The cerebral dominance and laterality preference in adults with persistent developmental stuttering

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Abstract

Stuttering is reported to be the consequence of aberrant cerebral laterality in the processing and production of speech. The previous studies involving undirected attention to the stimuli during dichotic listening tests vary with their procedure and method, yielding inconclusive statements about the laterality of speech processing in persons with stuttering (PWS). This is also true with other laterality measures using imaging procedures, leading to equivocal results. Hence, there is a need to study the speech processing in PWS on a large sample using techniques that are more economical and simpler. The present study, a part of a large scale project, aimed to investigate the differences, if any, with respect to the handedness, footedness, ear and eye preference and the lateralization Index (LI) scores among PWS compared to persons with no stuttering (PWNS). Participants were 50 PWS and to PWNS in the age range of 18 to 30 years. All the participants were screened for hearing acuity and administered Modified Laterality Preference Schedule (MLPS) followed by Dichotic Consonant Vowel (CV) Test in Kannada Language. The statistical analysis showed no significant difference in the mean values of scores between PWS and PWNS on MLPS. However, the dichotic CV test results showed statistical significance. The findings partially support observation by many authors that the left laterality of the speech motor system is incomplete in PWS where there is reduced left hemisphere activation, bilateral activation or wide spread right hemisphere bias when listening to verbal information.

Key words: Dichotic listening, Lateralization Index (LI), Laterality preference, Handedness, Cerebral dominance

Introduction

Stuttering is a most fascinating speech fluency disorder that typically appears between the age range of 2 and 4 years and is characterized by sound and syllable repetitions and audible and silent prolongations. There are several theories and models proposed by researchers to understand its nature, etiology and characteristic features. The cerebral dominance theory (Orton, 1928 & Travis, 1931) is one of the oldest, yet most investigated theories contemporarily. According to this, stuttering is a consequence of aberrant cerebral laterality in the processing and production of speech. Several investigators have tried using many invasive and non-invasive procedures to compare children and adults with stuttering with respect to their laterality, suspecting a strong link between the two. Invasive methods include WADA test, Positron Emission Tomography (PET) and cerebral blood flow studies. Non invasive methods include laterality testing (handedness/eye/foot), dichotic listening tests, functional magnetic resonance imaging (*f*MRI), event related potentials (ERP"s), and electroencephalograph (EEG).

Researchers have also found the pre and post therapy changes for shift in hemispheric dominance, especially after therapeutic management of stuttering. Stromsta (1964), in his study using electroencephalograms (EEG), suggested a difference between PWS and normal group in terms of hemispheric dominance. The studies using the Wada test (intra-carotid sodium amytal test), also showed diverse results where one of the studies found bilateral speech representation in four PWS who underwent surgery for brain injury (Jones, 1966). Andrews, Quinn and Sorby (1972) reported normal left cerebral dominance in adult PWS.

Several neuroimaging studies have presented clear evidence of neural activation differences between PWS and PWNS. PET studies investigated the neural systems of stuttered speech, anomalous anatomy along the superior bank of the Sylvian fissure in PWS. These anomalies showed an increase in the bilateral supra-sylvian opercula gyrification, minor differences in the sulcal boundaries configuration of the Pars triangularis portion of the inferior frontal gyrus, and the presence of a doubled diagonal sulcus in the Pars opercularis (Foundas, Bollich, Feldman, Corey, Hurley, Lemen & Heilman, 2001). Several investigations have also explained regarding alterations of cerebral asymmetry patterns in persons with persistent developmental stuttering (PDS). The findings of the study included atypical patterns of lobar width asymmetry and Petalia in both the occipital and frontal lobes (Strub, Black & Neaser, 1987). An increase in the size of Planum temporale with an overall reduction in the degree of leftward asymmetry (Foundas et al. 2001), and atypical pre- frontal and occipital lobe volume asymmetries that deviate from expected distributions in healthy individuals was also noted by Foundas, Corey, Angeles, Bollich, Crabtre-Hertman & Heilman, (2003).

