2. REVIEW OF LITERATURE

All the studies that have used measures of auditory function in stutterers are directed to investigate the cerebral dominance for language and or probe into the anomalies in the auditory pathway. Hence, the following review of research will be dealt with reference to the above mentioned ideas.

2.1 Stuttering and cerebral dominance:

2.1.1 Orton and Travis Theory: Initially Orton (1928) and Travis (1931) proposed that many children go through a stage of disfluency because language has not yet lateralized to the appropriate hemisphere. As the child grows older, the language lateralization process becomes more complete and disfluency disappears. However a subgroup retains their abnormal representations and continues to stutter.

Consequent to Orton–Travis thesis many investigators addressed the prevalence of right and left handedness amongst stutterers, contending that if stuttering were a disorder due to abnormal cerebral laterality, such an abnormality should be reflected in a different matrix of handedness between stutterers and non stutterers. Due to varying definition of handedness and varying methods of ascertaining the presence or absence of stuttering in population, investigators derived conflicting data and arrived at disparate results (Bryngelson, 1935; Milisen and Johnson 1936; Daniels 1940; Spadino, 1941; Meyer, 1945; Despert, 1946).

The Orton – Travis thesis lay fairly dormant until Jones (1966) noted that all four stutterers who were to be operated upon for a cerebral disease became aphasic following Amytal injection in their right or left carotid artery (Wada test; Wada and rasmussen, 1960). This suggested that both hemispheres were contributing significantly to language production. A repeat Wada test elicited aphasia only after injection to the non-operated side. The patients no longer had bilateral speech representation and they no longer stuttered. However subsequent investigations by Andrews, Quinn and Sorby (1972) and Luessenhop, Boggs, Labrowi and Walle (1973) using the Wada technique and controlling for some the confounding variables in the Jones’ study failed to replicate the earlier observation of bilateral motor speech control in stutterers.
Investigations using the Wada technique are difficult to interpret for several reasons: handedness was different; neurological integrity was heterogeneous; onset of stuttering was not always controlled; age of subjects varied; a number of potentially important observations were not always adequately explained (Moore, 1984).

Other methods used in studying hemispheric processing in stutters.

2.1.2 Tachistoscopic Visual Procedures:

Most researchers using Tachistoscopic visual procedures have incorporated meaningful linguistic stimuli in linguistic decision task (Hand and Haynes, 1983; Moore, 1976; Plakosh, 1978). Moore (1976) reported a left field (right hemisphere) preference in most of the stutterers participating in the study.

2.1.3 Electromyographic studies:

Travis (1931) hypothesized stuttering results from the asynchronous arrival of nerve impulses in the bilaterally paired jaw muscles. In 1934, Travis presented EMG data recorded from the left and right masseter muscles of twenty four adult stutterers and non stutterers. He reported that action potentials from normal subjects were “practically identical”, while those from stuttering subjects were “strikingly different”. Other EMG investigations (Morley, 1935; Steer, 1937; Strother, 1935) seemed to support the findings of Travis (1931) and it was believed that competition between the cerebral hemispheres during motor speech behavior resulted in out of phase arrival of action potentials that disrupted speech.

Williams (1955) failed to find significant differences in amplitude and timing of action potentials between the two sides of the jaw in stutterers and non stutterers. Differences found between the stuttering and non stuttering groups were attributed to the excessive muscular tension and different patterns of jaw movements accompanying stuttering. Hence the electromyographic differences seen were viewed as an outcome of stuttering than its cause.
2.1.4 Alpha recordings:

Increased suppression of alpha brain wave frequency (8 to 13 Hz) has been demonstrated over the hemisphere, primarily processing specific kind of information under a specific task condition. An advantage of this procedure being that hemispheric processing using a variety of stimuli including more natural units of language (phrases, sentences and connected discourse) can be studied over time.

**Douglass (1943)** and **Knott and tjossen (1943)** found that stutterers as a group had less percept time alpha in their right occipital area compared to their left occipital areas during silence, while the non stutterers evidenced otherwise.

