Auditory temporal processing in children with stuttering

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Abstract

Purpose: To study auditory temporal processing performance in 30 children with stuttering (CWS) and compare it with 30 age-matched controls. **Materials and Methods:** Auditory temporal processing was compared in two groups of children: With and without stuttering; in the age-range of 9-14 years using Gap Detection Test (GDT) and Duration Pattern Test (DPT). Ear differences in the gap detection thresholds and duration pattern scores were also studied in both the groups. GDT was carried out using the GDT CD developed by Shivprakash and Manjula (2003) and DPT was carried out using the DPT CD developed by Gauri and Manjula (2003). **Results:** No significant difference was seen in the gap detection thresholds and DPT scores between the right ear and left ear scores in typical children and between the scores of the two ears in CWS. The performance of CWS group was significantly poorer as compared to that of typical children in both GDT and DPT. These auditory temporal processing deficits may interfere with the auditory feedback loop that is crucial to fluent speech production. Fluency inducing conditions like slow reading, DAF, or frequency-altered feedback reduce the dependence on auditory feedback thus inducing fluent speech. The results of the present study show that deficient auditory temporal processing in CWS may add to the demands placed on the feedback mechanism thereby increasing stuttering. **Conclusions:** As a group, CWS show evidence of compromise in their auditory temporal processing abilities. Tests of temporal processing should be included in assessment of IWS as a pre-therapy assessment tool along with assessment of stuttering.

Key words: Auditory processing, duration pattern test, random gap detection test, stuttering, temporal resolution

Introduction

Fluent speech is characterized by continuous flow of sounds, syllables, and information; rate of speech; ease of speech production; and rhythmical patterning in terms of temporal sequencing of similar events.[1] Breakdown in this fluency is considered as a fluency disorder or stuttering.[1] Stuttering develops when there is abnormally high occurrence of disfluencies or abnormally long duration of disfluencies in the forward flow of speech.[1] Various theories have attempted to explain the origin of stuttering such as constitutional-based theories, developmental-environmental theories, and integrated theories. Many theories have tried to explain the neurophysiological basis of this disorder. One of them is Mysak's cybernetic theory which is based on servomechanism feedback model.[2] This model contains a sensor, through which part of the output of the machine is fed back to the controller unit. The controller unit contains a comparator, which compares the actual output with expected output. The

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difference between these two is the error signal which modifies the action of the effector unit so that its output approximates the intended one. When applied to stuttering, the sensor unit is the ear, the effector unit are the vocal organs, and their motor innervations and the controller is the central auditory system. Disruption at any level of the model can cause an altered feedback that may result in impaired speech production fluency. When the controller, i.e., the brain by itself has altered neurophysiology or central auditory processing deficit this disintegration effect in verbal output is evident.

One of the important parts of the central auditory system that has a significant role in auditory processing is the planum temporale.[3] The planum temporale extends from Heschl's gyrus on the superior temporal gyrus posteriorly to the sylvian fossa. It is larger in the left hemisphere as compared to that in right hemisphere in typical individuals, i.e., typical individuals show leftward asymmetry of planum temporale, whereas the asymmetry is reversed in individuals with stuttering who show a larger planum temporale in the right hemisphere.[4] This in turn gives evidence that central auditory processing or auditory perception is deviant in stutterers which in turn may lead to speech production deficits. It has been suggested that a poor performance of individuals with stuttering on auditory processing tasks reflects a basic auditory deficit, which hampers fluency because speech is monitored by auditory feedback.[3] This means that, because these individuals do not get appropriate auditory feedback, they develop a misconception that an error in speech has occurred. Stuttering, therefore, results when the speaker tries to correct an error that has not occurred.

