations.

Lexical decision task is one of the most popular tasks employed to study word processing, both in the auditory and the visual modality. In an auditory lexical decision task, the participants are presented with spoken stimuli and are expected to decide whether the stimuli form is a word or not. In majority of the studies reported in the literature, data collected from the typically developing children was compared to atypically developing children, and the results revealed that the second group performed poorer compared to the first group.

Taroyan and Nicolson (2009) studied the behavioral correlates of lexical decision processes in English speaking nine normal adolescents. They showed significantly longer response times and lower accuracy for the pseudowords/non-words. Sela et al. (2011) did a study on twenty two adults (age 25±2.48 years) and twenty five 7th grade children (age 12.65±0.467 years) using a visual lexical decision task and found that younger group exhibited slower reaction time as compared to adults. They also found that compared to words both the groups exhibited longer reaction time for pseudo words. With respect to accuracy, they

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found that accuracy was higher for pseudo words in both the groups. Pizzioli and Schelstraete (2007) investigated lexical processing in children using a lexical decision task to evaluate the accuracy and speed of spoken-word recognition. They found greater errors on pseudo-words compared to real-words. With respect to reaction time, they found a significant effect on word type, with longer reaction times for pseudo-words than real words.

The above mentioned studies included tasks which only revealed the end performance of subjects; however it has often been found that an understanding of the complex neuro-cognitive processes involved in language processing would be difficult through such offline behavioral tasks. There is lack of adequate methodologies to understand online, real-time language processing in the brain during complex neuro-cognitive processes throughout the linguistic skills development (Osterhout & Holcomb, 1995). The electrophysiological recording of event-related potentials (ERPs) of the brain is one of the few methods which are well suited for the investigation of real-time language processing in the brain. N400 is one such ERP mostly used and found to be associated with language processing. The N400 typically is the most negative peak which occurs at approximately 400 ms post-stimulus (Kutas & Hillyard, 1980a, 1980b, 1980c, 1984; McPherson & Ballachanda, 2000). Kutas and Hillyard in their very first studies in 1980s used sentences that ended with semantically inappropriate word to elicit stronger N400. Osterhout and Holcomb (1993) also found that grammatically incorrect sentences elicited larger N400 responses as compared to grammatically correct sentences. Polich (1985) investigated using different set of stimulus such as a series of words that were interspersed with occasional semantically inappropriate word and obtained N400 in both selective and active attention.

The N400 component has been elicited in response to semantic errors for both visual and auditory modalities (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984; Bessen, Faita, Czternasty, & Kutas, 1997; Kutas & Hillyard, 1980a, 1980b, 1980c, 1983, 1984; Swaab, Brown & Hagoort, 2003). The studies conducted by Connolly, Byrne, and Dywan (1995) and Byrne, Dywan, and Connolly (1995a, 1995b) indicated that the N400 could be elicited by semantic errors in both children and adults. However, there are fewer studies done on school aged children reporting N400 (Byrne, Conolly, MacLean, Dooley, Gordon & Beattie., 1999; McCleery, Ceponiene, Burner, Townsend, Kinnear & Schreibman, 2010). Byrne, Conolly, MacLean, Dooley, Gordon, and Beattie (1999) found that the N400 amplitude was significantly higher for incongruent picture-word pair than congruent picture-word pair. This N400 effect was found in all the four age groups such as 5 to 6 years, 7 to 8 years, 9 to 10 years, and 11 to 12 years involving a total of 56 typically developing children. Coch, Maron, Wolf and Holcomb (2002) studied N400 for words in 10 to 11 years aged children. But the stimulus consisted only of visual and pictorial representations of the words. For auditory presentation of stimuli, there was an earlier and more prolonged effect of N400 when compared to visual presentation, which was slightly lateralized to the right hemisphere during auditory presentation (Holcomb & Neville, 1990). However, there are very few studies investigating the N400 effects using only the auditory stimuli, especially how each word with and without meaning elicit N400 in school going typically developing children.

