Journal of Communication Disorders, Deaf Studies & Hearing Aids

Valentine, Commun Disord Deaf Stud Hearing Aids 2019, 7:1
DOI: 10.4172/2375-4427.1000189

Research Article Open Access

Absence of P300 Amplitude Laterality in Persons Who Stutter

Daniel T Valentine
Department of Communication Disorders, University of Montevallo, Montevallo, Alabama, United States

Abstract

Objective: This study investigated differences in P300 auditory-evoked potentials between Persons Who Stutter (PWS) and Persons Who Do Not Stutter (PWNS).

Methods: Responses to tonal and synthetic speech stimuli were recorded from electrodes over the right and left parietal locations and amplitude and latency measures were analyzed. The speech stimuli /bA/-/pA/ and /bA/-/dA/ were two sets of syllables contrasting across and within categorical boundaries on the first phoneme.

Results: PWS demonstrated different inter-hemispheric activity in response to the stimuli than PWNS. Whereas PWNS had significantly greater P300 amplitudes over the left than the right parietal location, PWS did not demonstrate significantly greater P300 amplitudes over either location.

Conclusion: This lack of laterality for PWS is discussed in the light of cerebral dominance theories and speech development.

Keywords: Stuttering; Auditory-evoked potentials; P300; Electrophysiology; Laterality; Cerebral dominance

Introduction

The concept of atypical cerebral dominance in People Who Stutter (PWS) has received much attention since Orton and Travis [1] first suggested that stuttering was a result of greater right hemisphere dominance in PWS compared to Persons Who Do Not Stutter (PWNS). Gaeschwind and Galaburda [2,3] hypothesized that stuttering is a result of delayed left hemisphere development. Because of the significantly higher incidence of stuttering in males, they speculated that a combination of genetic and biological factors (particularly high testosterone levels) may impede cerebral development in the left hemisphere. The researchers speculated that a consequence of delayed development of the left hemisphere is anomalous dominance in the right hemisphere and a lack of cerebral laterality. To compensate for this lack of development, neural connections for speech and language functions are generated in the right hemisphere, which is less efficient for language processing. Without the development of more efficient networks for speech and language, an atypical cerebral architecture is established and results in disorder such as stuttering or dyslexia.

Kent [4] speculated that one factor among others which contributes to stuttering is the inability to create temporal patterns in order to generate complex motor sequences. He suggested that a central auditory processor is responsible for integrating the temporal ranges of input and output information that are processed on the left and right hemispheres. If this is the case, both speech perception and production are affected because of a decreased ability to generate temporal patterns. Fluency inducing strategies, such as choral repetition or delayed auditory feedback, decrease the temporal uncertainty and thereby increase fluency.

Various research methodologies have been utilized to examine different inter-hemispheric function in PWS as compared to PWNS. Some of these have included: sodium amobarbital or the Wada test [5], handedness [6] verbal dichotic listening tests [7-9], tachistoscopic procedures [10,11], Positron Emission Tomography (PET) [12-19], Magnetic Resonance Imaging (MRI) [20-22], electroencephalogram recordings [23], and Late Auditory Evoked Potentials (LAEPs) and Event Related Potentials (ERP) [24-29]. A literature review of these methodologies shows that brain imaging studies consistently demonstrate inter-hemispheric differences between PWS and PWNS, although the anatomical areas in which these differences are observed is inconsistent across the brain imaging studies. An overview of imaging studies and the differences in methodologies and experimental designs is outlined in Ingham [30]. The primary aim of the current study was to determine if PWS exhibit greater right hemisphere activity for speech discrimination tasks involving both spectral and temporal cues.

Auditory evoked potentials (AEPs)

In the absence of specific sensory stimulation, the Central Nervous System (CNS) generates spontaneous neural activity. This activity can be recorded by electrodes and is called the Electroencephalogram (EEG). Auditory Evoked Potentials (AEPs) are neural response patterns that occur in response to an auditory stimulus. The AEPs are extracted from the resting EEG by signal averaging. AEPs are classified based on their latency of occurrence following the auditory stimulus. AEPs such as the Auditory Brainstem Response (ABR) and Middle Latency Response (MLR) have latencies below 50 ms and arise from the VIII nerve/brainstem (ABR) or the thalamus (MLR). Late-latency AEPs (LAEPs) have latencies greater than 50 ms and arise from the cortex [31].