In another study by Paus, Petridesm, Evansa, and Meyere, (1993), PWS and PWNS depicted clear differences in lateralization of cortical regions involved in speech production. The speakers with no stuttering showed a pattern of largely unilateral left hemisphere activation, including Broca's area, and primary sensori-motor and temporal cortex. The speakers with stuttering also explained a similar activation pattern; however that was clearly lateralized to the right hemisphere. Also, over-activations of the motor system and right lateralization of primary and extra primary motor cortices were detected, along with an absence of left- lateralized activations of the auditory system (Fox, Ingham, Ingham, Hirsch, Downs, Martins, Jerabek, Glass & Lancaster, 1996). Subsequent investigations using PET in PWS along with stuttering performance correlations reported a similar lack of left hemisphere speech-motor lateralization during stuttering, bilateral deactivations in the auditory association area were also reported (Braun, Varga, Stager, Schulz, Selbie, Maisog, Carson & Ludlow, 1997; Fox, Ingham, Ingham, Zamarripa, Xiong, & Lancaster, 2000).

Structural imaging studies in PWS showed aberrant features of white matter tract connectivity and right-hemispheric white matter volume; accompanied with atypical perisylvian anatomy and cerebral asymmetry patterns. A decline in fractional anisotropy in the left Rolandic operculum of PWS had been detected with diffusion tensor imaging (Sommer, Koch, Paulus, Weiller & Buchel, 2002). These findings were interpreted as white matter disconnections within the left hemisphere that might obstruct the sensori-motor integration necessary for fluent speech production. Studies on One voxel-based morphometry (VBM) reported an increase in right hemisphere white matter volume in the superior temporal gyrus, the precentral gyrus, the Pars opercularis portion of the inferior frontal gyrus, and the middle frontal gyrus of PWS (Jancke, Hanggi & Steinmetz, 2004). However, the above study did not detect any gray matter density or cerebral volume differences or any white matter anomalies in the left hemisphere of participants with developmental stuttering.

The findings of all these neuro-imaging studies are intriguing and suggest that structural differences in PWS may relate to the abnormal functional activity of stuttered speech. The procedure for imaging studies are more tedious, expensive and not possible to use in daily clinical settings. In this perspective there is a need to use alternate methods to study the speech processing in PWS through more cost effective means. Kimura's dichotic listening theory and testing provided some direction into this. Kimura (1961) attributed the right ear advantage (REA) to the specialization of the left hemisphere for speech and language processing, which is seen in majority of normal individuals. The contra-lateral pathway from the right ear to the left temporo-parietal lobe is more effective than the ipsi-lateral pathway. Concurrently, the left ear advantage (LEA) is attributed to the specialization of the right hemisphere for nonverbal processing. Curry and Gregory (1969) tested PWS and they evidenced better left- ear than right-ear advantage on a dichotic word task in them compared to PWNS.

The dichotic listening performance in adults with and without stuttering as a function of gender and handedness was investigated by Foundas, Bollich, Feldman, Corey, Lemen, and Heilman, (2004). The participants were grouped according to gender and handedness. The results indicated that for the adult PWNS, gender and handedness had no influence on any of the dichotic listening tasks. However, the study reported mixed cerebral dominance in an adult PWS.

Asbjornsen and Helland (2006) reported that when two differing linguistic stimuli in the form of a consonant-vowel (CV) are simultaneously presented, there is typically a REA. This REA is found for both right-handed and left-handed individuals. However, speech-language dominance, along with lateral processing has been found to be less robust for left-handed people (Bryden, Munhall, & Allard, 1983). Some of the previous studies reported of no evidence of a higher incidence of left handedness in PWS compared to that found in the general population (Records, Heimbuch & Kidd, 1977; Webster & Poulos, 1987).