Hence the present study investigated the implicit phonological processing using event-related potential (ERP) correlates during the recognition of spoken words in typically developing children. It is important that an assessment of phonological processing is done at an explicit as well as implicit level in order to understand the relative difficulty of a child at various levels such as lexical access, decoding, phonemic categorization and awareness. Thus, the aim of the present study was to understand the implicit phonological processing comparing the behavioral correlates with event-related potential (ERP) correlates during the recognition of spoken words in typically developing children.

Method

Participants

Sixteen typically developing children in the age range of 8-10 years were selected for the study. They were divided into two subgroups of ages 8-9 years (Males=2, Females=6) and 9-10 years (Males=2, Females=6) of 8 children in each subgroup. All the children were screened using the WHO ten disability checklist (cited in Singhi, Kumar, Prabhjot & Kumar, 2007) and Developmental screening test (Bharath Raj, 1983) to rule out any sensory, motor, behavioural, or intellectual deficits. ELTIC (English Language Test for Indian Children, Bhuwaneshwari, 2010) was administered to assess the English language skills of the children and whoever passed the test were considered for the study. Native language of all the participants was Kannada with English as the medium of instruction in school. All the participants had air conduction thresholds and bone conduction thresholds within 15 dB HL at octave frequencies from 250 Hz - 8 kHz and 250 Hz - 4 kHz respectively (ANSI S3.21, 2004). There were no symptoms of otological and neurological disorders. There was no history of any middle ear pathology. “A” type tympanogram with normal ipsilateral and contralateral acoustic reflex thresholds were obtained for all the participants. Participants with good speech perception in noise with SPIN scores of more than 60% were considered for the study.

Instrumentation

A calibrated two-channel Madsen Orbiter-922 clinical audiometer (version 2) with TDH-39 headphones and Radio ear B-71 bone vibrator was used to establish air conduction and bone conduction pure tone thresholds respectively. A calibrated Grason Stadler Inc.-Tympstar immittance meter (version 2) was used to rule out middle ear pathology. Compumedics Neuroscan instrument with Scan™ 4.4 module along with Quick Cap®, Model C190 was used for recording of cortical evoked event related potentials. And Stim^2 version 4.4 module was used to deliver the stimulus. A personal computer with DMDX software was used to carry out behavioral task.

Preparation of stimuli

A list of 100 stimuli was prepared which included 50 pairs of words - non words combination (e.g. leaf-meaf). All the words selected were picturable, which occur in the vocabulary of 8-10 year old children. The non-words were prepared by substituting the initial phoneme of the word conforming to the rules of English. It was also made sure that the changed phoneme in the non-word accounted to the frequency spectrum of the initial phoneme of the word. This stimuli list was given to five experienced judges (Speech-Language Pathologists and Audiologists) for familiarity rating on a three- point scale as ‘highly familiar’, ‘familiar’, and ‘unfamiliar’. Out of the 50 word-non word pairs, 30 pairs which were rated as highly familiar or familiar by at least three out of the five judges were selected. The selected 30 pair of words was recorded by 4 male speakers. The audio samples were given for goodness rating to 5 audiologists. The audio samples were rated on a 0-5 rating scale, 5 representing the higher quality and 0 representing the poorest. The ratings were done by considering the parameters: intelligibility, clarity, loudness, naturalness and the overall quality of the audio sample. The audio sample which got the highest rating for all the parameters was selected as the final stimulus.

Stimuli presentation

Both behavioral task and ERP measure were considered separately for the study. For the behavioral task, the 30 recorded words were programmed on DMDX software for presentation. The presentation of the stimuli were controlled and was presented through the DMDX software version 3.13.0 (Forster & Forster, 2003) for measuring the reaction times (RTs) and accuracy of responses. A practice session with 10 stimuli (5 words & 5 non-words) was given to familiarize the subjects with the instructions and task. Stimuli words in each list was randomized and presented.

For the ERP recording, the stimuli were presented using Gentask module in Stim^2. Each word and non-word was presented twice in a list. Thus a list consisted of 120 stimuli. A total of 4 lists were made arranging the words and non-words in a random order. Each participant was presented two out of the four lists randomly during the ERP recording. The inter stimulus interval between any two word in a list was 3000 ms. Different trigger values were specified for word and non-word respectively. The stimuli were presented binaurally at 60 dB SPL using ER-3A insert earphones.