LAEPs are named according to their wave deflection (positive or negative) and approximate latency. LAEPs include the first negative going wave (N100 or N1), the first positive going wave (P200 or P2), the second negative going wave (N200 or N2), and the next largest occurring wave following N2 is the P300 (P3) [32]. The N1, P2, and N2 waves are related to the encoding of the stimulus [33,34]. The P300 wave is an endogenous response to an unexpected event that is thought to rep-

***Corresponding author:** Daniel T Valentine, Department of Communication Disorders, University of Montevallo, Montevallo, Alabama, United States, Tel: 205-665-6722; E-mail: dvalentine@montevallo.edu

Received January 21, 2019; **Accepted** April 10, 2019; **Published** April 24, 2019

Citation: Valentine DT (2019) Absence of P300 Amplitude Laterality in Persons Who Stutter. Commun Disord Deaf Stud Hearing Aids 7: 189. doi: 10.4172/2375-4427.1000189

resent a classification or categorization of the stimulus by the listener [35,36]. The P300 component is believed to reflect a conscious cognitive process in discriminating the stimuli. Some research scientists claim that results are more robust when the subject is actively discriminating between the rare and frequent stimuli [32,37,38].

Auditory evoked potentials (AEPs) and Persons who stutter (PWS)

Early studies measuring neurophysical responses of PWS have reported hemispheric asymmetry. Most of these early studies focused on alpha wave suppression. Moore and Lange [39] and Moore and Haynes [27] measured alpha waves (8 13Hz) from EEG recordings in response to speech stimuli. The suppression of alpha waves (resulting in lower amplitudes) in these studies represents an active response to rare stimuli. In both studies the alpha wave amplitudes were lower in the right hemisphere than in the left hemisphere for PWS when compared to PWNS. In the first study participants were exposed to massed oral readings and the researchers found a greater degree of alpha waves on the left hemisphere. In the second study the participants listened to a reading passage from the Congressional Record and nonverbal stimuli consisting of 500, 1000, and 4000 Hz tones. In both tasks, PWS showed decreased alpha wave amplitudes in the right hemisphere. These results led the researchers to conclude that PWS may process information differently than PWNS.

Finitzo et al. [25] recorded LAEP measurements from 20 PWS and 12 PWNS over the entire cortex. P1, N1, and P2 LAEP amplitudes were measured in response to a 103 dB tone burst. Analysis showed lower amplitudes for all three potentials for PWS when compared to PWNS. PWS displayed significantly lower amplitudes for the P1 wave over the left temporal, lower amplitudes for the N1 wave also over the left temporal region, and significantly lower amplitudes for the P2 wave over the medial frontal cortex. Within-group differences showed lower amplitudes for mild to moderate PWS when compared to severely disfluent PWS. Amplitudes of N1 and P1 for individuals with a severe stuttering rating were similar to those in the normal speech group at the Cz location (midline at the top of the head). P2 amplitudes were comparable to PWNS at the T3 location (left temporal). The authors speculated that differences in the amplitudes for P1 and N1 might suggest a deficit in the left temporal cortex for individuals who stutter.

Morgan and Haynes [27] compared the amplitude of P300 responses from central locations on the right and left hemispheres of PWS and PWNS. The study measured the P300 amplitudes of eight PWS and eight PWNS in response to a frequent 1000 Hz tone burst and a 2000 Hz rare tone in an 80/20 probability paradigm. Results demonstrated that PWS did not differ significantly from PWNS in their mean amplitude response in the right hemisphere. However, the interaction between group and hemisphere was significant for PWNS. Differences in P300 amplitudes in the right and left hemispheres did not differ significantly for PWS, whereas the mean amplitude difference between the hemispheres for PWNS was statistically significant. The authors conceded that although five of eight PWS subjects had greater P300 amplitudes on the left hemisphere, this could not be considered abnormal; rather, the two groups exhibited different patterns of hemispheric activity. This research study measured mean amplitude measures on tone bursts and only over the left and right central locations (C3 and C4). Although the central locations have often been used in other research when obtaining P300 responses to tones bursts [40,41], other locations may be necessary for more subtle speech discrimination tasks.