**Moore and Haynes (1980)** found that comprehension of connected verbal discourse was unaffected in male stutterers who also demonstrated reduced right hemispheric alpha, a finding which could also reflect the right hemisphere’s superiority in processing semantic aspects of language. He suggested that “stuttering may emerge when both hemispheric processing of incoming information and motor programming of segmental linguistic units is in the right hemisphere (a non segmental processor). These processing differences may be related to an inability, under certain circumstances, to handle the segmentation as it relates to motor programming in some stutterers.”

**McFarland and Moore (1982), Moore, Carven and Faber (1982), Moore and Haynes (1980), Moore and Lang (1977), Moore and Lorendo (1980)** found that alpha was suppressed over the right posterior temporo-parietal areas in stutterers. **Moore and Haynes (1980b)** found that stutterers recalled fewer words across word lists than stutterers. These findings may reflect the stutterers’ right hemisphere verbal short term memory to have a shorter span (**Zaidel, 1979**).

**Boberg et al. (1983)** gathered hemispheric alpha asymmetry data from anterior and posterior brain sites before and after treatment. Prior to treatment stutterers showed less alphas over the right posterior frontal region for verbal tasks, while after treatment there was less alpha over the left posterior frontal region. These findings suggest that alpha ratio over frontal motor areas may implicate motor programming aspects of stuttering and that increased fluency accompanying treatment shifts alpha suppression from right to the
left hemisphere. Similar results were reported by McFarland and Moore (1982) who recorded alpha hemispheric asymmetries before and after treatment. The results showed right hemispheric alpha suppression during baseline (relatively high frequency of stuttering) with a gradual and consistent suppression of left hemisphere as fluency increased. This indicates that following treatment, which increases fluency, stutterers apparently show a shift to more segmental left hemispheric processing strategies.

On the other hand Pinsky and McAdam (1980) performed alpha recording on five adult stutterers and five fluent speakers over hemispheres during performance of cognitive tasks, contingent negative variation with either an articulatory or bilaterally symmetrical response and readiness potential with same responses. All subjects showed consistent patterns of cerebral laterality indicative of localization of speech functions in the left hemisphere.

### 2.1.5 Cortical Blood Flow:

Wood, Stumps and Sheldon and Proctor (1980) subjected two stutterers to cerebral blood flow measurements while reading aloud. During disfluent moments both stutterers showed higher cortical blood flow in Broca’s area on the right compared to the left hemisphere. However during fluent speech a greater flow was observed in the left hemisphere as compared to the right. These results provide support to the relationship proposed between stuttered speech and hemispheric processing reported by Boberg et al. (1983) and McFarland and Moore (1982).

### 2.1.6 CT and PET Scans:

CT and PET scans have also been used to study Cerebral Dominance. Wu et al. (1997) investigated the role of the dopamine system using 6-FDOPA for PET on three patients with moderate to severe developmental stuttering in comparison with six normal controls. Stuttering subjects showed significantly higher 6-FDOPA uptake than normal controls in medial prefrontal cortex, deep orbital cortex, insular cortex, extended amygdale, auditory cortex, and caudate tail. Elevated 6-FDOPA uptake in ventral limbic and subcortical regions is compatible with the hypothesis that stuttering is associated with an overactive presynaptic dopamine system in the brain regions that modulate verbalization.
Fox et al (1996) using PET scans showed stuttering induced widespread overactivation of the motor system in both cerebrum and cerebellum with right cerebral dominance. Stuttered reading lacked left lateralized activations of the auditory system which are thought to support the self monitoring of speech and selectively deactivating multiple neural systems for speaking.

Strub and Black (1987) tested two siblings for stuttering for speech language, neurological and neuropsychological functions, dichotic listening, auditory evoked responses. EEG and CT scan asymmetry. The data showed atypical cerebral dominance on variables investigated. CT scans showed atypical asymmetry especially in occipital regions. The above findings suggest hemispheric processing differences between stutterers and non stutterers.

2.1.7 Auditory Evoked Potentials:

Auditory Evoked Potentials have been used for determining the hemispheric dominance as well, to investigate the central auditory processing in stutterers. Some of the studies in which hemispheric processing is investigated through measures of auditory evoked potentials are discussed here. Averaged evoked responses are a neuro-electrical measure of the cortical activity. It is a non invasive technique where changes in cortical electrical activity are averaged over trials.