Procedure

Behavioral task

All the participants were tested individually in a room. The recorded stimuli were presented using a head phone. The subjects were instructed as follows: “You will hear words. It may be true word/ meaningful word or false word/non-word/ non meaningful word. You have to press ‘1’ for a meaningful word and ‘0’ for a non-meaningful word as soon as you hear the stimuli.” Reaction times were recorded to the nearest millisecond and stored in the computer and error rates were calculated

A ‘+’ sign appeared on the screen for 300 ms before the stimuli was presented. This would help the subject to be vigilant for the upcoming stimuli. The target word was then presented while the screen remained blank and remained so for the next 4000 ms or till the subject responded, whichever occurred first. If the subject failed to respond to a target within 4000 ms, that item was recorded as an error. For the ERP measure, the subjects were considered with a gap of minimum 10 days after the behavioral test to avoid any learning effect.

ERP task

The cortical event related potentials were recorded using SynAmps[2]. The participants were seated comfortably in a reclining chair. The Quick Cap consisting of 64 sintered silver chloride electrodes was used for recording evoked potentials. The event related potential was recorded from 15 electrode sites of 10-20 system: Fz, FCz, Cz, CPz, Pz, F3, F4, C3, C4, C5, C6, T7, T8, P3 & P4 (Jasper, 1958). Linked mastoid was used as a reference/ active electrode. An electrode site between FPz and Fz was used as ground electrode. The electrode impedance was lesser than 5kΩ. The participants were shown a cartoon video while placing the electrodes to distract their attention and facilitate electrode placement. A blunt needle was used to clean the electrode site. Quick Gel™ filled up in the syringe was used as conduction gel to bridge the scalp with the electrode surface. A continuous EEG data was recorded and digitized at 1000 Hz. The data was low pass filtered at 100 Hz, and high passing DC. The time window of 1500 ms with a pre stimulus interval of 200 ms was considered for online averaging. The corresponding trigger values as given in Stim[2] was entered such that the responses recorded will be time locked with the stimulus given. To maintain the attention of the participants, they were instructed to press button no.1 on a response box if they hear meaningful word and to press no. 2 if they hear non-meaningful word. Two recordings were obtained to check for the replicability of the waveforms. The total duration of the testing was one hour per participant.

Scoring and Analysis

The reaction time was tabulated in milliseconds. All wrong responses and those responses which exceeded the 4000 ms frame duration were eliminated from the data analysis. This was done for both subgroups. Accuracy was calculated for both words and non-words. A score of '1' was provided for each correct response and '0' for wrong/ absent response. The data was coded and tabulated and then subjected to statistical analysis.

Offline analysis of ERP waveforms

The continuous EEG waveform was DC offset corrected with a polynomial order of two to decrease the drift in the waveforms. The DC corrected waveforms were band pass filtered at 0.1-10 Hz. The continuous filtered EEG waveform was epoched from -100 to 1500 ms and was baseline corrected. Finally the epoched files were averaged to obtain different waveforms for words and non-words. Only N400 peak was considered for the analysis. The negativity between 400 to 800 ms was marked as the N400 peak. The amplitude and latency of N400 for 15 channels was tabulated for further statistical analysis. The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 17.1 software. Independent Sample t-test was done to compare the performance of children for RT and accuracy for words and non-words across the two subgroups. Paired Sample t-test was done to analyze the performance of children for RT (in ms) and accuracy measure for words and non-words separately. Kolmogorov-Smirnov test was done to check for the normality of the ERP data. Two way repeated measure analysis of variance (ANOVA) was carried out with condition (word, non-word) and channels (15 channels) as repeated measures variables and both N400 peak amplitude (in microvolts) and latency (in milliseconds) as dependent variable. Paired sample t-test was done to compare the differences of amplitude and latency of N400 across channels for words and non-words. Karl Pearson's correlation was done to study the relation between behavioral measures (including RT & accuracy) and N400 measures (including amplitude & latency).