Recent research by Cuandroado and Fox-Weber [24] investigated Event-Related Brain Potentials (ERP) while participants silently read sentences and made grammatical judgments. Of particular interest was the P600 wave, where lexical processing is hypothesized to occur [42]. The researchers found that violations of subject-verb agreement elicited significantly lower P600 wave amplitudes for PWS and these were confined to the right hemisphere. Differences between the two groups were significant only in what the researchers referred to as an "online" task. In other words, the participants read sentences at a fixed rate and could not reread the sentence. The researchers speculated that the verbal working memory demands of an online task influence syntactic access processing and that the processing is decreased in PWS. In a similar study conducted by Weber-Fox [29] ERP waveforms (N280 and N400) were collected during a semantic-anomaly task. Results did not show significant differences in latency response between a group of adults who stuttered and those who did not stuttering. However, results did demonstrate that peak latencies were greater over the right hemisphere than the left when compared to adults who did not stuttering. Kriedler et al. [26] used ERPs in order to investigate whether there are differences in semantic processing among children who persisted in stuttering, those that recovered from stuttering, and children who did not stutter. Among the results, there were no differences in N400 peak amplitudes or latencies across the three groups of 5 year-old children. The researchers, however, did find that the N400 peak amplitudes were higher over the right hemisphere for children who persisted in stuttering and the N400 peak amplitudes were higher over the left hemisphere for children who recovered from stuttering.

The primary purpose of the current study was to identify whether PWS exhibited a lack of laterality of hemispheric activity to tonal and speech stimuli. Previous electrophysiological literature from resting activity and from activity evoked by non-speech stimuli has shown a lack of laterality for PWS [25,27,28]. The current investigation recorded P300 waves in response to synthetic speech stimuli that varied temporal and spectral cues. In addition, it recorded the P300 responses over the P3 and P4 locations. The parietal areas, particularly the left temporal-parietal location has been thought to be responsible for phoneme processing [43]. By recording P300 waves, this study investigated whether PWS revealed hemispheric asymmetry of P300 latencies or amplitudes when compared to PWNS in response to tonal stimuli and synthetic speech stimuli within and across categorical boundaries.

Method

Participants

A total of 18 adult males (9 PWS and 9 PWNS) between the ages of 18 to 45 from the University of Tennessee campus and the Knoxville community participated in this study. The mean age for the individuals in the PWS group was 27; 2 years and 32; 6 for the individuals in the PWNS group. All participants were right-handed, based on results from the Edinburgh Handedness Inventory [44] and all participants had normal pure tone audiometric thresholds [45] at 20dB HL or better at 500, 1000, 2000, and 4000 Hz. Subjects in both groups reported no history of head injury, seizures, learning disabilities, or dyslexia *via* a screening questionnaire. In addition, all participants reported a history of stuttering or language learning delays. PWS completed an additional stuttering history questionnaire, which reported developments of stuttering and intervention techniques. In order to assess the presence and level of stuttering severity, all of the participants in both groups were videotaped or audio taped while completing a reading from the Stuttering Severity Instrument-3, (SSI-3) [46] and an approximate 300 syllable conversational speech sample with the investigator. Table 1 summarizes the characteristics of the participants in the stuttering group. Note that most of the subjects were classified as having "very mild" (4) or "mild" (3) stuttering severity based on the SSI-3 results, with only 1 subject classified as either "severe" or "very severe."

Stimuli

Stimuli in the current study consisted of pure tones and synthetic Consonant-Vowel (CV) stimuli. Tonal stimuli consisted of one hundred sixty 1000 Hz (frequent) and forty 500 Hz (infrequent) tones. These stimuli were generated on a Macintosh 6100 av computer and then randomized in an odd-ball paradigm. The duration of the tone was 300 ms. Thus, the infrequent stimulus was presented 20% of the time and the frequent stimulus was presented 80% of the time, yielding an 80/20 probability ratio. The inter-stimulus interval varied from 2.0 to 4.0 seconds in order to decrease predictability of the stimuli and reduce inattention. From the computer, this file was recorded onto Maxell UR normal bias standard audio cassettes with a JVC TD-W303 Stereo Double Cassette Deck.

