List of Studies Concerning Auditory Processing Deficits and Stuttering

1 Rousey, C. L., Goetzinger, C. P., & Dirks, D. (1959). Sound localization ability of normal, stuttering, neurotic, and hemiplegic subjects. *Archives of General Psychiatry, 1*(6), 640–645. doi: 10.1001/archpsyc.1959.03590060102011

Method: Twenty CWS and 20 controls participated, with 10 boys and 10 girls in each group, mean age 11 years (9-12). A pure tone threshold was obtained for each subject at 500, 1000, and 2000 Hz. In the experimental condition, each child was presented a pure tone stimulus to the right ear three times, to the left ear three times, to both ears out of phase three times, and to both ears in phase three times in two levels of intensity, 15 and 30 dB above the previously determined thresholds. The children were asked where they heard the tone.

Results: There was a marked inconsistency in the response pattern, although normal children were the least inconsistent. In terms of frequency of responses to binaural stimuli, CWS tended to give more displaced (out of the head) responses, but normal children more head responses. Under monaural stimuli, the major difference was in the greater number of displaced responses found among the CWS. However, all groups tended to show some variance in responses

2 Curry, F. K. W. & Gregory, H. H. (1969). The performance of stutterers on dichotic listening tasks to reflect cerebral dominance. *Journal of Speech and Hearing Research, 12(1)*, 78–82. doi: 10.1044/jshr.1201.73

Method: Twenty AWS and 20 controls performed one monotic verbal listening task and three dichotic listening tasks, one verbal and two nonverbal. Left and right ear scores, as well as difference scores between the ears, were derived from each of these tests.

Results: AWS had smaller difference scores between ears on the dichotic verbal task than controls. Seventy-five percent of the contols obtained higher right ear scores on the dichotic verbal task, whereas 55% of the AWS had higher left ear scores. No differences were found between the two groups on the other tests.

3 MacCulloch, M. J. & Eaton, R. (1971). A note on reduced auditory pain threshold in 44 stuttering children. *International Journal of Language & Communication Disordorders, 6*(2), 148–153. doi: 10.3109/13682827109011541

Method: The threshold of auditory pain has been measured in 44 CWS and in 44 controls. Pure tone sound was applied via headphones over frequencies from 60 Hz to 300 Hz, across a power range from zero to 250 milli watts. The data consisted of threshold figures at 9 frequencies for 35 boys and 9 girls both in the experimental group and the control group.

Results: Pain threshold in CWS was lower than controls in the groups as a whole. When each group was sub-divided for sex, the females had a lower threshold than did the males. When the results were dichotomised in this way, there were still no overlap between the groups' threshold.

4 Brown, T., Sambrooks, J. F., & MacCulloch, M. J. (1975). Auditory thresholds and the effect of reduced auditory feedback of stuttering. *Acta Psychiatrica Scandinavica, 51*(5), 297–311. doi: 10.1111/j.1600-0447.1975.tb00009.x

Method: Using an accurately calibrated binaudal pure tone producer on 27 7-18 yr old male PWS and 68 controls, a comparison was made of both auditory hearing and discomfort thresholds in the 2 groups. The tolerance (discomfort) threshold for auditory sounds was determined for 13 frequency values between 30 and 10,000 Hz. Each sound was presented first at an easily tolerable lever, e. g., 90 dB.

Results: The hearing thresholds did not differ between the groups. Results do, however, replicate an earlier finding which suggested that PWS have a lower threshold for auditory discomfort than do normal speakers, and show that fluency is inversely related to auditory feedback. The discussion suggests that a necessary cause of stuttering is a physiological abnormality in side-tone conduction and central processing.

5 Hall, J. W., & Jerger, J. (1978). Central auditory function in stutterers. *Journal of Speech and Hearing Research 21*(2), 324–337. doi: 1044/jshr.2102.324

Method: Central auditory function was assessed in 10 PWS and 10 controls. Performance of the two groups was compared for seven audiometric procedures including acoustic reflex threshold, acoustic reflex amplitude function, performance intensity function for monosyllabic phonetically balanced (PB) words, performance intensity function for Synthetic Sentence Identification, Synthetic Sentence Identification with Ipsilateral Competing Message, Synthetic Sentence Identification with Contralateral Competing Message, and the Staggered Spondaic Word test.

Results: Relative to the control group, the performance of the stuttering group was depressed on three procedures – the acoustic reflex amplitude function, Synthetic Identification with Ipsilateral Competing Message, and Staggered Spondaic Word test. As a group, the stutterers presented evidence of a central auditory deficiency. The pattern of test results suggests a disorder at the brainstem level. The subtlety of the deficiency is emphasized.