Results

The behavioral correlates [such as reaction time (RT) and accuracy] for words and non-words were compared with event-related potential (ERP) correlates (such as the absolute peak amplitude and latency of N400 peak) in order to study the implicit phonological processing during the recognition of spoken words in typically developing children. Independent Sample t-test was done to compare RT and accuracy for words and non-words across two subgroups. There was no significant difference between two groups in reaction time for words and non-words ($t=0.69$, $p=0.49$ & $t=0.64$, $p=0.53$ respectively, at p value 0.05). Also, no significant difference was noted between the two subgroups when accuracy for words and non-words were considered ($t=-0.34$, $p=0.74$ & $t=-0.21$, $p=0.84$ respectively, at p value 0.05). As there was no significant difference noted between the two sub groups, 8-9 year old and 9-10 year old were clubbed into one single group of 8-10 years age.

Performance of children on behavioral measure and ERP (N400) measure

For the behavioral measure, Paired Sample t-test was done to analyze the RT (in ms) and accuracy measure for words and non-words separately.

The mean and standard deviation (SD) for reaction time and accuracy for performances of children on words and non-words were obtained which is shown in Table 1.

Table 1: *Mean and SD for performances on words and non-words*

		Mean	SD
RT (in ms)	Words	705.13	205.85
	Non-words	946.17	340.82
Accuracy	Words	25.69	2.12
	Non-words	21.81	3.47

Analysis of results from Table 1 indicated that the reaction time for words (Mean=705.13ms; SD=205.85) was shorter compared to non-words (Mean=946.17ms; SD=340.82). That is, the participants responded faster for words than for non-words. With respect to accuracy, it was found that the performance was better for words (Mean=25.69; SD=2.12) than non-words (Mean=21.81; SD=3.47). This indicated that more errors were observed for performance on non-words than words. Analysis of results also revealed that there was a significant difference for RT between words and non-words [t=-4.982, (p<0.05)]. A significant difference was also found for accuracy between words and non-words [t=4.453, (p<0.05)].

It was also observed that, majority of the children made errors on the non-word stimuli “drush” and “lesk” followed by other non-words such as “prapes”, “pum”, “galk”, “shirl”, “plass”, “gaste”, “dion”. This means that children identified these non-words as true words. Considering words, the stimuli “bus” had the maximum errors followed by the words “bird” and “brush”. This indicates that the subject erroneously identified these words as non-words.

The data of ERP measure was also analyzed statistically. For this purpose the latency and amplitude of the N400 peak at 15 different channels were considered separately. The mean and SD of amplitude and latency for both words and non-words at 15 different channels are shown in Table 2. The analysis of results from Table 2 indicated that the mean N400 amplitude for non-words was consistently higher than words indicating the N400 effect.

Table 2: *Mean and SD of peak amplitude and latency of N400 for words and non-words at 15 different channels*

	Words				Non-words			
	Amplitude(in µV)		Latency(in ms)		Amplitude(in µV)		Latency(in ms)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
C3	-21.01	8.00	512.00	55.91	-24.37	6.32	542.18	76.63
C4	-21.91	8.72	532.06	117.99	-24.98	8.19	557.56	94.32
C5	-19.80	8.57	539.31	51.27	-23.82	7.81	565.25	68.48
C6	-18.83	7.57	527.62	90.64	-20.87	6.75	544.18	81.90
CPz	-12.30	6.25	473.00	72.94	-14.27	3.80	504.81	95.26
Cz	-15.98	7.05	485.37	74.54	-18.79	5.91	533.06	83.93
F3	-29.05	9.31	531.06	74.10	-35.52	9.26	585.56	70.01
F4	-28.88	7.78	561.81	86.76	-32.84	8.88	588.68	83.96
FCz	-20.86	8.20	504.81	73.29	-26.05	8.15	565.62	87.73
Fz	-27.23	8.90	569.43	104.35	-33.24	9.53	597.87	82.18
P3	-12.43	6.90	478.31	67.68	-14.53	4.66	507.62	80.78
P4	-13.47	6.71	484.00	82.67	-14.73	4.60	506.81	87.59
Pz	-10.20	5.61	464.68	66.86	-11.57	3.68	482.06	81.42
T7	-14.17	7.98	611.50	84.40	-17.87	8.29	629.06	67.45
T8	-16.09	5.57	603.50	105.57	-17.25	5.06	630.75	81.34

The results from Table 2 also show that the mean peak latency for words is shorter when compared to non-words. It suggests that the children show longer processing time for non-words than words generally. This might also suggest that there might be greater number of generator sites involved in non-word processing than in word processing leading to higher amplitude values for non-words.