There is a vast literature on the central auditory processing disorder in adults and children with stuttering. The studies have used different neuroimaging techniques such as computed tomography (CT) scan, magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), regional cerebral blood flow, etc.;[5,6] electrophysiological tests such as middle latency response (MLR), P300, mismatch negativity (MMN)[7-9] and behavioral tests such as dichotic listening tests, stuttering severity instrument with ipsilateral competing message (SSI-ICM), duration pattern test, metachromatic leukodystrophy (MLD).[10-12] The neuroimaging studies give evidence that stutterers have an anomalous organization of the speech and language areas in the cortex. As compared to typical individuals, individuals with stuttering (IWS) show right hemisphere activation for speech production and to some extent for speech perception along with left hemisphere activation. One study investigated neural activation in stuttered production in IWS vs fluent production in typical individuals. Typical individuals experienced activation in areas like primary motor cortex, premotor cortex, supplementary motor area, rolandic operculum, lateral cerebellum, and auditory areas. IWS showed activation of similar regions of the brain for fluent and stuttered speech but certain differences were evident. Their motor areas such as primary motor cortex, supplementary motor area, cingulate motor area, and cerebellar vermis were over-activated in stuttered speech. Their frontal operculum, rolandic operculum, and anterior insula showed rightward asymmetry and they did not demonstrate activation of auditory areas due to hearing their own speech.[13]

These physiological differences have also been reflected in electrophysiological test findings in IWS. Corbera, Corral, Escera, and Idiazabal compared the MMN potential elicited for tonal and phonetic contrasts in IWS with that recorded in typical individuals. The results revealed that IWS showed no abnormality in MMN elicited by tonal contrasts whereas MMN elicited by phonetic contrasts revealed supratemporal enhancement over the left hemisphere. Further, the augmented MMN was positively correlated with speech disfluencies as self-rated by IWS. They concluded that IWS have abnormal cortical representation for speech sounds which could be the underlying basis of their speech deficit.[4]

Behavioral tests of auditory processing have also been used to compare performance of children with stuttering children with stuttering (CWS) as compared to typical children. LaSalleand Duginske[14] examined auditory processing abilities in five school-aged children with stuttering using dichotic digits test, temporal patterning test, and auditory discrimination test. Their performance was compared with age-matched controls. CWS showed significantly poorer scores only on the auditory discrimination subtest. Their preliminary findings suggested that CWS are not different from typical children on temporal processing abilities especially temporal patterning. However, contrasting results were noted by Howell, Davis, and Williams[15] who studied temporal processing in CWS using backward masking. The auditory sensitivity of thirty CWS was evaluated on absolute threshold, simultaneous masking, and backward masking using broadband and notched noise maskers. The participants were assessed again after 2 years to reveal that 12 participants showed persistent stuttering while 18 participants had recovered. The results revealed that the persistent stuttering group had significantly poorer threshold for the broadband backward-masking task as compared to the recovered group. They concluded that the backward masking performance at teenage could be used to separate speakers who persist in their stutter from those who recovered from stuttering. Further, Deshpande[16] evaluated temporal processing using duration pattern test and gap detection test in IWS and typical adults, and showed that the groups differed significantly on duration pattern test (DPT) scores and gap detection (GD) threshold (GDT). They concluded that temporal processing abilities are compromised in IWS which needs to be taken into consideration along with assessment of stuttering.

Auditory temporal processing refers to the perception of the temporal envelope or the change in durational characteristics of a sound within a defined time interval.[6] Auditory temporal processing necessitates precise durational clues of the signal and is a prerequisite for higher order skills of speech perception and spoken language processing. Specifically, the temporal processing skills are crucial for the perception of voice-onset-time, lexical and prosodic differences, and auditory closure.[4]

Van Riper claims stuttering to be a speech timing disorder.[17] Salmelein used magnetoencephography to show that while fluent participants showed activation of left frontal brain areas involved in language planning prior to the activation of central areas underlying speech production, this sequential pattern was absent or reversed in IWS.[18] Thus, it is important to study if the deficit in speech production timing is linked to the deficits in auditory temporal perception. This is justified by the fact that changes in speech production temporal patterns such as prolongation, chorus reading, and delayed auditory feedback reduce stuttering. Further, there is need to study temporal processing in CWS as less work has been done on CWS and the results of different studies are contradictory. Present study has used behavioral tests like gap detection test and duration pattern test to assess temporal processing in CWS as both tests are standardized on Indian population. Also, they are easily accessible for use and are non-linguistic thereby, suitable for administering in a multi-lingual culture like India.