A recent study conducted by Deepika and Geetha (2012) compared the performance in 10 children with stuttering (CWS) between the age range of 7 to 11 years and 30 typically developing children of the same age range on dichotic CV and modified laterality preference schedule (MLPS) tasks. There was no significant difference observed between both the groups of participants on modified laterality preference schedule in terms of hand, eye, ear and leg preferences. However, a significant difference was observed on dichotic CV test in the participants of both the groups. CWS showed more left ear advantage compared to typically developing children who exhibited right ear advantage, which implied laterality differences.

Sowman, Crain, Harrison, and Johnson (2014) noted that a common finding in the numerous studies on brain imaging and other techniques is the shift observed in the speech related brain activity to the right hemisphere in adults who stutter. They further suggest that hyper activation of right hemisphere could be a reflection of neuro-plastic adaptation rather than the cause of stuttering. The authors confirm this observation based on their magneto-encephalographic picture naming study in fluent and non-fluent preschool children.

Thus, there are still unanswered questions regarding the laterality issues as some studies have identified bilateral anomalies (Foundas et al. 2001, 2003), left-lateralized anomalies (Sommer et al. 2002), or right-lateralized anomalies (Jancke et al. 2004). Moreover, not all studies have observed these abnormalities to be present in all PWS (Foundas et al. 2001, 2003). The imaging studies have given more equivocal findings. However, dichotic listening test is one of the noninvasive and more economical tests used to determine perceptual biases and assess brain lateralization and asymmetry. Also, there are other non invasive techniques to measure laterality like the Modified Laterality Preference Schedule (MLPS). The MLPS measures laterality with regard to eye, ear and foot preferences, in addition to ear preference. Hence, it may provide additional information regarding laterality. But the studies are limited on this and more so comparing persons with and without stuttering. Hence, there is a need to study lateralization and the speech processing during dichotic listening tests in persons with stuttering compared to their peer group.

In this perspective, the present study, part of a larger study investigating the altered auditory feedback effects in persons with and without stuttering, was undertaken with the main aim to investigate the laterality differences, if any, with respect to adult PWS and PWNS. The specific objectives of the study were:

1. To investigate the differences, if any, with respect to the handedness, footedness, ear and eye preference among PWS compared to PWNS using Modified Laterality Preference Schedule (MLPS)

2. To investigate if the lateralization Index (LI) scores, based on Dichotic Consonant Vowel test in Kannada language, differ with respect to PWS and PWNS

Method

Participants: The participants in the study included 50 PWS in the age range of 18 to 30 years and age and gender matched 60 individuals in the control group (PWNS). The PWS were diagnosed by qualified SLPs to have moderate and above severity of stuttering based on Stuttering Severity Instrument (SSI-3). All the participants were native speakers of Kannada. The participants of both groups were screened to rule out for hearing and any other psychological and neurological deficits.

Materials: A Checklist to elicit demographic and other details from the participants was prepared for the purpose of collecting details from the participants which consisted of demographic and other information. In addition, for PWS the checklist also included questions regarding onset and development of stuttering, family history of stuttering, situational variability in stuttering and severity of stuttering. Stuttering severity Instrument (SSI-3; Riley, 1994) was used for assessing the severity of stuttering in persons with stuttering based on the frequency, duration and physical concomitants of stuttering instances. The Modified Laterality Preference Schedule (MLPS; Venkatesan, 1992), with a series of tasks to be performed by the individual, for checking the hand, foot, eye and ear preference by the individuals while performing certain tasks was also administered on all participants. This test not only provides information regarding laterality but also regarding the preferred hand, foot, eye and ear. This is a simple, non-invasive and less time consuming procedure used for measuring laterality. The Dichotic Consonant Vowel Test in Kannada language (Yathiraj & Maggu, 2012), a standardized test was used to find the ear preference in individuals. The stimuli of 30 CV combinations are presented to both the ears simultaneously and the participants are made to write down the perceived stimuli coming from both the ears.