Synthetic CV speech stimuli consisted of two stop consonant contrasts: a Voice Onset Time (VOT) contrast and a labial-alveolar Place of Articulation Contrast (POA). These were synthesized using a PC version of the Klatt formant synthesizer [47] with a sampling rate of 10 kHz. The vowel sound /A/ was constant across all the stimuli. To create the VOT continuum, the amplitude of the voicing parameter (AV) in the synthesizer was manipulated to occur at differing times relative to the initial burst. Thus, for one endpoint stimulus, both the Amplitude of Frication (AF) and the AV parameter were simultaneously initiated, simulating a VOT of 0 ms. In succeeding stimuli, the AV parameter was initiated at 10, 20, 30, 40, 50, and 60 ms following initiation of the AF parameter, thereby simulating VOT values of 10 to 60 ms. The typical boundary for voiced/voiceless distinction for labials in English, as measured by Lisker and Abramson [48] is 30-40 ms. For VOT values greater than 10 ms, aspiration noise (AH) was initiated following the burst and terminated just before the onset of periodicity (onset of AV). The burst duration was 10 ms and the syllable was 295 ms.

To create the POA (Place of Articulation) continuum, the onset frequency of the second Formant (F2) transition was varied from 900 to 1500 HZ in 100-Hz steps. These onset frequencies span the labial/alveolor stop contrast in the /A/ vowel context. Thus, each stimulus had its own unique F2 transition onset value. For all the stimuli, the first Formant (F1) began at 300 Hz and reached steady state at 700 Hz, and the third Formant (F3) began at 2000 Hz and reached steady state at 2600. The changes in F1 and F3 are part of the parameter values listed for synthesis of stop consonants in a CV context before a front or central vowel [46] for all stimuli, F1, F2, and F3 frequency changes were completed in the first 40 ms of the CV. The AV and the AF parameters were initiated 10 ms following the burst and both were held constant throughout the continuum.

Participant	SSI-3 Severity	Previous Therapy	History of Stuttering
1	very mild	FS	Yes
2	very mild	FS	No
3	severe	SM	Yes
4	mild	FS	No
5	very mild	FS	No
6	very severe	unknown	unknown
7	very mild	FS	Yes
8	mild	SM	No
9	mild	FS	No

Table 1: Severity, Previous Therapy and Family History of Stuttering for the Stuttering Group. (Note: SSI-3: Stuttering Severity Instrument-Third Edition; FS: Fluency Shaping; SM: Stuttering Management).

The speech stimuli were recorded onto a cassette deck and digitized on a Macintosh 6100av computer using SoundEdit 16, version 1.0 [49]. SoundEdit 16 allows the user to enhance, play, and analyzed stored sounds on the computer's hard drive. The SoundEdit program software was used to arrange the speech stimuli into the 80/20 probability ratio and varied the inter-stimulus interval (2.0 to 4.0 seconds). From the computer, this file was recorded onto Maxell UR normal bias standard audio cassettes with a JVC TD-W303 Stereo Double Cassette Deck.

The validity of the linguistic characteristics of the synthetic speech stimuli was tested perceptually. For this task, ten adult university students (age range 18-40) were recruited. Each individual had hearing thresholds of 20 dB HL or lower for pure tones at 500, 1000, 2000 and 4000 Hz in both ears [44]. Each listener was a native English speaker and reported no known speech, neurological, cognitive or learning disabilities. The stimuli were Digital-to-Analog (D/A) converted, low pass filtered at 4.9 kHz, routed to a headphone buffer, and delivered to Sennheiser headphones worn by the listener in a sound booth. Endpoint stimuli from the VOT /bA/-/pA/ continuum was presented first and then endpoint stimuli from the POA /bA/-/dA/) continuum were presented. The listeners were asked to identify the stimuli. A total of 60 equally divided stimuli were randomized and presented to the subject. Accurate identification of the two stimulus sets by the listeners was greater than 95%.