The ERP data (includes N400 peak amplitude and latency) was checked for normality using Kolmogorov-Smirnov test and was found that the data was significantly normal (p>0.05). The data with sixteen children across fifteen channels and between two conditions (word-nonword) were further analyzed using Two-way repeated measure analysis of variance (ANOVA). Two-way repeated measure ANOVA was carried out to analyze the N400 peak amplitude (in microvolts) as dependent variable with condition (word, non-word) and channels (15 channels) as repeated measures variables. The results indicated that there was a significant main effect for condition [F (1,15)=14.521, at p< 0.05)] and channels [F (14, 210)=41.251, at p<0.01]. A significant interaction effect was also found between condition and channel [F (14,210) = 6.454, at p<0.01]. A Paired sample t-test was done to analyze and compare the differences of amplitude across channels for words and non-words. The results showed a significant difference for amplitude between words and non-words for the channels: C3, C4, C5, Cz, F3, F4, FCz, Fz, P3 and T7 (t=2.85, 2.51, 4.37, 2.65, 5.32, 3.06, 4.68, 5.97, 2.39, & 3.82 respectively, at p<0.05 level).

Similarly, the data was analyzed for N400 latency measure using two way repeated measure ANOVA with condition (word, non-word) and channels (15 channels) as repeated measure variables and N400 peak latency (in milliseconds) as the dependent variable. The main effect of condition [F(1, 15)=7.440, at p<0.05] and channel [F(14,210)= 14.189, at p<0.01] was significant. But there was no significant interaction effect of condition with channels for latency [F(14,210)= 0.879, p>0.05]. Paired sample t-test was carried out to compare the differences in latencies across channels for words and non-words. The latency of N400 peak for words was significantly shorter compared to non-words for the channels: C3, Cz, F3 and FCz (-2.56, -2.67, -2.92 & -2.68 respectively, at p<0.05).

Correlation between behavioral and N400 measures

Karl Pearson's correlation was done to study the relation between behavioral measures (including RT & accuracy) and N400 measures (including amplitude & latency). There was significant positive correlation of RT and N400 peak amplitude for words at the channels C5, F3 and T7 (r= 0.516, 0.533, & 0.530 respectively, at p<0.05). But when reaction time was correlated with N400 peak amplitude for non-words, there was no significant correlation at any channels except a positive correlation at T7 (r=0.537, at p<0.05). There was no significant correlation between N400 peak amplitude and accuracy for words. When peak latency was correlated with RT for words, there was no significant correlation except a positive correlation at T8 (r=0.595, p<0.05). When peak latency was correlated with RT for non-words, there was no significant correlation except at T8 which was positive (r= 0.542, at p<0.05). There was significant negative correlation between peak latency and accuracy for words at channels C5, F3 and T7 (r=-0.664, -0.598 & -0.568 respectively, at p<0.05). There was also significant positive correlation between peak latency and accuracy for non-words at channels C5 and F3 (r=0.665 & 0.609, at p<0.05). There was no significant correlation between non-words peak amplitude and non-words accuracy for any of the channels.

The difference in the amplitude for words and non-words is termed as N400 effect. The N400 effect was correlated with the difference in reaction times for words and non-words using Karl Pearson's correlation. The results showed a significant negative correlation of reaction time difference with the N400 effect in channels such as C3, C4, CPz, Cz, F3, F4, FCz, P4 and Pz (Table 3). But when the N400 effect and the difference in peak latencies for words and non-words was correlated with the difference in accuracy for words and non-words, there was no significant correlation seen (p>0.05). The difference in peak latencies of N400 for words and non-words was also correlated with the behavioral differences in reaction time for words and non-words using Karl Pearson's correlation. The results indicated a significant negative correlation in few channels such as C4, C6, F4 and Fz (r= -0.775, -0.539, -0.543 & -0.505 respectively, at p<0.05).