Ponsford, Brown, Marsh and Travis (1975) used AEPs to investigate hemispheric differences between stutterers and non stutterers. The stimuli used were meaningful words embedded in phrases. Stutterers showed greater inter-subject variance as opposed to normals whose responses were most different in the left hemisphere.

Zimmerman and Knott (1974) recorded the contingent negative variation; Two control conditions with non verbal stimuli (tones) requiring a nonverbal response were compared with two experimental conditions in which meaningful linguistic stimuli (words) were used. In one experimental condition the subjects indicated whether or not they thought they would stutter on the word presented by pushing one of the keys marked “yes” and “no”. In the second condition subjects were instructed to speak each word upon signal. Results revealed differences between stuttering and non stuttering groups for frontal
electrodes placed over Broca’s area on the left and its contralateral homologue on the right. They stated “when processing verbal stimuli, stutterers appear to show more variable inter hemispheric relationship than non stutterers.

Molt and Brading (1994) used a sixteen channel topographic brain mapping procedure to examine hemispheric patterns for dichotically presented consonant – vowel stimuli and noted the P300 and N200 components. No ear advantage were observed between the stutterers and non- stutterers. Stuttering subjects demonstrated significantly less cross hemispheric amplitude differences for the P300 component. Similar results were observed for the N200 component, thus indicating differences in hemispheric activity patterns.

Ferrard et al. (1991) performed simultaneous measurements of P300 brain potentials (using tones of 500 Hz and 2000 Hz as frequent and in frequent stimuli respectively), and laryngeal positioning prior to vocal fold closure and vocal fold vibration. No significant differences were found in the temporal patterning of three activities between the ten stutterers and ten non- stutterers, who participated in the study.

Pinsky and Mc Adam (1980) presented data of the Contingent Negative vibration recording using a non linguistic stimulus (1000 Hz tone) under two response conditions. One condition required subjects to press a button with each thumb simultaneously when a tone stopped. For the second condition subjects uttered a fluent word at the termination of the tone. The results provided insufficient evidence to support hemispheric asymmetries between stutterers and non stutterers. In the various above mentioned studies, differences may well be due to the differences in behavioral tasks and the nature of stimuli used.

2.1.8 Dichotic Listening:

Dichotic listening paradigms have been used in the largest number of investigations exploring hemispheric processing strategies in stutterers. These paradigms, according to some investigators, provide a relatively simple test of the Orton – Travis thesis. The stutterers’ lack of suitable hemispheric dominance should therefore be revealed through an appropriate dichotic test (Rosenfield and Jerger, 1985).

One of the early investigations using dichotic listening was by Curry and Gregory (1969). They tested twenty adult stutters and twenty non stutters as controls, all of who
were reportedly right handed. The dichotic test included in their study were the dichotic word test, dichotic environmental sound test and dichotic pitch discrimination test. The dichotic test involved recognition of pairs of highly familiar consonant-vowel-consonant words presented in groups of six pairs with 0.5 seconds separating each pair. After presentation of each group of six pairs, subjects were to recall twelve words in any order. Seventy five percent of non stutterers demonstrated right ear advantage i.e. their right ear scores were higher that their left ear. This was true for only forty five percent of the stutterers. The mean of absolute difference between two ears in non stutterers was twice as greater as that seen in stutterers.

**Sussman and McNeilage (1975)** employed a dichotic test paradigm and pursuit auditory tracking. Their experiment involved matching the frequency of a variable tone in one ear to the frequency of an externally varied tone in the other ear. The former tone was altered by a transducer attached to the tongue/jaw. Results revealed no differences in the dichotic listening paradigm between stutterers and non stutterers. On the tracking paradigm however, normals had a right ear advantage where as stutterers did not.