To determine the within phoneme boundary parameters for each contrast, all seven stimuli within each continuum were presented to the listeners. The participants were asked to identify the syllable by marking a response sheet and the data were analyzed to select the parameters of the within phoneme boundary syllables. The best exemplar of a category, and stimulus 2 steps removed from the best exemplar, were selected as the stimuli for the within-phoneme category tasks. Thus, results from the pilot experiment validated the linguistic characteristics of the stimuli, determined the categorical perceptibility of the stimuli, and determined the stimuli to be used in the within phoneme boundary tasks. Table 2 is a summary of the five stimulus conditions.

P300 response

P300 AEPs were recorded *via* 6 mm cup disk surface electrodes with protected leads (E5 GH) placed on the participants' scalp on the following locations according to the International 10-20 system [50]: Central Zenith (Cz) and Left/Right Parietal (P3/P4). The parietal region was selected because of its association with auditory phoneme processing [43]. In addition, the parietal midline has been suggested as a recording site in a sample protocol for obtaining a P300 clinically to auditory stimulation [37]. Further, the parietal midline has been used to obtain the largest amplitude response for the P300 component (P3b) that represented counted rare auditory stimuli [51]. Linked electrodes for reference were placed on both ears and a ground electrode was placed on the forehead. Impedance measures were taken prior to the experimental testing; measures of 5K ohms or less for each electrode and no more than a 5 K ohm difference between any two electrodes as measured with a Grass electrode impedance meter (Model EZM5A) were acceptable. Following electrode placement, participants sat in a comfortable chair in a sound treated room where the stimuli were presented *via* an overhead Speco speaker (Model DMS-3PW) at approximately 70 dB A-scale (fast response). The presentation level of 70 dB A was measured by a Realistic sound level meter (#33-2050) held at what would be ear level

Stimulus		
/bA/ - /pA/	/bA/ (frequent)	AV +10 ms
	/pA/ (infrequent)	AV +60 ms
within /pA/	/pA/ (frequent)	AV +60 ms
	/pA/ (infrequent)	AV +40 ms
/bA/-/dA/	/bA/ (frequent) second formant	900 Hz
	/dA/ (infrequent) second formant	1500 Hz
within /dA/	/dA/ (frequent) second formant	1500 Hz
	/dA/ (within) second formant	1300 Hz
Tone	high (frequent)	1000 Hz
	low (infrequent)	500 Hz

Table 2: Summary of the stimuli used to elicit P300 response..

for the subjects. Participants were asked to keep physical movement to a minimum. A sequence of black and white slides showing a figure of a square going around a figure of a circle was presented to focus attention and minimize eye and head movement.

The electrodes were attached to Grass amplifiers (P511k) with an independent power supply (Grass RPS107), amplified 50,000 times and passed through an analog-to-digital converter (MAD.56.6.8 Memory Analog System, Bench-top Instrument compatible). Tektronix 2201 Digital Storage Oscilloscopes displayed the unaveraged responses as the participant listened to the stimuli. The recording window included a 100 ms pre-stimulus period and 700 ms of post-stimulus onset time. The Evoked Potential Analysis and Data Collection System (EPACS) [52] were used to display, format, and average the waveforms on a Macintosh SE 40 personal computer. A parameter file was constructed to instruct the program to expect different stimuli, sampling rate, and the total number of stimuli. This program detected the beginning trigger signal after which sampling occurs simultaneously for each channel for the number of points specified by the parameter file. Positive and negative wave peaks were calculated manually with mouse clicks and the EPACS system generated both amplitude and latency data.

Participants were instructed to listen to the syllables or tones presented in each condition and to press a button when they identified the infrequent speech syllable or the rare tone. The button was a small handheld device manipulated easily by the thumb with little or no extraneous body movement. When the participants pressed the hand-held button, a light in the investigator's booth indicated their responses. The investigator monitored the participants' attention to the task by keeping track of the positive responses. When the testing procedure was completed, electrode impedances were re-checked to ensure that there was no greater than 3.5 K ohm difference for between electrodes. Presentation of the five conditions was randomized for each subject. Following the five experimental tapes, a control tape was presented without auditory stimuli. Results from this tape were analyzed to verify the P300 responses from the previous conditions were not random or incidental artifacts. To further minimize eye movement or movement of any other kind, an artifact rejection was completed for each condition to reject amplitudes under 800 UV and amplitudes exceeding 3000 UV. The data from the sampling was stored on the hard drive of the computer and averaging of the signals was completed off-line.