The study aimed at studying temporal processing performance using GDT and DPT in CWS. Ear differences in the gap detection thresholds and duration pattern scores were also studied in both the groups.

Materials and Methods

This prospective quasi-experimental study was conducted at the audiology and speech therapy department of a hospital in Mumbai. It was approved by the institutional ethics committee. The study protocol was in adherence to the approved procedure by the ethics committee. Informed consent was taken from all the participants of the study.

Participants

Two groups of 30 children each in the age-range of 9 to 14 years participated in the study. Control group included typical children with no known speech and language disorder. The experimental group included 30 CWS as diagnosed by the investigators using stuttering checklist.[19] Their severity of stuttering varied from very mild to severe as indicated by stuttering severity instrument.[20] All participants had normal hearing sensitivity from 250 Hz to 8000 Hz (thresholds within 25 dBHL); no significant middle ear pathology based on A type tympanogram and presence of acoustic reflex; and average or above average scholastic performance. Children with concomitant speech, language, hearing, and/or learning disorders were excluded from the study.

Test material and instrumentation

Pure-tone Audiometry was carried out using Interacoustics AC-40 clinical audiometer with TDH 39P earphones and MX-41/AR cushions and Radio ear B-71 bone vibrator in a sound-treated room. GDT were determined using the GDT developed by Shivaprakash and Manjula[21] at the audiology department of the All India Institute of Speech and Hearing, Mysore. DPT was carried out using the DPT developed by Gauri and Manjula[22] at the Department of Audiology of the All India Institute of Speech and Hearing, Mysore. Both the materials had been recorded on compact discs. A Panasonic Sign model SG-888A CD player was used to play each CD. The output was amplified by connecting the CD player to inter-acoustics model AC-40 clinical audiometer and were presented via TDH 39 earphones housed in MX-41/AR cushions. Audio-recording for computing the stuttering severity was done using a Transcend MP320recorder.

Procedure

Pure-tone audiometry was carried out in a sound treated room using modified Hughson-Westlake procedure. Stuttering assessment was done for experimental group using SSI to compute the severity of stuttering using recorded speech sample.

GDT was administered for both groups by seating the participants comfortably in a sound treated room and instructing in the language understood by them. The test was carried out at an intensity level of 50dBSL (ref: PTA) with the right ear tested first followed by the left ear. The test consisted of 3 trial items and 54 test items. Each item consisted of 3 noise bursts of 300 msec in duration and separated by a silence of 750 msec. Out of the 3 noise bursts 2 were continuous and 1 was discontinuous, i. e., had a gap. The gap was introduced at the center (50% of total burst duration of each noise burst). The duration of gap within this noise burst was varied from 20 to 1 msec (20, 18, 16, 14, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1). The duration of gap was reduced in 2 msec steps from 20 msec to 11 msec and in 1 msec steps from 11 msec to 1msec. Three presentations were made at each gap duration. Six catch trials were included to reduce false positive responses. The participant had to respond in three alternate forced choice paradigm, i. e., had to indicate which noise burst out of the three noises was discontinuous. The smallest gap that he/she could detect was determined and was called the "GDT threshold."

DPT was also administered for both the groups. The test was carried out at an intensity level of 50 dBSL (re: PTA) with the right ear tested first and then the left ear. The test consisted of few trial items followed by thirty test items. Stimuli consisted of short (250 msec) and long (500 msec) tones of 1 kHz which were presented in a three tone sequence, e. g., 250 msec-500 msec-500 msec. The three tones were separated by 250 msec from each other. Total of six such patterns were possible (i. e., long long short, long short long, long short short, short long short, short short long, and short long long). The participant had to respond verbally in terms of duration of stimuli (short-long-long). No repetitions were provided. In instances where the participant was not responding verbally or could not comprehend the instructions, he/she was given visual analogy by drawing two lines, one long and one short, and participant had to point out the sequence using the visual analogy.

