Research Paper: The Relationship Between Emotional Content and Phonological Processing in Persian Speaking Children Who Stutter: A Study by Event-related Potential

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Citation: Salehi S, Khatoonabadi AR, Ashrafi M, Mohammadkhani G, Maroufizadeh S. The Relationship Between Emotional Content and Phonological Processing in Persian Speaking Children Who Stutter: A Study by Event-related Potential. Journal of Modern Rehabilitation. 2020; 14(3):141-150. http://dx.doi.org/10.18502/jmr.v14i3.7712

http://dx.doi.org/10.18502/jmr.v14i3.7712

Article info:
Received: 10 Jan 2020
Accepted: 23 May 2020
Available Online: 01 Jul 2020

Keywords:
Phonological processing, Emotional content, Developmental stuttering, Persian, ERP

ABSTRACT

Introduction: Emotion can contribute to the severity of stuttering, although the underlying mechanism is unknown. Event-related Potential (ERP) could be very helpful for assessing emotional processing in persons with stuttering. Our study aimed at the investigation of phonological processing for emotional and neutral words in Children Who Stutter (CWS) by ERP.

Materials and Methods: Ten CWS were given 120 emotional and neutral words to read. Phonological processing was assessed by aloud reading task, while simultaneously ERP was recorded. The results were analyzed as behavioral (reaction time and accuracy) and electrophysiological (amplitude and topography).

Results: There were significant differences in reaction time and accuracy between positive, negative, and neutral words (P<0.05). The electrophysiological data analysis showed significant differences for a minimum of amplitude in the left frontal area, for a maximum of amplitude in the right temporal area, and peak to peak distance in the left frontal area (P<0.05). Visual inspection suggested that recorded fluctuations have a bigger amplitude range for neutral words in all brain regions, except prefrontal, frontal and right frontal.

Conclusion: Valence would affect behavioral measures. Generally, emotion facilitates word processing by reducing activity in anterior brain areas in phonological processing time.

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1. Introduction

Developmental stuttering is a type of developmental speech disorder characterized by block, repetition, and prolongation in speech [1]. There are reports in the prevalence of stuttering in various areas in Iran. Overall, previous reports suggest that the prevalence of stuttering in Iran is about 1% [2, 3]. Developmental stuttering is a multi-dimensional speech disorder affected by various factors, including psychological [4].

Language processing also has an effect on stuttering in children who stutter (CWS) [1]. Considering the Levelt model of speech production, phonological processing is the next to the final level of language processing before articulation [5]. Therefore there is a growing body of studies on motor speech areas, but limited studies on the formulation and conceptualization processes [6]. Furthermore, the majority of these studies are conducted on adults who stutter, and phonological processing is controversial in CWS because only one aspect of language processing is discussed in CWS [1, 7]. Additionally, limited literature in CWS is another gap in stuttering research. As compensatory strategies in CWS are not well shaped, the recorded neurophysiological characteristics are directly attributed to stuttering [8]. Thus, phonological processing can be assessed by different tasks, such as reading aloud [9].

One the other hand, emotion is a psychological factor that has two main dimensions in a verbal expression: arousal and valence (pleasant) [10]. Valence is affectivity which can be positive and negative: high valence or positive like “celebration” and low valence or negative like “sadness.” Arousal means how much exciting or calming a word can be: low arousal like “peace” and high arousal like “war” [11]. There are both electrophysiological and behavioral studies in the Persian language which illustrate that emotional content (valence) has an effect on word processing in fluent children [12, 13]. Previous behavioral investigations show that valence affects word processing so that neutral words are processed faster than emotional words [13]. Also, the valence effect on word processing was demonstrated by electrophysiological assessments: high valence words were processed faster [12, 14, 15] and more accurate [15].