Results

Analysis of responses

The P300 waveforms were analyzed for peak latency and amplitude. The EPACS system software [52] averaged the responses and provided amplitude data for the P300 base on Baseline to Peak (BTP). The BTP is the difference between the voltage at the P300 peak and the average voltage 100 ms before the stimulus. BTP measures were analyzed for both frequent and rare stimuli at each location. In order to obtain the amplitude reading, it was necessary to position the cursor at the point of the peak. Data for latency measurements were displayed for the onset of the stimulus to the data point placement of the cursor.

P300 latencies

To determine whether PWS and PWNS participants would differ in hemispheric activity, a 3-way repeated measures Analysis of Variance (ANOVA) was computed with electrode site (right or left parietal), type of stimuli (tone, VOT across-boundary, POA across-boundary, VOT within-boundary, POA within-boundary), and participant group as factors. The dependent variable was P300 latency. A Huynh-Feldt correction was used to guard against lack of sphericity. Results did not show significant differences in P300 latencies between the groups, {$F(1, 44)=0.46$, $p=0.50$}, electrode sites {$F(1, 16)=0.03$, $p=0.88$}, or type of stimuli {$F(2, 38.5)=0.78$, $p=0.48$}. Although P300 latencies did not reach statistical significance, PWNS did have longer latency times for every stimulus condition across both right and left parietal sites with the exception of the tone stimulus on the left parietal site.

P300 amplitudes

In order to investigate whether PWS have greater P300 amplitude measurements in the right parietal area than PWNS, a three-way repeated Analysis of the Variance (ANOVA) was performed on the amplitude data. The three factors were electrode site, stimulus type, and participant group. The 3-way ANOVA revealed a significant effect of stimulus type {$F(2.54, 40.67)=9.13$, $p<0.001$} and a significant interaction between electrode site and group {$F(1, 16)=8.4$, $p<0.010$} (Table 3). To explore the interaction, a one-way ANOVA was performed on the amplitude data in order to determine if there was a significant difference between amplitude values for left and right hemisphere electrode locations within each group for each condition. The results of the ANOVA computed on data from the PWS and PWNS groups are found in Table 4. P300 amplitudes for the left parietal site were significantly greater for two out of the five tasks for the PWNS group (Table 4). There were no significant differences found for any of the conditions for PWS (Table 4). PWS demonstrated greater amplitudes on the right parietal site than PWNS. This occurred across all stimulus conditions. There were no significant differences between the groups for P300 amplitude measures over the left parietal location.

Further exploration of the electrode site and group interaction consisted of a series of one-way ANOVAs with group as the factor, and electrode site as the variable. The results from these ANOVAs show significantly more right hemisphere activity occurring for the PWS group than the PWNS group. These results are summarized in Table 5.

Discussion and Conclusion

P300 latencies

The current study did not show P300 response latency hemispheric laterality for either PWS or PWNS participant groups. Differences in latency between the right and left hemispheres for the two groups were also not significant for the conditions outside categorical boundaries or within categorical boundaries (those that that varied the POA or VOT). Although the results from the current study did not show statistically significant latency differences between PWS and PWNS, 9 of the 10 stimulus/electrode site pairs revealed longer response latencies

Source	Df	Error	F value	p value (<.05)
Electrode Position	1	16	1.11	0.31
Elec. Pos.-Group	1	16	8.4	0.01
Stimulus	2.54	40.67	9.13	<.001
Stimulus-Group	2.54	40.67	0.44	0.69
Elec. Pos.-Stimulus	3.16	50.66	0.79	0.51
Elec. Pos.-Stim.-Group	3.16	50.66	1.03	0.34
Group	1	44.2	2.3	0.15

Table 3: ANOVA table for amplitude measures..

Condition	PWS p value	PWNS p value
Tone	0.56	0.2
/bA/-/dA/	0.4	0.09
within /bA/-/dA/	0.49	0.03
/bA/-/pA/	0.54	0.03
within /bA/-/pA/	0.47	0.14

Table 4: ANOVA table for R *vs.* L. hemispheric amplitude differences for each condition for PWS and PWNS. (Note: Significance p=0.05).