6 Molt, L. F. & Guilford, A. M. (1979). Auditory processing and anxiety in stutterers. *Journal of Fluency Disorders, 4*(4), 255–267. doi: 10.1016/0094-730X(79)90002-0

Method: The study utilized the Synthetic Sentence Identification/Ipsilateral and Contralateral Competing Message subtests and the State-Trait Anxiety Inventory to examine auditory processing deficits, anxiety levels, and the interaction of these two components in 15 AWS and 15 controls.

Results: Results support brainstem auditory processing deficits in stutterers and equalization of cortical functioning between groups. Group differences were not found in anxiety levels. Nonsignificant correlations between anxiety levels and auditory processing were revealed.

7 Toscher, M. M. & Rupp, R. R. (1979). A study of the central auditory processes in stutterers using the Synthetic Sentence Identification (SSI) Test battery. *Journal of Speech and Hearing Research, 21*(4), 779–792. doi: 10.1044/jshr.2104.779

Method: The performance of 14 PWS and 14 controls was compared on the Synthetic Sentence Identification Test. The test is designed to assess central auditory function.

Results: The performance of the stuttering group was significantly poorer (0.01 level of confidence) than that of the controles on the Ipsilateral Competing Message Subtest.

8 Liebetrau, R. M. & Daly, D. (1981). Auditory processing and perceptual abilities of "organic" and "functional" stutterers. *Journal of Fluency Disorders, 6*(3), 219–231. doi: 10.1016/0094-730X(81)90003-6

Method: Dichotic listening and masking level difference (MLD) tasks were administered to CWS and controls. CWS were differentiated into "organic" and "functional" subgroups on the basis of neuropsychological test performances.

Results: Organic stutterers performed significantly poorer than did controls on one MLD experimental condition. Functional stutterers performed more like controls than like organic stutterers.

9 Hannley, M. & Dorman, M. F. (1982). Some observations on auditory function and stuttering. *Journal of Fluency Disorders, 7*(1 pt 2), 93–108. doi: 10.1016/S0094-730X(82)80003-X

Method: Previous empirical studies of auditory processing in PWS were evaluated and discussed, particularly concerning acoustic reflex (threshold, latency, and amplitude), dichotic listening, and central processing (synthetic sentence identification test).

Results: Presence or absence of the acoustic reflex is not a necessary precondition to stuttering. No replicable differences were found between PWS and normal speakers at the level of lateralization, temporal lobe function, or brain stem function.

10 Wynne, M. K. & Boehmler, R. M. (1982). Central auditory function in fluent and disfluent normal speakers. *Journal of Speech and Hearing Research, 25*(1), 54–57. doi: 10.1044/jshr.2501.54

Method: The Synthetic Sentence Identification - Ipsilateral Competing Message (SSI-ICM) test at a -20-dB message-to-competition ratio was used to investigate central auditory function of fluent and disfluent, normally speaking, male college students. The disfluent group consisted of 10 subjects who demonstrated part-word repetitions while speaking extemporaneously. The matched fluent group of 10 subjects had extemporaneous speech containing no part-word repetitions and with speaking times matched to those of the disfluent group. All subjects had intact peripheral hearing skills and no known history of stuttering.

Results: As hypothesized, the disfluent normal speakers had lower scores on the SSI-ICM test than did the fluent normal speakers.

11 Blood, I. M. & Blood, G. W. (1984). Relationship between stuttering severity and brainstem-evoked response testing. *Perceptual and Motor Skills, 59*(3). 935–938. doi: 10.2466%2Fpms.1984.59.3.935

Method: Brainstem-evoked-response testing was performed on 8 AWS and 8 controls.

Results: AWS demonstrated prolonged central conduction time as measured by the interpeak latency (IPL) differences between Waves I to V. Five AWS manifested abnormalities unilaterally, while three showed abnormal responses bilaterally. No relationship was found between brainstem-evoked-response testing and severity of stuttering.

12 Bonin, B., Ramig, P, & Prescott, T. (1985). Performance differences between stuttering and nonstuttering subjects on a sound fusion task. *Journal of Fluency Disorders, 10*(4), 291–300. doi: 10.1016/0094-730X(85)90027-0

Method: Central auditory processing was examined in 8 AWS and 8 controls. Each subject participated in a sound fusion task under three variable conditions: 1) group performance (nonstutterers vs. stutterers); 2) ears (right vs. left); and 3) lead-time presentation (0–100 msec).

Results: Statistically significant differences were found for lead-time presentation.

13 Howell, P., Marchbanks, R. J., & El-Yaniv, N. (1986). Middle ear muscle activity during vocalization in normal speakers and stutterers. *Acta Oto-Laryngologica,102*(5-6), 396-402. doi: 10.3109/00016488609119423

Method: Middle ear muscles contract prior to vocalization, and there were contradictory reports about whether this activity in PWS differs from that of normal speakers. To tackle these questions, extratympanic pressure measurements prior to vocalization are reported for normal speakers and PWS. This measure allows activity deriving from the two middle ear muscles to be differentiated and for the temporal course to be followed more accurately than by impedance measurement.