Table 3: *Pearson's correlation coefficients for reaction time difference and peak amplitude difference across significant channels*

Reaction time difference	C3	C4	CPz	Cz	F3	F4	FCz	P4	Pz
Pearson Correlation	-.517*	-.595*	-.565*	-.633**	-.664**	-.530*	-.658**	-.551*	-.514*
Significance	.040	.015	.023	.009	.005	.035	.006	.027	.041

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level

Discussion

The accuracy and reaction time for the recognition of words and non-words was evaluated using a behavioral (lexical decision) task. As previously evidenced in literature reaction time was less for words as compared to non-words (Pizzioli & Schelstraete, 2007; Taroyan & Nicolson, 2009; Sela et al., 2011). Also, results of the previous studies (Pizziolo & Schelstraete, 2007 & Taroyan & Nicolson, 2009) indicated a lower accuracy for pseudo words. The results of the present study confirm those of the above studies but contraindicated with the study by Sela et al (2011) which showed higher accuracy for pseudo words. Figure 1 shows grand averaged ERP waveforms of 16 subjects for words and non-words. From the Figure 1, it can be evidenced that the mean peak amplitude of N400 for non-words was greater than that for the words. This indicates that there was N400 effect for the words even when it is presented auditorily alone. The results also showed that the N400 effect can be seen for auditory stimuli without any semantic priming. It can also be seen from the Figure 1 that the N400 peak is broader and of more amplitude in frontal channels compared to other channels. There is no much difference in the amplitude of N400 for words and non-words in the parietal channel. In temporal channels such as T7 and T8, T7 shows N400 effect while there is very lesser N400 effect seen in T8 when compared to T7. The coronal channels show good N400 effect but not as much as the frontal channels.

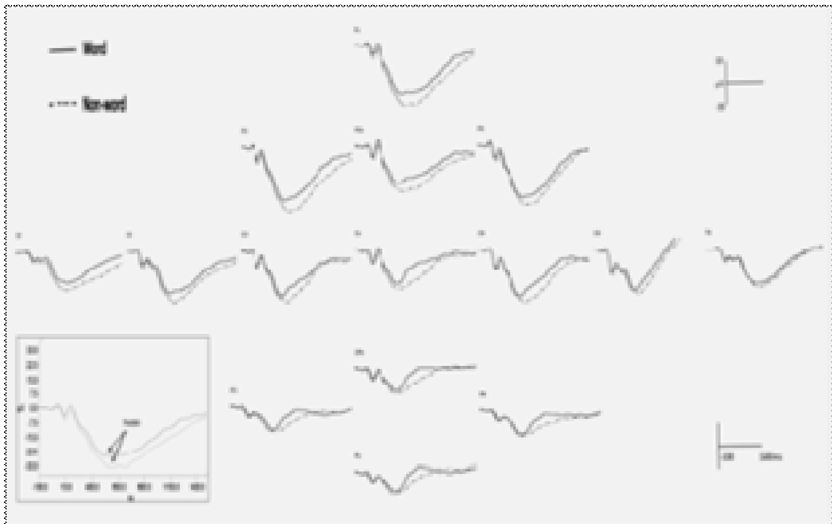

Figure 1: *Grand average ERP waveform at 15 different channels for both words and non-words. Waveform enlarged at Fz showing N400 in the bottom left*

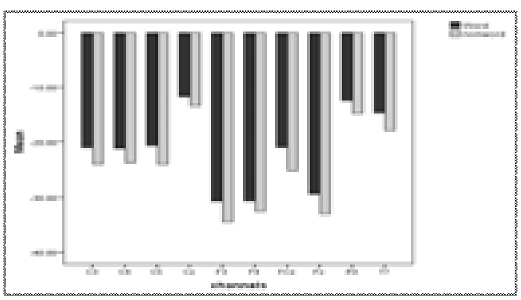

Figure 2: *Mean N400 amplitude for words and non-words at different channels which were significant*