Condition	Hemisphere	F value	p value
Tone	L	0.03	0.87
	R	4.23	0.05
/bA/ - /dA/	L	0.03	0.86
	R	5.97	0.03
Within /bA/ - /dA/	L	0.05	0.83
	R	10.26	0.01
/bA/ - /pA/	L	0.02	0.89
	R	6.63	0.02
Within /bA/-/pA/	L	0.01	0.92
	R	4.99	0.04

Note: R: Right hemisphere, L: Left hemisphere

Table 5: ANOVA table for R *vs.* L hemispheric differences between PWS and PWNS.

for PWS as compared to PWNS. In two unpublished studies presented at the International Fluency Conference, longer latencies for PWS were reported in response to linguistic and nonlinguistic stimuli [53] and to auditory and visual stimuli [54]. Longer latencies across different sensory systems suggest that longer processing times are needed before making endogenous responses to stimuli. Previous research has hypothesized that people who stutter have reduced auditory processing capacities based on poorer performance on a synthetic sentence identification task [55] and an auditory masking task [56].

P300 amplitudes

P300 amplitudes for PWNS in this investigation show hemispheric laterality for 2 of the 4 speech stimuli conditions, with another speech stimulus condition close to statistical significance. A comparison of Table 4 shows marked differences in the p values representing hemispheric laterality between PWS and PWNS groups. Results from the PWS group showed no trends of laterality for any stimulus condition. These results are consistent with those reported by Morgan and Haynes [27] who did not find a significant difference between the right and left hemisphere areas (C4 and C3) in a tone discrimination task for PWS. The present study extends the results found by Morgan and Haynes [27] to include speech stimuli. In fact, it is the results from the speech stimuli in the current study that show the largest laterality for the PWNS, and, indirectly, the largest difference between the PWS and PWNS groups. For every speech discrimination condition, PWS demonstrated significantly greater right hemisphere activity when compared to PWNS. The results from the speech stimuli suggest that there is greater right hemisphere activity for PWS when processing the speech signal. The results, however, are not conclusive to differentiate whether this greater right brain activity represents processing of the speech signals in less efficient language centers of the brain or represents an over activation of areas over the right hemisphere.

The findings in the present investigation also show that there was significantly more right hemisphere activity for PWS as compared to PWNS. Luper asked how to properly interpret this activity in a published discussion from the Third Banff Conference on the Neuropsychological of Stuttering [56]. The question he proposed was whether reports of greater right hemisphere activity in the literature represented increased emotions or speech anxiety, rather than displaced processing of the auditory or visual stimuli. Research by Kinsbourne and Bemporad [57] has led to the hypothesis that emotional regulation, or emotions that regulate withdrawal or avoidances that may lead to blocks and tense pauses in speech, are lateralized to the right hemisphere. If PWS have more right brain temperament, as Guitar [58] has suggested, along with years of lateralizing avoidance behaviors, greater right hemisphere EEG activity might be manifested even in a less threatening situation. This is an interesting point; however, the majority of the research that has measured right brain activity in PWS has not placed demands on the individual that would elicit any degree of anxiety.

Research findings showing greater right hemisphere activity has led to a process overload theory to the nature of stuttering. [58] Used Positron Emission Tomography (PET) technology to measure brain activity of PWS and PWNS during an oral reading task. These researchers identified equal activity on both the right and left sides of the brain for PWS. They theorized that there is less laterality for specific linguistic tasks (such as speech production and perception) and for nonlinguistic tasks (visual/spatial) for PWS. If both hemispheres of the brain are equally processing linguistic and nonlinguistic information in a multi-modality task, this equal processing could exceed linguistic capacity and a breakdown may occur. This breakdown, they hypothesized, results in stuttering behaviors.

Both the current study and the Morgan and Haynes study [27] have shown a lack of laterality for P300 responses in PWS as compared to PWNS listeners. Results from these studies suggest that interhemispheric activity for PWS may be different from that of PWNS, and suggests that further AEP studies be performed to explore the extent and nature of these differences. These studies also suggest the potential use of AEPs as a less intrusive methodology to examine interhemispheric function in PWS.

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