Results: Contrary to other reports, there is no difference between normal speakers and PWS in the time course of this activity.

14 Kramer, M. B., Green, D., & Guitar, B. (1987). A comparison of stutterers and nonstutterers on masking level differences and synthetic sentence identification tasks. *Journal of Communication Disorders, 20*(5), 379–390. doi: 10.1016/0021-9924(87)90026-8

Method: Ten PWS and ten controls were tested for Masking Level Differences (MLDs) at 500 Hz, and were evaluated on the Synthetic Sentence Identification test with Ipsilateral Competing Message (SSI-ICM) under message-to-competition ratios (MCRs) of 0, -10,and -20 dB.

Results: No significant differences on the SSI-ICM task were seen between groups, but PWS did produce significantly ($p<.01$) poorer MLDs than the controls.

15 Meyers, S. C., Hughes, L. F., & Schoeny, Z. G. (1989). Temporal-phonemic processing skills in adult stutterers and nonstutterers. *Journal of Speech and Hearing Research, 32*(2), 274–280. doi: 10.1044/jshr.3202.274

Method: The performance of 20 male AWS and 20 controls was studied using two auditory processing tasks. The subjects listened to stimuli with differential onset asynchronies during temporal order judgment (TOJ) and dichotic listening tasks.

Results: AWS and controls were not significantly different at judging which ear received the stimulation first (TOJ task) at varying stimulus onset asynchronies (SOAs). During the dichotic listening task, AWS made significantly fewer double-correct responses (correct report for both stimuli in a dichotic pair) than controls. AWS correctly classified one of the syllables in a pair (single-correct response) more frequently than controls on the dichotic listening task.

16 Dietrich, S., Barry, S. J., & Parker, D. E. (1995). Middle latency auditory responses in males who stutter. *Journal of Speech and Hearing Research, 38*(1), 5–17. doi: 10.1044/jshr.3801.05

Method: Auditory middle latency responses were recorded from 10 male AWS and 10 controls using a variety of filter passbands in response to clicks presented binaurally at various rates.

Results: The latency of the Pb wave was found to be significantly shorter in the group of AWS.

17 Blood, I. M. (1996). Disruptions in auditory and temporal processing in adults who stutter. *Perceptual & Motor Skills, 82*(1), 272–274. doi: 10.2466%2Fpms.1996.82.1.272

Method: 10 stutterers' and 10 controls' abilities to perceive accurately prosodic information (stress, contrast, and emotion), linguistic stimuli staggered in time and nonspeech stimuli (tone bursts) were examined.

Results: Significant differences between the two groups on the Staggered Spondaic Word Test and the stress subtest of the Sentence Disambiguation Task. In addition, 7 of the 10 PWS performed more poorly on the three measures than controls did.

18 Salmelin, R., Schnitzler, A., Schmitz, F., Jäncke, L., Witte, O. W., & Freund, H. J. (1998). Functional organization of the auditory cortex is different in stutterers and fluent speakers. *Neuroreport, 9*(10), 2225–2229. doi: 10.1097/00001756-199807130-00014

Method: To characterize processing at the auditory cortical level, the authors recorded neuromagnetic responses to monaural tones in 9 PWS and 10 fluent speakers while the subjects were reading silently, with mouth movements only, aloud, and in chorus with another person.

Results: The basic functional organization of the auditory cortices was found to be different in PWS and controls. The altered interhemispheric balance in PWS was affected by speech production, due to changes in the left auditory cortical representation, and more severely by self-paced than accompanied speech. This may lead to transient non-optimal interpretation of the auditory input and affect speech fluency.

19 Barasch, C. T., Guitar, B., McCauley, R. J., & Absher, R. G. (2000). Disfluency and time perception. *Journal of Speech, Language, and Hearing Reseach, 43*(6), 1429–1439. doi: 10.1044/jslhr.4306.1429

Method: The authors compared the ability of AWS and controls to estimate protensity and to distinguish the relative lengths of short tones. They also examined whether there is a correlation between stuttering severity and the ability to measure protensity or judge the relative lengths of short tones. Twenty AWS and 20 controls were given the Duration Pattern Sequence Test. They were also asked to estimate the lengths of 8 tones and silent intervals.

Results: A negative correlation was found between degree of disfluency and ability to determine the relative lengths of short tones. A positive correlation was found between degree of disfluency and length of protensity estimates.

20 Howell, P., Rosen, S., Hannigan, G., & Rustin, L. (2000). Auditory backward-masking performance by children who stutter and its relation to dysfluency rate. *Perceptual and Motor Skills, 90*(2) 355–363. doi: 10.2466/pms.2000.90.2.355

Method: Stuttering and nonstuttering children's (mean age 10 yr.) performance was investigated in a task that involves central auditory processing (backward masking).

Results: CWS had deficits in backward masking (indicated by higher thresholds) compared with the control group. The backward-masking thresholds were positively correlated with frequency of stuttering.