Procedure: The study obtained clearance from the AIISH ethics committee for bio-behavioral research. After obtaining consent from the participants, general history including onset related and therapy related information was collected from PWS. Information was also elicited to rule out any associated hearing, psychological and neurological problems from all the participants. The control group participants were also screened and administered the checklist to ensure no associated problems. The MLPS was administered to check laterality preferences. The participants were instructed to carry out thirty activities to document their preferred hand, foot, ear and eye for the selected tasks. This schedule includes 30 tasks (18 hand related; 6 foot related; 4 eye related and 2 ear related tasks). A score of 1 was given for each task with respect to the participant's preferred side (right/left/ ambidextrous) and scores were totaled and percentage was calculated to obtain laterality index as per the instruction manual of the test. This was followed by Dichotic Consonant Vowel (CV) Listening Test in Kannada Language. The stimuli consist of six stop consonants (pa, ta, ka, ba, da, ga). The test employed undirected attention skills in which stimuli were presented in zero lag condition with equal loudness in both the ears. Between the paired stimuli, a gap of 6 seconds was provided. The participants were instructed that they will hear two sounds at the same time, one in right ear and the other in left ear. They were asked to write down the responses of what was heard and the order was not specified. The single ear responses were considered and lateralization index was calculated. Laterality Index (LI) = (npr-npl)/(npr+npl), where npr refers to correctly detected stimuli in right ear and npl to that detected in left ear.

The scores of modified laterality preference schedule were tabulated, in order to investigate the difference with respect to the handedness, footedness, ear and eye preference among PWS compared to their control group. Scores of laterality index (LI) in Dichotic CV test aimed to investigate the right ear advantage (REA) and left ear advantage (LEA) with respect to PWS and the control group to measure laterality preferences. The data on both test scores were tabulated and statistical analysis was done using SPSS (version 16) software package

Results and Discussion

The cerebral dominance and laterality differences among PWS and PWNS with respect to hand, foot, eye and ear preference were studied using Modified Laterality Preference Schedule

(MLPS) and Lateralization Index (LI) scores using dichotic CV test. Chi-square test of association was administered to check significance with respect to the handedness, footedness, eye and ear preference and laterality index scores in PWS and PWNS groups.

Laterality in PWS and PWNS based on MLPS

Table 1 shows the number and percentage of PWS and PWNS exhibiting preferences for hand, leg, eye and ear on various activities. All the participants except one in the PWNS group showed right side preference for handedness and footedness. Eye (80%) and ear (62%) preference also were more lateralized towards right. Ambidexterity was not found in any of the participants in the control group for handedness and footedness. However, ambidexterity was observed in 5% of the participants for eye and 17% for ear preference in the PWS group.

In the PWS group, all the participants showed 100% right side laterality for handedness. While footedness was lateralized to left side in 8%, 92% showed right side preference. Also, they showed 6% eye preference towards left side, 90% towards right and ambidexterity was noticed in 4%, which was not significant.

Table 1

Total number and mean percentage of participants and hand, foot, eye and ear preferences among PWS and PWNS

Groups	Hand		Foot		Eye			Ear		
	R	L	R	L	R	L	A	R	L	A
PWNS	59 (98%)	1 (2%)	59 (98%)	1 (2%)	48 (80%)	9 (15%)	3 (5%)	37 (62%)	13 (22%)	10 (16%)
PWS	50 (100%)	0 (0%)	46 (92%)	4 (8%)	45 (90%)	3 (6%)	2 (4%)	32 (64%)	9 (18%)	9 (18%)

R-Right; L-Left; A-Ambilateral

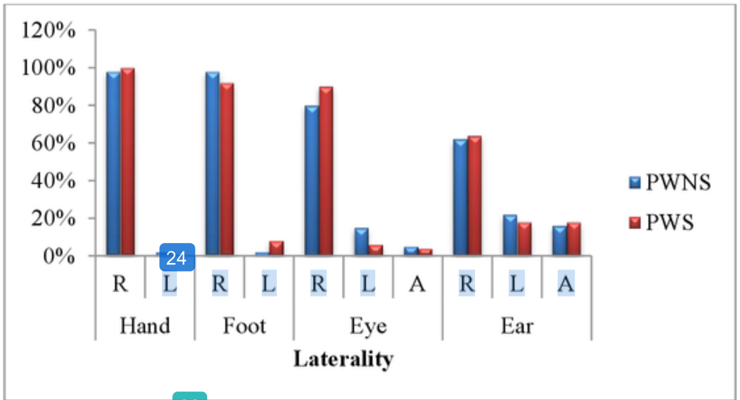

Figure 1- Mean percentages of hand, foot, eye and ear preferences among PWS and PWNS

