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An exploration of dichotic listening among adults who stutter

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Abstract

A pilot investigation of dichotic listenin of CV stimuli was undertaken using seven adults who stutter (AWS) and a comparison group of seven adults who do not stutter (AWNS). The aim of this research was to investigate whether AWS show a difference in the strength of the right ear advantage (REA) in both undirected and directed attention tasks when compared to AWNS. The undirected attention task involved manipulating the interaural intensity difference (IID) of the CV stimuli presented to each ear. The CV stimuli were presented with equal intensity for the directed attention task. The undirected attention results indicated that both AWS and AWNS have a REA for processing speech information, with a primary difference observed between groups in regard to the IID point at which a REA shifts to a LEA. This crossing-over point occurred earlier for AWS, indicating a stronger right hemisphere involvement for the processing of speech compared to AWNS. No differences were found between groups in the directed attention task. The differences and similarities observed in dichotic listening between the two groups are discussed in regard to hemispheric specialization in the processing of speech.

Keywords: Attention, dichotic listening, language, stuttering, speech processing

Introduction

Dichotic listening

Dichotic listening involves the simultaneous presentation of two different speech or non-speech auditory signals to the left and right ears. The technique is noninvasive and is used to determine perceptual biases and assess brain lateralization and asymmetry (Broadbent, 1954; Foundas, Corey, Hurley, & Heilman, 2006; Hugdahl, 2011; Hugdahl, Westerhausen, Alho, Medvedev, & Hamalainen, 2008a). Depending on the type of auditory signal presented to the listener, an ''ear advantage'' can occur, with the signal presented to one of the ears perceived as more dominant (Rimol, Eichele, & Hugdahl, 2006). Research has shown that when two differing linguistic stimuli in the form of a consonant + vowel (CV) are simultaneously presented (one to each ear), there is typically a right ear advantage (REA) (Asbjornsen & Helland, 2006; Hugdahl et al., 2008a; Kimura, 1961; Tallus, Hugdahl, Alho, Medvedev, & Hamalainen, 2007). This REA is found for both right-handed and left-handed individuals; however, speech-language

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dominance, along with lateral processing has been found to be less robust for left-handed people (Bryden, Munhall, & Allard, 1983; Foundas et al., 2006). When non-speech stimuli, such as two differing melodies, are presented simultaneously, a left ear advantage (LEA) is usually found (Kimura, 1961).

The REA can be explained by two models of verbal information processing: (1) structural and (2) attentional, both of which involve the corpus callosum. In the structural model postulated by Kimura (1967), the REA was thought to reflect an interaction of the anatomy of the auditory system and the cerebral laterality for processing speech (Westerhausen et al., 2009). Because the left hemisphere is dominant for processing speech, the contralateral connection between the right ear and the left hemisphere is stronger compared to the ipsilateral connection between the left ear and left hemisphere, which necessitates transfer from the right hemisphere via the corpus callosum. This structural model describes what is referred to as *bottom-up processing* (Foundas et al., 2006; Kimura, 1961, 1967; Satz, Bakker, Teunissen, Goebel, & Van der Vlugt, 1975; Westerhausen & Hugdahl, 2008).

The second model of dichotic listening considers the role of directed attention. Kinsbourne (1970) suggested that a REA may not be entirely due to bottom-up processing. The simple act of anticipation of verbal stimuli may preferentially activate the left hemisphere, resulting in an enhanced REA. Thus, a REA may result from either (or both) of two processes: (1) being able to hear what was presented to the right ear due to a priming of the left hemisphere in preparing to process speech stimuli, or (2) suppression of what is being presented in the left ear due to an anticipation of speech stimuli. This process of anticipation by the left hemisphere for speech stimuli is referred to as *top-down processing*. In support of this attentional influence on the REA, Hugdahl & Andersson (1986) subsequently demonstrated that directed attention to either the right or left ear during a dichotic listening task served to either enhance or suppress the REA.