21 Foundas, A. L., Corey, D. M., Hurley, M. M., & Heilman. K. M. (2004). Verbal dichotic listening in developmental stuttering: subgroups with atypical auditory processing. *Cognitive and Behavioral Neurology, 17*(4), 224–232. No doi; PubMed: 15622019

Method: Eighteen AWS and 25 controls were studied by simultaneous binaural (dichotic) presentation of consonant-vowel stimuli in three attention conditions: nondirected attention, attention directed right, and attention directed left. Sex-handedness groups (stutter and control) included right-handed men and women and left-handed men, but not left-handed women because this stutter subgroup could not be recruited. To study ear advantage and auditory laterality, two dependent measures were examined: percent left and right ear responses and lateralization shift magnitude. Potential relationships between degree of handedness and dichotic listening measures were also examined.

Results: Matched controls and right-handed men who stutter had the expected right-ear advantage (REA) in the nondirected attention condition. In contrast, left-handed men who stutter had a left-ear advantage (LEA), and right-handed women who stutter did not have a lateral ear bias in the nondirected attention condition. Right-handed women who stutter had the greatest tendency to hear a sound that was not presented to either ear, and were relatively unable to selectively direct attention left or right. In contrast, left-handed men who stutter were able to shift attention to the left and right ear better than any other group. For the fluent control group, there were no significant relationships among degree of handedness and dichotic-listening variables. For the stutter group, degree of handedness was significantly related to percentage left and right ear response and to the lateralization shift magnitude.

22 Howell, P. & Williams, S. M. (2004). Development of auditory sensitivity in children who stutter and fluent children. *Ear and Hearing, 25*(3), 265–275. doi: 10.1097/01.aud.0000130798.50938.eb, PMC: 1999300

Method: The auditory sensitivity of 37 PWS and 44 controls, ages between 8 and 19 yr, assigned to three age categories, were obtained in five listening conditions: Pure tone threshold, simultaneous masking, backward masking, notched backward masking, and simple dichotic (simultaneous) masking.

Results: Across all listening conditions and both talker groups, thresholds decreased over age. The thresholds of participants who do not stutter decreased for simultaneous, backward, and notched backward masking conditions over the 8- to 19-year age range. Analysis of each condition only showed significant improvement over age groups for backward masking for the PWS. The results indicate that auditory sensitivity for sounds in noise continues to develop through to teenage, and a different pattern of auditory development exists for the PWS compared with controls.

23 Corbera, S., Corral, M.-J., Escera, C., & Idiazábal, M. A. (2005). Abnormal speech sound representation in persistent developmental stuttering. *Neurobiology, 65*(8), 1246–1252. doi: 10.1212/01.wnl.0000180969.03719.81

Method: The authors compared the mismatch negativity (MMN) event-related brain potential elicited to simple tone (frequency and duration) and phonetic contrasts in a sample of PWS with that recorded in a control group.

Results: PWS had normal MMN to simple tone contrasts but a significant supratemporal left-lateralized enhancement of this electrophysiologic response to phonetic contrasts. In addition, the enhanced MMN correlated positively with speech disfluency as self-rated by the subjects.

24 Andrade, A. N. de, Gil, D., Schiefer, A. M., & Pereira, L. D.(2008). Behavioral auditory processing evaluation in individuals with stuttering. *Pró-Fono Revista de*

Atualização Científica, 20(1), 43–49. doi: 10.1590/S0104-56872008000100008

Method: Auditory processig was tested in 56 PWS, 49 male and 7 female, ranging in age from 4 to 34 years.

Results: From the total of 56 individuals who were evaluated, 92.85% presented auditory processing disorders. The most common auditory processing disorders were supra-segmental and decoding.

25 Chang, S. E., Kenney, M. K., Loucks, T. M., & Ludlow, C. L. (2009). Brain activation abnormalities during speech and non-speech in stuttering speakers. *Neuroimage, 46*(1), 201–212. doi: 10.1016/j.neuroimage.2009.01.066, PMC: 2693291

Method: Using fMRI with sparse sampling, separate BOLD responses were measured for perception, planning, and fluent production of speech and non-speech vocal tract gestures.

Results: During both speech and non-speech perception and planning, PWS had less activation in the frontal and temporoparietal regions relative to controls. During speech and non-speech production, PWS had less activation than the controls in the left superior temporal gyrus (STG) and the left pre-motor areas (BA 6) but greater activation in the right STG, bilateral Heschl's gyrus (HG), insula, putamen, and precentral motor regions (BA 4). Differences in brain activation patterns between PWS and controls were greatest in females and less apparent in males.