In addition, high valence words produced larger amplitude and dipolar fronto-occipital topography in brain areas of language processing in the normal population [12, 16, 17]. Notably, this larger amplitude for high valence words is recorded in the left parietal lobe, while the larger amplitude for neutral words is recorded in the central region [17]. These electrophysiological studies were conducted by event-related potentials (ERPs). This neuroimaging method records small changes in the brain’s electrical activity from the scalp with millisecond time resolution [18]. These changes are arising from a specific event, thus ERP is very useful for language processing investigations. Besides, emotional language is processed very fast, thereby ERP can be helpful for our study [19]. ERP analysis is conducted in two methods: stimulus-locked and response-locked [20]. Generally, the analysis method is selected based on the study purpose [21]. Overt articulation during the aloud reading task is recorded in our study, then there is a vocal response which can be analyzed through response-locked method.

Although situational stressors enhance emotional diathesis and negative emotional reactivity increases the percentage of disfluencies [22, 23], emotion can be a responsible factor in developmental stuttering [24]. There is no data about the relationship between emotional content and stuttering as well, the underlying mechanism of emotional language processing in stuttering is unknown yet. On the other hand, the facilitating role of emotion in normal people is well-established [15].

Consequently, the present study aims to investigate phonological processing of emotional words (negative and positive) and neutral words by ERP in Persian speaking CWS. The main focus of our study is determining differences between the amplitude values of recorded ERP in the phonological processing time range, 100-400 ms before articulation, between emotional words and neutral words by reading aloud task. So, as mentioned before, the response-locked method is used and 100-400 ms before voice (articulation) is assumed phonological processing time [25].

2. Materials and Methods

Study design and participants

Ten CWS (7 boys and 3 girls), aged 7-10 years old (Mean±SD=105.6±11.74 months), participated in this non-experimental cross-sectional study (Table 1). All participants met the inclusion criteria as follows: monolingual native Persian speakers with corrected to normal or normal hearing and vision, had normal speech and language development, with normal psychomotor development according to parent’s report and medical history, and were right-handed according to Edinburg Handedness Inventory [26]. The study was approved by the Ethics Committee of Tehran University of Medi-

Table 1. Demographic features of participants

ID	Children Who Stutter		
	Age (mo)	Gender	Stuttering Severity Instrument, the Third Edition (SSI-3)
1	91	F	Moderate
2	105	F	Very mild
3	129	M	Moderate
4	98	M	Mild
5	97	M	Severe
6	120	M	Mild
7	105	M	Moderate
8	95	F	Mild
9	111	M	Severe
10	105	M	Moderate
Mean±SD	105.6±11.74	-	-

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cal Sciences, Tehran, Iran. All parents signed a written informed consent form. Table 1 presents demographic data and stuttering severity.

Stimulus materials

Before the study, a list of 180 emotional Farsi words was prepared based on arousal and valence (pleasant) score [27]. Then, in another study, 120 emotional words were selected. Next, a list of 120 emotional words was prepared according to recorded scores of comprehensibility of the words for children [13]. Since the frequency of words is a significant factor in word and emotion processing [28], these words were matched in terms of frequency and length of words (Table 2).

Study procedure

First, the laboratory setting and the procedure of the ERP recording method were explained to the children and their parents completely. Personal information forms were filled out by the parents, and at the same time, an expert speech therapist assessed the severity of stuttering was with the Persian version of stuttering severity instrument third version (SSI-3) in CWS [29].

The place of recording was an acoustic room; children were asked to sit on a chair in this room facing a PC monitor at a distance of 40 cm. An ERP cap with 64 electrodes was placed over the children's heads, considering the Fpz at 1/10 Nasion to Inion. It was metered by a measuring tape for each participant.