Interaural intensity differences

The difference in sound level of stimuli presented to the left and right ears is termed the interaural intensity difference (IID). Dichotic listening studies have been designed to determine whether changes in IID have an impact on the strength of the ear advantage. Tallus et al. (2007) sought to modulate the strength of the REA by manipulating the IID between the right ear and the left ear inputs, thereby giving higher intensity CV sounds a better chance of being processed irrespective of the ear of delivery. One-third of trials were preceded with a greater intensity in the left ear, one-third had greater intensity in the right ear and the remaining trials had equal intensity in both ears. By manipulating the IID, the strength of the REA could indeed be modulated with a gradual reduction in the strength of the REA that eventually transfers to a LEA.

Hugdahl et al. (2008a) examined the minimum IID required to balance the effect of the REA (i.e. the point at which equivalence is shown between the left and right ears). Participants took part in an undirected listening task, where the IID was modulated with either the left or the right ear being more intense. The results revealed a clear REA at 0 dB (i.e. no IID between the left and right ear) that persisted until the IID was 9 dB more intense in the left ear, at which time the listening advantaged shifted (i.e. ‘‘cross-over’’) to the left ear. The results were indicative of a strong left hemisphere (REA) influence for processing speech even when the intensity of the auditory signal was modulated to favor the left ear. Tallus et al. (2007) have suggested that modulating the strength of the REA through IID manipulation provides a unique approach to examining laterality and the nature of auditory processing among normal and clinical populations, particularly those groups who are thought to display processing difficulties (such as schizophrenia).

Dichotic listening and stuttering

There is a long history of research that has implicated the role of the brain in stuttering. The Orton-Travis theory developed over 80 years ago suggested that stuttering was a consequence of aberrant cerebral laterality in the processing and production of speech (Orton, 1928; Travis, 1931). These early speculations have since been substantiated with the advent of neuroimaging techniques. There is evidence that adults who stutter (AWS) demonstrate anomalous cerebral volume, composition and gyrification, which typically favor the right hemisphere (Foundas et al., 2003; Jancke, Hanggi, & Steinmetz, 2004). Fox et al. (1996) documented anomalous patterns of cerebral activation in AWS during fluent and disfluent speech production. Braun et al. (1997) found that during fluent speech, the left inferior frontal and primary auditory cortices (i.e. areas associated with self-monitoring, comprehension & fluency) were activated in adults who do not stutter (AWNS) but not among AWS. Structural anomalies of the corpus callosum among AWS were recently reported by Choo et al. (2011). These researchers found that AWS exhibited a larger overall callosa compared to AWNS, and suggested that this size difference could be linked to atypical brain function.

In addition to neuroimaging studies, there is a body of research examining the dichotic listening performance of AWS compared to AWNS. The combined results of these studies are far from clear in regard to laterality and the auditory processing abilities of AWS. For example, Curry & Gregory (1969) compared the performance of AWS and AWNS on various undirected dichotic listening tasks. In particular, results on the Dichotic Word Test (DWT), where consonant + vowel + consonant (CVC) words of high familiarity were used, found that a majority (75%) of AWNS achieved higher scores for the right ear verbal task, whereas fewer than half (45%) of AWS had scores higher for their right ear. The less robust REA performance found for the AWS group was interpreted to reflect atypical auditory processing. Studies by Quinn (1972) and Brady & Berson (1975) found all of their AWNS participants and a majority of the AWS participants to show a REA for processing of CV syllable pairs on undirected listening tasks. However, a small percentage of AWS participants in both studies (fewer than 25%) showed a LEA for the processing of speech stimuli, suggesting aberrant cerebral laterality.

Rosenfield & Goodglass (1980) investigated undirected dichotic listening performance for speech and non-speech stimuli in AWS and AWNS participants. The speech task involved listening to CV syllables and the non-speech task consisted of two different melodies presented simultaneously followed by four binaural melodies. Participants were instructed to identify which two melodies had been played dichotically. The same speech and non-speech tasks were carried out one week later to determine stability of performance. Results found a clear REA for both groups for the processing of speech stimuli but the groups differed in performance for the non-speech task. The AWNS showed a significant LEA for the non-speech task; while no clear ear advantage was found for the AWS group. The results led the researchers to suggest that AWS may show unusual cerebral lateralization for auditory processing.