Figure 2 shows mean N400 amplitude for words and non-words at channels which were significant. The N400 effect for amplitude was seen in the frontal, fronto-central, central and one of the parietal channels, as shown in Figure 2, which is consistent with the previous researches (Byrne et al., 1999; Friedrich & Friederici, 2006; Holcomb & Neville, 1990; Kutas & Federmeier, 2000; Kutas & Van Petten, 1998; Landi & Perfetti, 2007; Lau, Almeida, Hines & Poeppel, 2009; McCleery et al., 2010). But along with these channels, the N400 effect is also seen in temporal channel. This might be because of the only auditory mode used for presentation of the stimuli. The previous studies have either used visual stimuli or both auditory and visual stimuli for presentation of words (Connolly et al., 1995; Byrne et al., 1995a, 1995b; Byrne et al., 1999; McCleery et al., 2010). As can be evidenced from Figure 1, when frontal channels (F3 & F4) were considered the effect was seen in both right and left hemisphere channels. When mid coronal channels (C3, C4, C5, C6, T7, T8) were investigated there was more activity towards the left hemisphere compared to right as the N400 peak amplitude was more in left hemisphere channels than right hemisphere channels. There was only left hemisphere activation when parietal and temporal channels were investigated as there was significant amplitude difference in P3 and T7 respectively. This result is contradicting to the study by Holcomb and Neville (1990), who opined that there is earlier and more prolonged effect of the N400 for auditory presentation, slightly lateralized to the right hemisphere. But in this study priming task was used in auditory mode and in the present study there was no prime that was used.

When the N400 peak latency was considered only frontal and central channels had significant difference between words and non-words. The mean peak latencies for non-words were significantly longer than the words as shown in Figure 3. This suggests that the processing at these sites takes place for longer time.

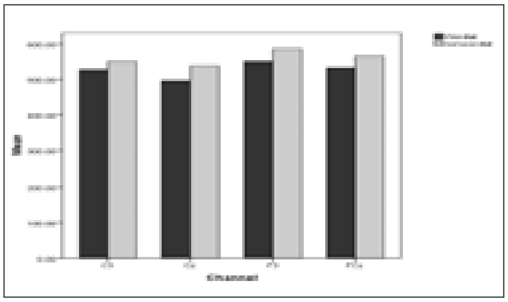

Figure 3: *Mean N400 latency for words and non-words at channels which were significant*

Correlation of behavioral and electrophysiological measures showed negative correlation of N400 effect with the difference in reaction times. This suggests that greater the N400 effect better is the performance of the individual on lexical decision. The channels which correlated were more of frontal, central and parietal in origin. Both right and left hemisphere channels equally contributed as there was good correlation with both the hemisphere channels in frontal and central regions. But there was strong correlation seen in F3, Fz and Cz channels indicating better processing at these sites. When parietal channels were correlated, there was more of right hemisphere participation and also the midline (Pz).

Summary and Conclusions

The present study investigated the comparison of performance of children on behavioral and N400 measures. The findings of the present study revealed that measures of N400 such as peak amplitude and latency measures correlated with reaction time significantly than accuracy measures. Thus indicating that peak amplitude and latency measure of N400 could serve as an important tool which reflects the integration of semantic information in children at a lexical processing level. The present study also revealed that significance in performance on the tasks was observed to be lateralized to channels in the left hemisphere. This indicates that since the tasks involved though are indicating only a lexical decision, this task also involves a higher level language (semantic) processing in children. Whereas, a few other studies conducted in adults indicated similar paradigm with results lateralized to the right hemisphere. A synthesis of results of present study and previous studies indicate that this could be a developmental shift of semantic processing in children to adults when tasks are learnt initially with the aid of language processing in left hemisphere and the task becomes more automatic in adults who process through the right hemisphere.

The present findings to some extent explain that the behavioral and neurophysiological measures are equally important, but behavioral measures may not be as adequate in revealing subtle differences as ERP measures. Direction for future research through the present study would be to investigate these differences in the clinical population such as children with dyslexia who are found to show difficulties at various language levels, phonological processing being one of them. This attempt would facilitate development of neurocognitive language assessment batteries or tools that may be more sensitive compared to other less sensitive methods.

Limitation of the present study is that the sample size was small. Similar study on a larger population at wider age ranges would facilitate a better understanding of development of phonological processing skills in children.

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