There were 3 sizes for ERP-cap selected based on the children's heads circumferences. The verbal response was recorded by a microphone that was at a distance of 10 cm from the participant's mouth. Afterward, the participants were instructed to read the words aloud as soon as these words appear on the monitor. At first, the training phase was done before the main trial by 10 selected words. When the subjects were familiarized with the procedure, then the main phase of the study began with 120 emotional words. The emotional words presentation on the monitor was in a pseudorandom sequence. A total of 120 emotional words were presented for each child, including 40 neutral, 40 positive, and 40 negative

Table 2. Characteristics of word stimuli

Emotional Words	Mean±SD			P
	Positive	Negative	Neutral	
Valence	5.83±0.37	2.20±0.51	4.25±0.31	0.07
Arousal	4.35±0.57	4.64±0.9	3.72±0.21	0.11
Word length (syllable)	2.10±0.77	1.80±0.75	1.92±0.57	0.83
Frequency	1.89±0.28	1.74±0.25	1.78±0.27	-

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words. A plus sign (+) was shown as a fixation for 1000 ms between the presented words. Each word was typed in black font (B Titr, size 64) on a grey background and demonstrated for 2000 ms in the center of the screen.

This study was conducted in the ERP lab in the Rehabilitation Faculty of Tehran University of Medical Sciences, from June to November 2017.

EEG recording

The ten-ten international system of electrode placement was used for electrode arrangement on the head cap for EEG recording. In total, 64 electrodes were placed on the cap and all of them were re-referenced to the average of left and right mastoids. The sample rate of recording data was 256 Hz by the EB-Neuro system and Galileo Net software (Italy). The data bandwidth was from 0.1 Hz to 40 Hz. The correct response was defined as a recorded response in 200-2000 ms after the written word illustration.

EEG analysis

ERP analysis and visualization were conducted by EEGLAB software. The recorded data were preprocessed with Automatic Speech Recognition (ASR) and early-stage preprocessing pipeline (the PREP pipeline) [30, 31]. The repeated measure was utilized by EEGLAB to specify time windows for ERP and the region of interest.

Statistical analysis

In this study, continuous variables were expressed as mean (standard deviation). We used Repeated-measures ANOVA, followed by the Bonferroni test, for comparison between word categories. The statistical analysis was carried out with SPSS V. 22. All statistical tests were two-sided and a P-value less than 0.05 was considered significant.

3. Results

Behavioral analysis

The behavioral data were statistically analyzed using repeated-measures ANOVA. There was a significant difference between word categories in response accuracy (F2, 36=9.68; P<0.001). Then, the Bonferroni post hoc test shows that response accuracy in positive words was significantly higher than that in negative and neutral words (P=0.007, P=0.002, respectively) (Figure 1).

There was also a significant difference between word categories in reaction time (F2, 36=6.2; P=0.005). As shown in Figure 2, the Bonferroni post hoc test reveals that reaction time in negative words was significantly more than that in neutral and positive words (P=0.001).

Electrophysiological analysis

Electrophysiological data includes plots (Figure 3), topography (Figure 4), and the statistical analysis of values of amplitude (minimum, maximum, and peak to peak measures).

As seen in Figure 3, by global field method and visual analysis [20], the following results are extracted: recorded fluctuations had a bigger range for neutral words in all regions, except prefrontal, frontal, and right frontal areas. Generally, emotional words had smaller amplitude fluctuations. It also was smaller in positive words (high valence) compared with negative and neutral words in some regions, including prefrontal, frontal, left frontal, central, left temporal and parietal areas.

Latency, in similar recorded components for negative words, is higher than that in positive and neutral words.