**Tsunoda and Moriyama (1972)** conducted the Tsunoda’s cerebral dominance test and standard audiometry on fifty seven adult Japanese stutters. Seventy nine percent of normal control showed a preference for vowel sound in the left ear, but this pattern existed only in about thirty nine percent in stutterers. This suggested the existence of a subgroup among stutterers in whom stuttering may be due to abnormal cortical function resulting from minimal brain damage. No information regarding subjects’ handedness and age was provided.

**Blood and Blood (1989)** compared eighteen male eighteen female stutterers between the ages eighteen to thirty six years, with a matched control group. All subjects were right handed and were to respond to a six item dichotic word test using a gestural double response paradigm. Results revealed significant differences between the stutterers and the controls in the magnitude of ear preference in both male and female stutterers.

**Blood (1985)** investigated seventy six stutterers and seventy six non stutterers in the age range of seven to fifteen years, using dichotically presented synthetic syllables. Results
indicated that although the direction of ear preferences was same for stutterers and non stutterers, the magnitude of ear preferences for the two groups was significantly different. Fifty five percent of the stutterers showed a right ear preference. These subjects formed the largest group followed by the ambilateral group and left ear preference group. According to them reporting mean data for stutterers in dichotic listening paradigms is inappropriate without a sub group and individual data analysis.

**Strong and Frick (1983)** administered dichotic CV listening task to ninety right handed boys in the ages of five, seven and nine years, half of the subjects being stutterers and other half being non stutterers. Two and half times as many stutterers as non stutterers were found to display either a left ear or a no ear advantage.

**Quinn (1972)** investigated hemispheric processing using the dichotic listening paradigm in sixty eight right handed stutterers and age/sex matched controls. No significant differences between the two groups were observed.

**Dorman and Porter (1975)** evaluated sixteen right handed adult stutterers with the controls on a task if writing down the responses to synthetically generated CV dichotic stimuli. There was no marked difference between stutterers and non stutterers.

Also, **Slorach and Noehr (1973)** examined fifteen stutterers in the age range of six to nine years. They presented dichotic digit pairs and tested not only free recall of digits but also reports from stutterers as to what digit they heard in which particular ear. Stutterers’ scores were akin to those of controls.

**Gruber and Powell (1974)** tested twenty eight right handed fluent and disfluent children using dichotic digit pairs. Free recall reports of both the groups failed to reveal significant differences between them. Here, one should note that since four percent of children stutter and only one percent of adult stutter, the mechanism/ type of stuttering may be different from that among adults.

**Manning and Reinsche (1978)** tested the auditory assembly abilities of thirty stuttering and thirty non stuttering children from first to fourth grade matched for age, grade level, sex and misarticulations. They were presented with meaningful consonant vowel consonant syllables with four silent interphonemic intervals (100, 200, 300, and 400 msecs). There was no significant difference in overall performance between the two groups.
Pinsky and McAdam (1980) tested five adult stutterers and five fluent speakers, all of who except one (stated to be “weakly right handed”) were right handed. Both groups yielded similar scores on the dichotic listening procedure.

Thus, studies using dichotic listening paradigms have yielded conflicting results regarding cerebral dominance in stuttering, one of the reasons being an array of contaminating variables influencing the results. Some of these are: handedness, order of reporting sounds as per instructions and failing to confirm ear advantage by employing a test retest experiment (Rosenfield and Jerger, 1985).

The non-auditory tests conducted to determine the cerebral dominance in stutterers have indicated insufficient cerebral dominance for language. However the audiological investigations have yielded equivocal results.

2.2 Stuttering and Auditory feedback:

The notion that stuttering might be due to a defect in the auditory feedback mechanism has been discussed by several authors (Fairbank, 1954; Mysak, 1960; Butler and Stanley, 1966; Timmons and Boudreau, 1972). The central nervous system dysfunction can affect the auditory feedback and fluency relationships in one of the two ways (Toscher and Rupp, 1978).

• A neurological dysfunction may block or distort the feedback signal or it may cause an inability to rectify correctly the observed disfluency.

• The feedback might be distorted before or during its transmission through the neurological system by non neural physiological factors.