26 Hampton, A. & Weber-Fox, C. (2009). Non-linguistic auditory processing in stuttering: Evidence from behavior and event-related brain potentials. *Journal of Fluency Disorders, 33*(4), 253–273. doi: 10.1016/j.jfludis.2008.08.001, pMC: 2663969

Method: The study focused on non-linguistic auditory processing. A pure-tone, oddball paradigm was utilized to compare behavioral responses of accuracy and reaction time, and event-related potentials elicited by brief standard and target tones.

Results: As a group, AWS tended to perform less accurately and were slower to respond to target stimuli. However, inspection of individual data indicated that most AWS performed well within the range of the controls, and only 3/11 AWS were clearly outside the range. No overall group differences were found for early perceptual processes (N100 and P200), however, the AWS with small amplitude N100 responses were those who performed less accurately and those with reduced P200 amplitudes performed more slowly. Thus, a small subset AWS demonstrated early perceptual processes indicative of reduced cortical representation of auditory input that may have resulted in reduced behavioral performance. P300 mean amplitude, which tended to be reduced overall for the AWS compared to the controls, did not correlate with behavior for the AWS. However, P300 mean amplitude was significantly correlated with accuracy for the controls, indicating that stronger working memory updating processes enhanced performance for them. The findings emphasize the importance of examining individual differences among AWS and point to the possibility of non-linguistic auditory processing deficits in only a subset of AWS.

27 Beal, D. S., Cheyne, D. O., Gracco, V. L., Quraan, M. A., Taylor, M. J., & De Nil, L.F. (2010). Auditory evoked fields to vocalization during passive listening and active generation in adults who stutter. *Neuroimage, 52*(4), 1645–1653. doi: 10.1016/j.neuroimage.2010.04.277

Method: Magnetoencephalography was used to investigate auditory evoked responses to speech vocalizations and non-speech tones in AWS and controls. Neuromagnetic field patterns were recorded as participants listened to a 1 kHz tone, playback of their own productions of the vowel /i/ and vowel-initial words, and actively generated the vowel /i/ and vowel-initial words. Activation of the auditory cortex at approximately 50 and 100 ms was observed during all tasks.

Results: A reduction in the peak amplitudes of the M50 and M100 components was observed during the active generation versus passive listening tasks dependent on the stimuli. AWS did not differ in the amount of speech-induced auditory suppression relative to fluent sprakers. AWS had shorter M100 latencies for the actively generated speaking tasks in the right hemisphere relative to the left hemisphere but the controls showed similar latencies across hemispheres. During passive listening tasks, AWS had longer M50 and M100 latencies than controls.

28 Liotti, M., Ingham, J. C., Takai, O., Paskos, D. K., Perez, R., & Ingham, R. J. (2010). Spatiotemporal dynamics of speech sound perception in chronic developmental stuttering. *Brain and Language, 115*(2), 141–147. doi: 10.1016/j.bandl.2010.07.007

Method: High-density ERPs were recorded in 8 AWS and controls while participants either repeatedly uttered the vowel 'ah' or listened to their own previously recorded vocalizations.

Results: The fronto-central N1 auditory wave was reduced in response to spoken vowels relative to heard vowels (auditory-vocal gating), but no difference in the extent of such modulation was found in the AWS group. Abnormalities in the AWS group were restricted to the LISTEN condition, in the form of early N1 and late N3 amplitude changes. Voltage of the N1 wave was significantly reduced over right inferior temporo-occipital scalp in the PERS group. A laterality index derived from

N1 voltage moderately correlated with the AWS group's assessed pre-experiment stuttering frequency.The late N3 wave was reduced in amplitude over inferior temporo-occipital scalp, more so over the right hemisphere. sLORETA revealed that in the time window of the N3 the AWS group showed significantly less current density in right secondary auditory cortex than the control group, suggesting abnormal speech sound perception.

29 Maxfield, N. D., Huffman, J. L., Frisch, S. A., & Hinckley, J. J. (2010). Neural correlates of semantic activation spreading on the path to picture naming in adults who stutter. *Clinical Neurophysiology, 121*(9), 1447–1463. doi: 10.1016/j.clinph.2010.03.026

Method: Fourteen AWS and 14 controls completed a picture–word priming task. On each trial, a picture was named at a delay. On some trials, an unattended auditory probe word was presented after the picture, before naming commenced. Event-related potentials recorded to probe words Semantically-Related to the picture labels, and to probe words Semantically- and Phonologically-Unrelated to the picture labels, were compared using spatial–temporal principal component analysis.

Results: Posterior N400 amplitude was attenuated for Semantically-Related versus Unrelated probes in controls, while in AWS posterior N400 amplitude was enhanced for Semantically-Related versus Unrelated probes. Marginal albeit potentially relevant group differences in the morphology of other ERP components were also observed. The posterior N400 results point to a strategic, inhibitory influence on semantic activation spreading in AWS on the path to naming. Group differences in the amplitude of other ERP components tentatively suggest that AWS allocated attentional resources differently than the controls during the task.