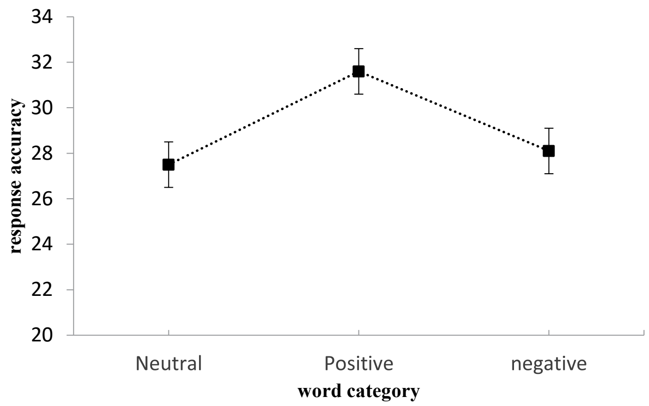

Figure 1. The mean response accuracy in emotional and neutral words

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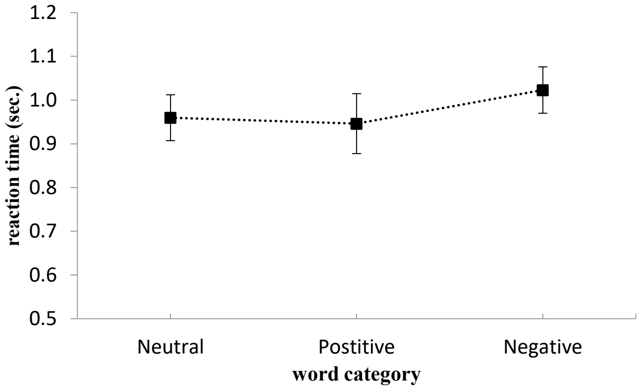

Figure 2. The mean reaction time in emotional and neutral words

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The recorded topography had a diffuse pattern for negative and neutral words. Although positive words had a more regulated pattern with more activity in the occipital area, as is expected for reading tasks (Figure 4) [32].

There were significant differences for a minimum of amplitude in the left frontal area between neutral words and negative words (P=0.017), for a maximum of amplitude in the right temporal area between negative words and positive and neutral words (P=0.004), for the peak to peak distance in the left frontal area between neutral words and emotional words (P=0.003) (Table 3).

4. Discussion

Our study aimed to explore the differences between emotional (high valence and low valence) and neutral words processing in CWS. The behavioral findings showed that low valence (negative) words had longer reaction time, so they are processed slower than neutral and high valence (positive) in CWS. Additionally, positive (high valence) words were more accurate than neutral and negative words. It is suggested that valence affect the speed and accuracy of word processing speed and accuracy. This finding is in line with the previous electrophysiological study, which is conducted in normally fluent people [12, 15].

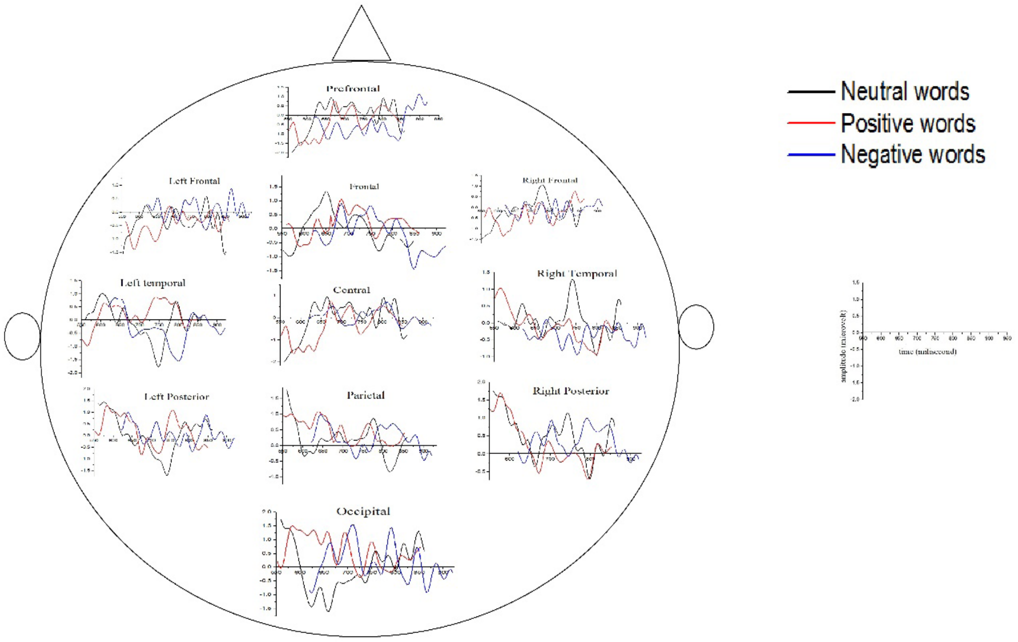

Figure 3. Recorded plots of children who stutter in 11 brain regions for three-word categories