Ear preference in PWS was lateralized to right side in 64% of the participants and 18% of the participants had preference for left side. Ambidexterity for ear preference was observed in 18% of the participants in the PWS group. The data analysis suggested almost similar results in both clinical and control group with respect to laterality preference. It ranged from 60-98% and 64-100% (right); 2-22% and 0-18% (left); 5-16% and 4-18% (ambidextrous) in PWNS and PWS respectively.

There was statistically no significant difference in the means of handedness scores between PWS and PWNS group [χ^2 (1) =0.841 p>0.05] as well as for foot [χ^2 (1) =2.52, p>0.05], eye [χ^2 (2) =2.408, p>0.05] and ear [χ^2 (2) =0.235, p>0.05] preference scores. However, Figure 1 shows more left and ambidexterity for ear preference scores.

The present study indicates that there is no evidence of a higher incidence of left handedness or ambidexterity in PWS. In other words, it was observed that most of the tasks in both the groups are lateralized to right. A few tasks demonstrated mixed (for eye & ear) and left sided lateralization (footedness, eyed & earedness). Though the scores on MLPS did not show any significant differences between the groups, a prominent right side preference was observed in both the groups in majority of the participants. Compared to hand and foot preferences, eye and ear preferences were more often lateralized to left or ambidextrous in both PWS and PWNS groups. It could be that due to practice effect from childhood, tendency to lateralize to right side could have been noted on all tasks, although people give more attention to the handedness and not for others. Thus, it appears that MLPS is not a very sensitive tool to detect laterality or hemispheric processing.

Laterality based on Dichotic CV Test

Dichotic Consonant Vowel Test in Kannada language was used to find the ear preference in PWS and PWNS. The stimuli consisting of six stop consonants (pa, ta, ka, ba, da, and ga) totaling to 30 CV combinations were presented to both the ears simultaneously. The test employed undirected attention skills in which stimuli were presented in zero lag condition with equal loudness in both the ears. Table 2 and Figure 2 provide the results on dichotic CV test for PWS and PWNS.

Table 2

Total number and mean percentage of participants and ear advantage on dichotic CV test in PWS and PWNS

Groups	R	L	A
PWNS	39 (65%)	14 (23%)	7 (12%)
PWS	17 (34%)	31 (62 %)	2 (4%)

Note: R-Right; L-Left; A-Ambilateral

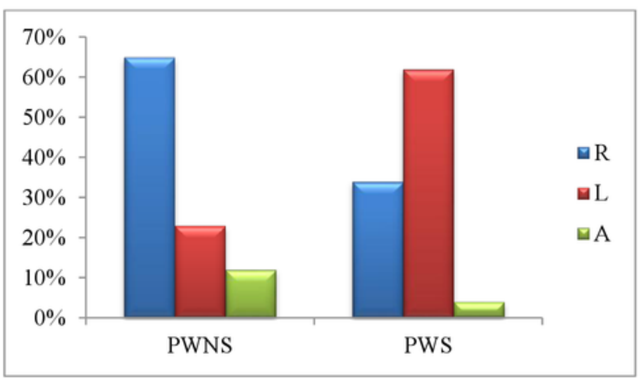

Figure 2- Mean percentage of ear advantage on Dichotic CV test for PWS and PWNS

During dichotic CV test, 62% of PWS had left ear preference and remaining 34% showed right ear preference and 4% of them were ambilateral. Control group also showed variations across participants and majority of the participants, that is., 65% showed right ear advantage (REA). Left ear advantage (LEA) was observed in 23% of the participants, while 12% were ambilateral. Statistical analysis revealed significant difference for laterality index (LI) scores in the dichotic CV test between PWS and their control group [χ^2 (2) =17.075, p<0.05]. Thus, the study showed more of LEA in PWS compared to PWNS who showed more REA. This suggests that the bilateral activation or right hemisphere bias could be present among majority of PWS. The dichotic CV test revealed more drastic differences in PWS and PWNS in terms of ear laterality compared to the ear preference scores on MLPS. This could be because of the more subjective nature of the latter test.