30 Beal, D. S., Quraan, M. A., Cheyne, D. O., Taylor, M. J., Gracco, V. L., & De Nil, L. F. (2011). Speech-induced suppression of evoked auditory fields in children who stutter. *Neuroimage, 54*(4), 2994–3003. doi: 10.1016/j.neuroimage.2010.11.026, PMC: 0.3042852

Method: Magnetoencephalography was used to determine the presence of speech-induced suppression in children and to characterize the properties of speech-induced suppression in CWS. The auditory M50 was examined, as this was the earliest robust response reproducible across our child participants and the most likely to reflect a motor-to-auditory relation.

Results: Both CWS and contros demonstrated speech-induced suppression of the auditory M50. However, CWS had a delayed auditory M50 peak latency to vowel sounds compared to controls, indicating a possible deficiency in their ability to efficiently integrate auditory speech information for the purpose of establishing neural representations of speech sounds.

31 Kikuchi, Y., Ogata, K., Umesaki, T., Yoshiura, T., Kenjo, M., Hirano, Y., et al. (2011). Spatiotemporal signatures of an abnormal auditory system in stuttering. *Neuroimage, 55*(3), 891–899. doi: 10.1016/j.neuroimage.2010.12.083

Method: The authors examined the functional and structural changes in the auditory cortices of PWS by using a 306-channel magnetoencephalography system to assess auditory sensory gating (P50m suppression) and tonotopic organization. Additionally, we employed voxel-based morphometry to compare cortical gray matter (GM) volumes on structural MR images.

Results: PWS exhibited impaired left auditory sensory gating. The tonotopic organization in the right hemisphere of PWS is expanded compared with that of the controls. Furthermore, PWS showed a significant increase in the GM volume of the right superior temporal gyrus, consistent with the right tonotopic expansion. Accordingly, we suggest that PWS have impaired left auditory sensory gating during basic auditory input processing and that some error signals in the auditory cortex could result in abnormal speech processing.

32 Maxfield, N. D., Pizon-Moore, A. A., Frisch, S. A., & Constantine, J. L. (2012). Exploring semantic and phonological picture-word priming in adults who stutter using event-related potentials. *Clinical Neurophysiology, 123*(6), 1131–1146. doi: 10.1016/j.clinph.2011.10.003, PMC: 3.77650

Method: The aim was to investigate how semantic and phonological information is processed in AWS preparing to name pictures, following-up a report that event-related potentials (ERPs) in AWS evidenced atypical semantic picture-word priming (Maxfield et al., 2010). Fourteen AWS and 14 controls participated. Pictures, named at a delay, were followed by probe words, ERPs were recorded.

Results: The controls evidenced typical priming effects in probe-elicited ERPs. AWS evidenced diminished Semantic priming, and reverse Phonological N400 priming. Results point to atypical processing of semantic and phonological information in AWS.

33 Neef, N. E., Sommer, M., Neef, A., Paulus, W., Gudenberg, A. W. v., Jung, C., & Wüstenberg, T. (2012). Reduced speech perceptual acuity for stop consonants in individuals who stutter. *Journal of Speech, Language, and Hearing Research, 55*(1), 276–289. doi: 10.1044/1092-4388(2011/10-0224)

Method: The authors tested the stability of phoneme percepts by analyzing participants' ability to identify voiced and voiceless stop consonants. Two syllable continua were generated by systematic modification of the voice onset time. Speech perceptual acuity was determined by means of discriminatory power in 25 PWS and 24 controls by determining the phoneme boundaries and by quantifying the interval of voice onset times for which phonemes were perceived ambiguously.

Results: In PWS, discriminatory performance was weaker and less stable over time when compared with control participants. In addition, phoneme boundaries were located at longer voice onset times in PWS.

34 Asal, S. & Abdou, R. M. (2014). The study of central auditory processing in stuttering children. *The Egyptian Journal of Otolaryngology, 30*(4), 357–361. doi: 10.4103/1012-5574.144976

Method: Twenty CWS and 20 controls were included in the study. All participants were subjected to the following central auditory processing tests: pitch pattern sequence test (PPST), dichotic digit test (DDT), speech in noise test (children version) (SPIN), auditory fusion test revised (AFT-R), and binaural masking level difference (MLD) test.

Results: The stuttering group scored significantly poorer in the PPST, DDT, and SPIN, whereas they scored similar to the controls in MLD and AFT-R. There was no correlation between the severity of stuttering and the performance on the central auditory processing tests. Conclusion: Stuttering children have an intact brain stem integrity shown by the normal MLD and an intact right hemisphere as signified by the normal right and left ear difference in the DDT and by the improvement in the PPST on humming. Left hemisphere deficit appears in more complicated tasks such as PPST, DDT, and SPIN, but not in simple tasks such as AFT-R. The deficit is within the left cerebral hemisphere.