Scoring

In GDT, responses were scored by calculating the gap detection threshold by identifying the smallest gap at which the listener is able to identify the discontinuous tone consistently (at least 2 out of 3 presentations). Catch trials were not included in the scoring. Similarly, DPT test scores were expressed in percentage correct per ear. The number of correct responses were divided by the total test stimuli, i. e., 30 and then multiplied by 100 to compute the percentage correct per ear.

Results

The data on GDT and DPT was collected from 30 participants of both groups. Descriptive statistics of mean and standard deviation (SD) were computed [Tables 1 and 2].

As it is seen that two times the value of standard deviation was less than mean value, the data was assumed to be normally distributed was subjected to parametric statistical tests. Results were evaluated at 0.05 level of significance. Although results of DPT are plotted in percentages, statistical analysis was done using raw scores to minimize type I error.

Analysis of results between the ears for both groups

Paired two-tailed *t*-test was applied to analyze differences in scores of right ear vs left ear on both the tests in both the groups. The results indicated that there was no significant difference in the gap detection thresholds [t (29) = 0.75, $P > 0.05$] and DPT scores [t (29) = 1.97, $P > 0.05$] of the right ear vs left ear of typical children. Similarly, CWS group also showed no difference in results in the right ear vs left ear for gap detection thresholds [t (29) = 0.00, $P > 0.05$] and DPT scores [t (29) = 0.71, $P > 0.05$].

Analysis of results between the two groups

Ten children with stuttering had gap detection thresholds poorer than mean normative scores + 1 SD as opposed to two typical children. On DPT, 11 CWS scored below mean normative scores -1 SD as opposed to two typically developing children who scored below mean normative scores -1 SD.

Unpaired two-tailed *t*-test was applied to analyze differences between typical children and CWS on both the tests. The results indicated a significant difference between typical children and CWS on both the tests. In GDT, there was significant difference between the two groups in their right ear scores [t (58) = 2.79, $P < 0.01$] and left ear scores [t (58) = 2.30, $P < 0.05$]. Similarly, statistically significant difference was also noted between the study groups on DPT in their right

Table 1: GDT in typically developing children and in CWS

	Mean RGDT (ms)	SD (ms)
Typical children	3.3	0.53
CWS	3.93	1.11

GDT: Gap detection test; CWS: Children with stuttering

Table 2: DPT scores in percentage in typically developing children and in CWS

	Mean DPT	SD
Typical children	79.15	10.52
CWS	68.57	14.49

DPT: Duration pattern test; CWS: Children with stuttering ear scores [t (58) = 2.68, $P < 0.01$] and left ear scores [t (58) = 2.65, $P < 0.01$].

Discussion

The present study revealed no statistically significant difference in the right ear vs left ear on gap detection thresholds and DPT scores in typical children as well as CWS. These findings are in agreement with previous research.[9,16,21-23] These results may be obtained because of monotic stimulation used in both the tests. Monotic tests are useful for detecting alteration in auditory pathways but cannot specify the site of lesion. During monotic stimulation both ipsilateral and contralateral pathways are activated because of which there is lack of localization resulting in a similar performance by both ears. This may suggest that both the hemispheres are equivalent in their temporal processing ability.[24] On the contrary, Brown and Nicholls[24] analyzed gap detection using reaction time to the presence of gaps in broadband noise and reported a right ear advantage over the left ear thus suggesting that left hemisphere is superior in processing rapid temporal changes. They concluded that gap detection thresholds might possibly mask the right ear advantage, which maybe more evident in the reaction time analysis.