The results of dichotic CV test imply that majority of PWS heard stimulus presented to the left ear more accurately than right ear, indicating bilateral activation or widespread right hemisphere bias could be present among PWS. Placing this result in the context of previous reports on imaging studies in PWS, it is in agreement with many studies (Paus et al, 1993, Fox et al., 1996; Braun et al., 1997, Foundas et al., 2001, 2003; Jancke et al., 2004). This study is also in consonance with the findings of Curry and Gregory (1969), Brady and Berson (1975), Foundas, et al (2004) who observed significant REA in PWNS and LEA in PWS. The present study is also in consonance with the findings of one of the recent Indian study by Deepika and Geetha (2012), on a smaller sample of participants. They observed no difference between PWS and PWNS on modified laterality preference schedule in terms of hand, eye, ear and leg preferences while a significant difference was observed in PWS and PWNS on dichotic CV test. It was noted that PWS showed more left ear advantage compared to PWNS who showed typical right ear advantage. Conversely, this study is not in agreement with Dorman and Porter (1975) who observed no significant difference in the performance on dichotic CV test between PWS and PWNS.

Though there were no differences seen in laterality checklist (MLPS), differences in dichotic CV test were seen, which indicated that PWS may lateralize to right side on hand/foot/eye/ear preferences probably because of practice from childhood or forced change in laterality, especially for the handedness. Also, the association between handedness and other laterality (ear, eye and foot preference) measures are not very clear as to in what way they interact or interfere in language processing. However, few participants did show LEA in dichotic CV, as an actual response indicating right hemisphere dominance. More stringent performance related tasks for eye, hand, foot and ear laterality measures could yield more useful information with regard to laterality differences in persons with and without stuttering. Another important finding is that the left ear advantage was not observed in all PWS which may be because of atypical dominance in these individuals or sub groups of PWS with atypical laterality. In PWNS also about 23% showed LEA compared to 62% in PWS. Excessive usage of mobile phones on either of the ears indiscrimately could have altered the ear preferences in the two groups but the difference between the two groups in ear laterality is quite significant.

Summary and conclusion

The present study, part of a large scale study to investigate the altered auditory feedback mechanisms in persons with and without stuttering, aimed to investigate the handedness, footedness, ear and eye preference among PWS compared to their control group using MLPS and ear laterality using dichotic CV scores. The results revealed that there was no statistical evidence of difference between the PWS and PWNS groups based on handedness, footedness, and eye preference activities on MLPS. However, the results revealed significant difference for the ear preference scores in the MLPS and dichotic CV listening test between PWS and PWNS. This shows that auditory laterality is more important for deciding about hemispheric processing for speech and language than hand, leg and eye laterality. The findings of the study suggest that the left hemispheric laterality of the speech motor system may be incomplete in majority of PWS. Researchers have reported reduced left hemisphere activation, bilateral activation or widespread right hemisphere bias in PWS when listening to verbal information, which is supported by the current study. This atypical ear laterality could in some way interfere in the processing of linguistic information leading to breakdown in fluency, at least in a sub group of individuals with stuttering. The findings provide some support for the recent theoretical models proposed by many authors to explain stuttering phenomena like Lateralization /Neuro-psychological models, and Webster's Two-Factor interference model. More research is needed on children and adults with stuttering to investigate various issues related to ear and hemispheric laterality for speech and language processing and the breakdown in fluency, in terms of severity, recovery and persistency of stuttering.

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