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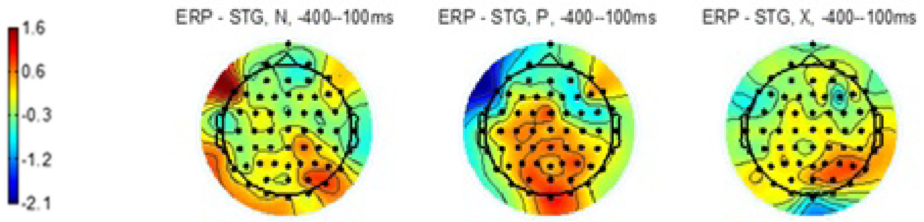

Figure 4. The topography of children who stutter in N: Negative words, P: Positive words and X: Neutral words

But the previous behavioral study of emotional word processing showed that neutral words are processed better than others [13]. Overall, in both behavioral and electrophysiological studies, low valence (negative) words are processed slower and with less accuracy. The processing of words is likely affected by valence in CWS, especially with low valence words. Therefore, negative words increase the complexity of the processing and may increase speech disfluencies. Therefore, more investigation for high valence words is suggested for speed processing.

Table 3. Comparison of maximum and minimum of amplitude and peak to peak and brain regions

Areas	Mean±SD			P†	Pairwise Comparisons
	Word Category				
	Neutral (X)	Positive (P)	Negative (N)		
	Minimum				
Prefrontal	-3.88±1.37	-4.01±1.35	-4.05±1.53	0.864	-
Frontal	-2.49±0.79	-2.26±1.58	-2.78±1.25	0.61	-
Right frontal	-2.6±1.09	-2.83±0.76	-2.22±1.29	0.425	-
Left frontal	-3.86±1.47	-3.03±1.15	-2.38±1.05	0.017	X<N
Central	-2.26±0.93	-1.74±0.93	-2.35±1.3	0.345	-
Left temporal	-2.98±0.96	-2.33(1.12	-3.04±2.08	0.197	-
Right temporal	-2.77±1.5	-2.41±1.64	-2.73±1.55	0.656	-
Parietal	-2.25±0.7	-2.33±1.25	-2.44±1.56	0.927	-
Left posterior	-3.41±1.28	-3.1±2.05	-2.46±0.94	0.185	-
Right posterior	-2.37±1.16	-2.45±1.51	-2.5±1.47	0.964	-
Occipital	-4.14±1.46	-3.47±1.82	-3.63±1.49	0.124	-
Areas	Mean±SD			P†	Pairwise Comparisons
	Word Category				
	Neutral (X)	Positive (P)	Negative (N)		
	Maximum				
Prefrontal	3.82 (2.42)	3.55 (2.30)	3.56 (2.24)	0.92	-
Frontal	2.46 (1.4)	2.49 (1.43)	2.33 (1.13)	0.83	-
Right frontal	2.39 (0.96)	2.36 (1.71)	2.53 (1.44)	0.927	-
Left frontal	3.13 (1.73)	2.3 (0.78)	2.61 (1.83)	0.378	-
Central	2.75 (1.75)	2.58 (1.56)	2.33 (1.16)	0.623	-
Left temporal	2.84 (1.72)	2.24 (1.06)	2.18 (0.98)	0.351	-
Right temporal	2.9 (0.64)	2.47 (0.82)	1.76 (0.62)	0.004	N<P,X
Parietal	3.04 (1.18)	3.13 (1.46)	2.92 (1.78)	0.884	-
Left posterior	3.26 (1.38)	3.54 (1.16)	2.71 (1.59)	0.447	-
Right posterior	3.74 (1.34)	3.01 (0.87)	3.05 (0.85)	0.091	-
Occipital area	4.41±1.76	4.28±1.01	3.68±1.16	0.268	-