2.2.1 Phase disparity between AC and BC tones:

In 1957, Stromsta exploited the fact that two pure tones, 180 degrees out of phase but equal in frequency and amplitude, will cancel each other out. Stutterers and normal speakers listened to an AC tone introduced to the ear and to a bone conducted tone of the same frequency simultaneously introduced at the teeth. Subjects were asked to vary the phase and amplitude of the AC tone until a critical adjustment was achieved at which no
sound was audible to them. There was a significant difference between stutterers and non stutterers in the relative phase angle of the AC and BC sounds at 2000 Hz.

Using a similar method, Stromsta (1972) noted an unusual phase disparity between stutterers’ left and right ears. The stutterers adjusted the amplitude and phase of the two AC tones heard in either ear, until they cancelled an identical BC tone. At the point at which cancellation was achieved, the air conducted tones of the two ears had a phase disparity at several frequencies that was twice as wide for the stutterers as for the non stutterers. Stromsta (1957) concluded that that stutterers as group tended to differ from normals in transmission of feedback signals.

2.2.2 Acoustic reflex Studies:

The acoustic reflex due to its concurrent presence/initiation during the vocalization process was investigated by some authors. Webster and Lubker (1968) suggested that temporal abnormalities of the acoustic reflex unique to stutterers changes the synergy/ synchrony of air and bone conducted components of the speech signal in a way as to initiate and maintain stuttering behavior.

Shearer and Simmons (1965) investigated stapedius muscle activity in stutterers and non stutterers during ongoing speech. In stutterers, the parallelism between stapedius muscle activity and vocalization was less consistent. The muscle activity seemed to be delayed with respect to vocalization. In general, however difference between the two groups was not striking.

Hall and Jerger (1978) compared the acoustic reflex to external sound in stutterers and controls. Reflex threshold was equivalent in the two groups, but reflex amplitude was smaller in the stuttering group. Hannley and Dorman (1982) however failed to note any difference between stutterers and non stutterers.

These findings do not clarify the relationship between acoustic reflex and stuttering.
2.3 Tests of Central Auditory Dysfunction:

The auditory feedback defects in stutterers might only be part of a more comprehensive disorder of function in their central auditory perceptual mechanism (Rosenfield and Jerger, 1985). A number of investigators have attempted to explore this question using clinical audiometric measures and techniques developed specifically to assess the central auditory dysfunction. Both behavioral and electrophysiological techniques have been used for this purpose.

2.3.1 Behavior tests:

In 1959, Rousey et al. investigated sound localization abilities in twenty normal, seven hemiplegic, twenty stuttering and twenty emotionally disturbed children to reveal a relatively poorer sound localizing ability. Gregory (1964) further pursuing audiometric studies contended that there was no significant difference between adult stutterers and non-stutterers in tests of sound localization, binaural loudness balance and understanding of speech by frequency filtering. This was supported by Kamiyama (1964) and Asp (1968).

The findings with regard to the tests to central auditory processing are conflicting. However, it is suggested that a test battery approach be followed in assessing the central auditory functioning in stutterers as it permits comparison of the performance on several measures of auditory function (Hall and Jerger, 1978).

2.3.2 Electrophysiological tests:

Auditory evoked potentials have been used for determining the hemispheric dominance as well to investigate the central auditory processing in stutterers. Some of the studies in which hemispheric processing is investigated through measures of auditory evoked potentials are discussed here. Auditory evoked responses are a neuro-electrical measure of the cortical activity. It is non invasive technique where changes in cortical electrical activity are averaged over trials.
2.3.2.1 Auditory evoked brainstem responses (ABR):

ABR have yielded inconsistent evidence of a deficit in the auditory pathway between the cochlear nucleus and brainstem in people who stutter. The findings of prolonged conduction time in a variety of the individual components I-V have been reported for adults who stutter relative to fluent adults (Blood & Blood, 1984; Khedr, Abd El-Nasser, Abdel Haleem, Salama Bakr, & Trakhan, 2000). Interpeak latency differences for components I-III (Khedr et al., 2000) and I-V (Khedr et al., 2000; Smith, Blood, & Blood, 1990) have also been reported. Two other studies found no group differences in ABR (Newman, Bunderson, & Brey, 1985; Stager, 1990). Interestingly, although Khedr et al. (2000) found delays in the individual and interpeak latencies of the ABR in adults who stutter, the early latency cortical auditory responses were reportedly normal. The small number of studies examining ABRs in people who stutter, and the inconsistent findings, preclude the ability to make any conclusive statements about the functionality of the early auditory pathways in this population. However, based on the work of Khedr et al. (2000) it would appear that even if differences in the ABRs of adults who stutter exist, the impact on measurements of later cortical components is minimal.