35 Jansson-Verkasalo, E., Eggers, K., Järvenpää, A., Van den Bergh, B., De Nil, L., & Kujala, T. (2014). Atypical central auditory speech-sound discrimination in children who stutter as indexed by the mismatch negativity. *Journal of Fluency Disorders, 41*, 1–11. doi: 10.1016/j.jfludis.2014.07.001

Method: Participants were 10 CWS and 12 controls. Event-related potentials (ERPs) for syllables and syllable changes [consonant, vowel, vowel-duration, frequency (F0), and intensity changes], critical in speech perception and language development of CWS were compared to those of the controls.

Results: No significant group differences in the amplitudes or latencies of the P1 or N2 responses elicited by the standard stimuli. However, the Mismatch Negativity (MMN) amplitude was significantly smaller in CWS than in controls. For controls, all deviants of the linguistic multifeature paradigm elicited significant MMN amplitudes, comparable with the results found earlier with the same paradigm in 6-

year-old children. In contrast, only the duration change elicited a significant MMN in CWS. The results showed that central auditory speech-sound processing was typical at the level of sound encoding in CWS. In contrast, central speech-sound discrimination, as indexed by the MMN for multiple sound features (both phonetic and prosodic), was atypical in the group of CWS.

36 Tahaei, A. A., Ashayeri, H., Pourbakht, A., & Kamali, M. (2014). Speech evoked auditory brainstem response in stuttering. *Scientifica (Cairo),* 328646. doi: 10.1155/2014/328646

Method: Participants were 25 AWS and 25 controls. The speech-related auditory brainstem responses (ABRs) were elicited by the 5-formant synthesized syllable/da/, with duration of 40 ms.

Results: There were significant group differences for the onset and offset transient peaks. AWS had longer latencies for the onset and offset peaks relative to the control group. Conclusions. AWS showed a deficient neural timing in the early stages of the auditory pathway consistent with temporal processing deficits.

37 Halag-Milo, T., Stoppelman, N,, Kronfeld-Duenias, V., Civier, O., Amir, O., Ezrati-Vinacour, R., & Ben-Shachar, M. (2016). Beyond production: Brain responses during speech perception in adults who stutter. *Neuroimage: Clinical, 11*, 328–338. doi: 10.1016/j.nicl.2016.02.017

Method: The authors tested the hypothesis that developmental stuttering implicates neural systems involved in language perception, in a task that manipulates comprehensibility without an overt speech production component. Functional MRI data were recorded in AWS and controlsr, while they were engaged in an incidental speech perception task.

Results: Speech perception evoked stronger activation in AWS compared to controls, specifically in the right inferior frontal gyrus and in left Heschl's gyrus. Significant differences were additionally found in the lateralization of response in the inferior frontal cortex: AWS showed bilateral inferior frontal activity, while controls showed a left lateralized pattern of activation.

38 Lu, C., Long, Y., Zheng, L., Shi, G., Liu, L., Ding, G., & Howell, P. (2016). Relationship between speech production and perception in people who stutter. *Frontiers of Human Neuroscience, 10*, 224, doi: 10.3389/fnhum.2016.00224

Method: To investigate a possible relation between stuttering and speech perception difficulties, functional MRI data were collected on 13 PWS and 13 controls whilst the participants performed a speech production task and a speech perception task.

Results: PWS performed poorer than controls in the perception task and the poorer performance was associated with a functional activity difference in the left anterior insula (part of the speech motor area) compared to controls. PWS also showed a functional activity difference in this and the surrounding area [left inferior frontal cortex (IFC)/anterior insula] in the production task compared to controls. Conjunction analysis showed that the functional activity differences between PWS and controls in the left IFC/anterior insula coincided across the perception and production tasks. Granger Causality Analysis on the resting-state fMRI data showed that the causal connection from the left IFC/anterior insula to an area in the left primary auditory cortex (Heschl's gyrus) differed significantly between PWS and controls. The strength of this connection correlated significantly with performance in the perception task.

39 Arcuri, C. F., Schiefer, A. M., & Azevedo, M. F. (2017). Research about suppression effect and auditory processing in individuals who stutter. *Codas, 29*(3), e20160230. doi: 10.1590/2317-1782/20172016230, PDF

Method: Auditory processing abilities (using the Nonverbal Dichotic Test and the Frequency Pattern Test.) and occurrence of the suppression effect of Otoacoustic Emissions (OAE) were investigated in 15 AWS and 15 controls.

Results: AWS presented higher incidence of auditory processing disorders and higher incidence of absence of suppression effect of OAEs, indicating abnormal functioning of the efferent medial olivocochlear system. Functioning of the efferent medial olivocochlear system showed a deficit in stutterers, indicating difficulties in auditory discrimination.