Areas	Mean±SD Word Category Neutral (X)	Positive (P)	Negative (N)	P†	Pairwise Comparisons
	Peak to Peak				
Prefrontal	7.71±3.13	7.56±2.84	7.61±2.91	0.982	-
Frontal	4.96±1.75	4.75±2.01	5.11±2.09	0.815	-
Right frontal	4.99±1.96	5.18±1.73	4.75±1.68	0.784	-
Left frontal	6.99±2.41	5.34±1.57	4.99±1.99	0.003	X>N,P
Central	5.01±1.9	4.32±1.4	4.68±1.86	0.377	-
Left temporal	5.81±2.39	4.56±1.77	5.22±2.29	0.052	-
Right temporal	5.67±1.97	4.88±2.24	4.49±1.37	0.143	-
Parietal	5.29±1.49	5.46±2.01	5.35±2.67	0.95	-
Left posterior	6.67±2.08	6.63±2.71	5.18±1.79	0.099	-
Right posterior	6.11±1.81	5.46±1.74	5.55±1.95	0.241	-
Occipital	8.55±2.75	7.74±2.66	7.31±2.17	0.094	-

†Repeated Measures ANOVA.

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Electrophysiological results of our study showed that emotional words, including negative and positive ones, had smaller amplitude fluctuations, except in prefrontal, frontal, and right frontal areas, which are language production areas [32]. These differences were more significant in the left frontal area. It means that emotional words were processed with more activation changes than neutral words in prefrontal, frontal, and right frontal areas. The previous studies indicated that emotion facilitates word processing in the normal adult population [14, 15], but the study conducted on normally fluent children to investigate emotional word processing by ERP, suggested that emotional content elicit smaller amplitude in central areas, whereas larger amplitude is recorded for emotional words in language areas [12, 32]. Overall, emotional word processing in CWS and normally fluent children are similar but differ from emotional word processing in adults. This difference can be explained by the various experiences of an adult.

On the other hand, our recorded topography showed a dipolar fronto-occipital topography in positive words. This finding is consistent with the previous reports for normal adults and children [12, 13, 16, 17]. Moreover, negative and neutral words had diffuse topography without a regular pattern. This result is not in agreement with the results of previous studies [12]. Likewise, positive (high valence) words processing in CWS is similar to emotional words processing in the normal population, whereas negative and neutral words had a different topographic pattern. Altogether, negative and positive words and neutral words have been processed differently in CWS in the aspect of recorded topography.

There is limited literature in the relation of stuttering and emotional words processing, which can be utilized in discussing the results. Also, CWS can be categorized based on stuttering severity, stuttering onset, and stuttering fluctuations.

5. Conclusion

Our investigation suggested that high valence be associated with more accurate and less reaction time in CWS. Positive words facilitate word processing in the aspect of behavioral assessment in CWS. Also, topographical evidence confirms that positive emotional words have regular processing compared with neutral and negative words. Generally, considering electrophysiological data, emotional words facilitate word processing in central areas of the brain but increase brain activity in language processing areas in CWS. In other words, emotional words processing needs more activity compared with neutral words for CWS in language processing areas concerning the phonological processing time range.

Ethical Considerations

Compliance with ethical guidelines

This study was registered and approved by the Research Council, School of Rehabilitation, Tehran University of Medical Sciences (TUMS) on 2/28/2018 as a part of a PhD thesis. All participant's parents were signed the written informed consent.

Funding

This work was extracted from a registered PhD thesis of speech therapy at Tehran University of Medical Sciences.

Authors contributions

Conceptualization, design, writing-review and editing, and supervision: All authors; Methodology: Sousan Salehi, Ahmad Reza Khatoonabadi, Saman Maroufizadeh; Investigation, funding acquisition, resource: Ahmad Reza Khatoonabadi, Sousan Salehi.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgements

We would like to thank the personnel of the signal processing section in the National Brain Mapping Lab (NBML) for helping us to analyze the recording ERP.

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