Blood and Blood (1984) performed ABR on eight adult stutterers (four severe and four moderate) and eight non stutterers. Stutterers demonstrated prolonged central conduction time as measured by interpeak latency difference between waves I to V. Five of the stutterers showed abnormal responses unilaterally, while three of the subjects showed abnormal responses bilaterally. No relationship was found between ABR responses and the severity of stuttering.

Stager (1990) measured interpeak latency differences between waves I and V, amplitude ratio between waves V and I and latency shifts in wave V between low and high stimulus repetitions rates in ten male stutterers and twelve male non stutterers (with normal hearing sensitivity). As a group stutterers did not differ significantly from non stutterers on any of the measures. Individually, half of the stutterers demonstrated latencies greater than two standard deviation from non stutterers’ means on at least one measure.

Newman et al. (1985) obtained ABR responses of both the ears of active stutterers, recovered stutterers and non- stutterer, both male and female adults, at click rates of 11.1
and 71.1 per second. No significant differences were obtained between stutterers and non stutterers. However female subjects (stutterers and non – stutterers) showed faster neural conduction times than males.

**Smith, Blood and Blood (1990)**, recorded the ABR responses when subjects engaged in overt speech, whispering, silent articulation and covert verbal rehearsal tasks. Results revealed that the stutterers demonstrated significantly larger wave V to wave I amplitude ratio than non stutterers. However no significant differences were found between stuttering and non stuttering subjects for absolute/ interpeak latencies of the waves during the verbal rehearsal tasks.

### 2.3.2.2 Auditory Middle Latency responses (AMLR):

The results on AMLR have been quite equivocal. **Dietrich et al (1995)** recorded AMLR from ten male stutterers and ten controls using a variety of filter passbands in response to clicks presented binaurally at various rates. The latency of Pb wave was found to be significantly shorter in groups of subjects who stuttered. **Hood (1987)** found latency of wave Pb to be significantly longer for adult stutterers than for controls.

### 2.3.2.3 Late Latency Response (LLR):

**Pool, Freeman and Finitzo (1987)** identified cortical dysfunction over the medial frontal and left temporal cortex in three stutterers using multichannel long latency evoked Potential recording. **Finitzo et al (1991)** tested twenty adult stutterers and examined P1, N1 and P2 components of the auditory evoked responses. They found no significant differences in terms of latency; however amplitude was reduced in mild to moderate stutterers as compared to normals but not reduced for the severe stutterers. Hence a reduction in hemispheric amplitude was noted although reductions were persistently greater over left hemisphere. This suggested a left temporal cortex dysfunction in stutterers.
2.3.2.4 P300:

Andrade et al. (2007) conducted a pilot study aiming to investigate the relationship between stuttering improvement and brain activity, using the assessment of P300 in three PWS. They concluded that this population could show different patterns of inter-hemispheric activity in a task with P300 after Speech-Language therapy.

There is a need for further investigations to contribute in direction of substantiating the findings obtained through electrophysiological tests in the past. There is dearth of studies investigating the auditory pathway at both the brain stem and cortical level in a single subject. Hence doing so would help in determining whether there is any disturbance in the auditory processing of persons with stuttering and identifying the site of dysfunction. Pre and post speech therapy changes in the AEPs may indicate the improvement in the auditory processing at different levels in the auditory system. This finding may indicate the occurrence of functional neuroplasticity, which occurred as a consequence to the speech therapy, reflecting better neuronal promptness for auditory stimuli. The findings may also indicate role of cerebral dominance as more changes in a particular hemisphere may indicate occurrence of better functional neuroplasticity in that side.