Comparison between CWS and typical children

The present study showed deficits in the temporal processing abilities in CWS compared to typical children as measured on GDT and DPT which is in accordance with the study by Deshpande[16] in adults with stuttering. Deficits in temporal resolution may lead to severe impairment in the perception of rapid changes in speech leading to speech and language impairments as well as reading impairments especially in children.[22] Individuals with temporal patterning deficits may show difficulty recognizing and using prosody of speech due impaired perception of rhythm, stress, and intonation. These deficits at the auditory level may interfere with the auditory feedback loop that is crucial to fluent speech production. Further support for the role of auditory feedback in speech fluency comes from the observation that many stutterers show paradoxical reduction in their disfluencies using delayed auditory feedback (DAF). Fluency-enhancing behaviors like chorus reading, rhythmic speaking, and singing reduce temporal uncertainty and provide time for the preparation of temporal programs.

Foundas *et al*.,[25] conducted a study to determine if people with persistent developmental stuttering associated with atypical auditory temporal cortex showed changes in their stuttering when they were given delayed auditory feedback as compared to control subjects. They classified stutterers into two groups: Those with typical leftward asymmetry of planum temporale (PT) and those with atypical PT symmetry and used DAF with both groups. They noted that controls and the developmental stuttering group with typical PT asymmetry showed no change in stuttering with DAF, whereas the stuttering group with atypical PT asymmetry demonstrated significantly improved fluency associated with DAF. They proposed a two-loop model to explain their results. According to this model, fluent speech production is the result of co-ordinated working of two neural networks. They are an outer "linguistic" and an inner "phonatory" loop or circuit. The outer linguistic circuit is concerned with phonologic, lexical, syntactic, and semantic language functions and is crucial in auditory feedback. In contrast, the inner circuit is responsible for the motor programs of the vocal apparatus and controls the speech output. Foundas *et al*., explained that the outer linguistic loop included the PT, the inferior parietal lobe (PAR), and frontal language areas: Pars triangularis (PTR) and pars opercularis (POP). The inner phonatory loop involved cortical and subcortical motor areas. The inner and outer loops link to the final common pathway for speech output. This speech output is fed back to the auditory temporal areas Stuttering is thought to be a result of disruption in the timing between activation of these two networks. Fact that delayed auditory feedback helped IWS showed that they probably had slower inner loop as compared to the outer loop and DAF slowed the outer loop thereby maintaining timing synchronization in the loops and thereby induced fluency.

The importance of feedback mechanism in stuttering is also highlighted by the work of Civier and Guenther who proposed a neural model for speech production—Direction of Velocities into articulators (DIVA).[26] They believed that fluent speech production is so quick that it cannot be controlled by a feedback mechanism alone; rather it is mediated by feed forward projections that are finely tuned by auditory feedback loop. They suggested that stutterers had deficient feed forward mechanisms thereby necessitating greater reliance on auditory feedback. The simulation model demonstrated that an over-reliance on feedback control resulted in stuttering-like behavior. As auditory feedback control is absent before phonation starts, frequency of blocks are greater at the initial sound of a word. Fluency inducing conditions like slow reading, DAF, or frequency-altered feedback reduced the dependence on auditory feedback thus inducing fluent speech. The results of the present study show that deficient auditory temporal processing in CWS may add to the demands placed on the feedback mechanism thereby increasing stuttering.

It would be interesting to study in the future if the performance of CWS on auditory temporal processing tests improves after use of DAF. If so, it would provide further evidence to the relationship of auditory temporal processing and stuttering.

Conclusions

Thus, we can conclude that as a group, CWS are compromised in their temporal processing abilities. This implies that tests of auditory temporal processing can be included in assessment of IWS as a pre-therapy assessment tool along with assessment of stuttering. Hence, a tailor-made treatment can be considered focusing on a holistic approach by giving traditional therapy as well as treatment specifically to improve temporal processing. Further studies can explore the association of severity of stuttering with temporal processing abilities. Effect of therapy on temporal processing can also be studied.

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