40 Kikuchi, Y., Okamoto, T., Ogata, K., Hagiwara, K., Umezaki, T., Kenjo, M., Nakagawa, T., & Tobimatsu, S. (2017). Abnormal auditory synchronization in stuttering: A magnetoencephalographic study. *Hearing Research, 344*, 82–89. doi: 10.1016/j.heares.2016.10.027

Method: The dataset of Kikuchi et al. (2011) was reevaluated to further investigate how the right and left auditory cortices interact to compensate for stuttering. The authors evaluated bilateral N100m latencies as well as indices of local and inter-hemispheric phase synchronization of the auditory cortices.

Results: The left N100m latency was significantly prolonged relative to the right N100m latency in PWS, while healthy control participants did not show any inter-hemispheric differences in latency. A phase-locking factor (PLF) analysis, which indicates the degree of local phase synchronization, demonstrated enhanced alpha-band synchrony in the right auditory area of PWS. A phase-locking value (PLV) analysis of inter-hemispheric synchronization demonstrated significant elevations in the beta band between the right and left auditory cortices in PWS. In addition, right PLF and PLVs were positively correlated with stuttering frequency in PWS. The data suggest that increased right hemispheric local phase synchronization and increased inter-hemispheric phase synchronization are electrophysiological correlates of a compensatory mechanism for impaired left auditory processing in PWS.

41 Prestes, R., de Andrade, A. N., Santos, R. B., Marangoni, A. T., Schiefer, A. M., & Gil, D. (2017). Temporal processing and long-latency auditory evoked potential in stutterers. *Brazilian Journal of Otorhinolaryngology, 83*(2), 142–146. doi: 10.1016/j.bjorl.2016.02.015

Method: Twenty PWS and 21 controls were submitted to the duration pattern test and the random gap detection test, and long-latency auditory-evoked potentials were recorded.

Results: PWS showed poorer performance on Duration Pattern and Random Gap Detection tests when compared with fluent individuals. In the long-latency auditory evoked potential, there was a difference in the latency of N2 and P3 components; stutterers had higher latency values.

42 Saltuklaroglu, T., Harkrider, A. W., Thornton, D., Jenson, D., & Kittilstved, T. (2017). EEG Mu (μ) rhythm spectra and oscillatory activity differentiate stuttering from non-stuttering adults. *Neuroimage, 153*, 232–245. doi: 10.1016/j.neuroimage.2017.04.022

Method: The study compared spectral power and oscillatory activity of EEG mu (μ) rhythms between PWS and controls in listening and auditory discrimination tasks. EEG data were analyzed from passive listening in noise and accurate (same/different) discrimination of tones or syllables in quiet and noisy backgrounds. Independent component analysis identified left and/or right μ rhythms with characteristic alpha (α) and beta (β) peaks localized to premotor/motor regions in 23 of 27 PWS and 24 of 27 controls.

Results: PWS produced μ spectra with reduced β amplitudes across conditions, suggesting reduced forward modeling capacity. Group time-frequency differences were associated with noisy conditions only. PWS showed increased μ-β desynchronization when listening to noise and early in discrimination events, suggesting evidence of heightened motor activity that might be related to forward modeling deficits. PWS also showed reduced μ-α synchronization in discrimination conditions, indicating reduced sensory gating.

43 Devaraju, D. S., Maruthy, S., & Kumar, A. U. (2020). Detection of gap and modulations: auditory temporal resolution deficits in adults who stutter. *Folia Phoniatrica et Logopaedica, 72*(1), 13–21. doi: 10.1159/000499565

Method: Sixteen AWS and 16 controls participated. Temporal resolution abilities were assessed using the Gap Detection Test and temporal modulation transfer function (TMTF).

Results: Significant differences in TMTF between AWS and controls, but no differences in the gap detection thresholds. Results suggest that the sensory representations of the temporal modulations are compromised in AWS.

44 Shao, J., Bakhtiar, M., & Zhang, C. (2022). Impaired categorical perception of speech sounds under the backward masking condition in adults who stutter. *Journal of Speech, Language, and Hearing Research, 65*(7), 2554–2570. doi: 10.1044/2022_JSLHR-21-00276

Method: Fifteen Cantonese-speaking AWS and 15 controls were tested on the categorical perception of four stimulus continua, namely, consonant varying in voice onset time (VOT), vowel, lexical tone, and nonspeech, under the backward masking condition using identification and discrimination tasks.

Results: AWS demonstrated a broader boundary width than controls in the identification task. AWS also exhibited a worse performance than controls in the discrimination of between-category stimuli but a comparable performance in the discrimination of within-category stimuli, indicating reduced sensitivity to sounds that belonged to different phonemic categories among AWS. Moreover, AWS showed similar patterns of impaired categorical perception across the four stimulus types, although the boundary location on the VOT continuum occurred at an earlier point in AWS than in controls. The findings provide robust evidence that AWS exhibit impaired categorical perception of speech and nonspeech sounds under the backward masking condition. Temporal processing (i.e., VOT manipulation), frequency/spectral/formant processing (i.e., lexical tone or vowel manipulations), and nonlinguistic pitch processing were all found to be impaired in AWS.

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