A series of studies by Blood and colleagues (Blood & Blood, 1986, 1989; Blood, Blood, & Newton, 1986) provide varied results with regard to the dichotic listening performance of AWS. For example, Blood & Blood (1986) found that slightly more than half (57%) of AWS showed a REA for CV stimuli on an undirected attention task. Blood et al. (1986) compared AWS to AWNS on undirected and directed attention tasks, both of which involved the recall of digits. On the undirected task the AWS group showed no significant difference between the right and left ears, while the AWNS participants showed a significantly better right ear score. Both AWS and AWNS had significantly more correct responses when required to direct their attention to the right ear but the groups differed in their performance for attending to the left ear. The AWS were less accurate in recalling digits when asked to attend to the left ear compared to the AWNS group.

The researchers suggested that for AWS there may be a more even spread of cerebral activation for speech processing, whereby attentional directions may confuse AWS or their processing strategies are incompatible with specific listening directions.

Blood & Blood (1989) later investigated dichotic listening performance in an undirected listening task on the basis of a laterality quotient (i.e. ratio of the number of correct right-ear responses and left-ear responses). Although the AWS and AWNS groups both showed a REA for speech stimuli, the groups differed in their magnitude of performance. The AWNS group demonstrated a proportionally higher number of correct responses. This finding was taken to suggest that AWS and AWNS both show a REA; however, the strength of the ear advantage was significantly reduced for the AWS group.

Most recently, Foundas, Corey, Hurley, & Heilman (2004) investigated dichotic listening performance in AWS and AWNS participants as a function of gender and handedness. The AWS and AWNS participants were grouped according to gender and handedness and completed three tasks: (1) an undirected attention task, (2) a directed-right attention task and (3) a directed-left attention task. Results indicated that for the AWNS participants, sex and handedness had no influence on any of the dichotic listening tasks. Among the AWS participants, the male right-handed group showed a REA across the three tasks. However the female right-handed and male left-handed AWS participants showed atypical auditory processing as reflected in a lack of perceptual bias in the undirected task. During the directed-right and directed-left tasks, these same AWS participants were able to shift attention to left and right ear better than any of the other groups. The lack of difference between the AWNS participants and the male right-handed AWS participants led the researchers to conclude that aberrant auditory-speech dominance cannot account for all cases of stuttering. However, the results obtained for the female right-handed and male left-handed AWS group would support the notion of mixed cerebral dominance among a particular subgroup of AWS.

The present study

Comparing the results of past dichotic listening studies for AWS is difficult because of differences in methodological approaches. However, a feature common to a majority of studies is to examine dichotic listening performance in an undirected attention task using equal binaural intensity (Blood & Blood, 1986, 1989; Brady & Berson, 1975; Curry & Gregory, 1969; Quinn, 1972; Rosenfield & Goodglass, 1980). These studies indicate there is aberrant speech processing, as evidenced in either a lack of perceptual bias or LEA for some, but not all AWS. The first aim of the present study was to explore this finding further by considering dichotic listening performance on undirected attention tasks as a function of IID. Hugdahl et al. (2008b) have shown that systematically varying the IID manipulates the strength of the ear advantage in a parametric way (cf. Westerhausen et al., 2009). To date there have been no dichotic listening studies with AWS that have manipulated the speech signal in such a fashion. We anticipated that the clarity of the data obtained using these IID manipulations would serve to further highlight the aberrant speech processing abilities of AWS compared to AWNS. Specifically, we predicted that upon systematic manipulation of the IID, AWS would show a shift from REA to LEA prior to AWNS. That is, we anticipated a weaker REA response among AWS participants.

There are fewer studies of AWS that have examined dichotic listening by employing directed attention tasks (Blood et al., 1986; Foundas et al., 2004). These studies provide somewhat conflicting results, with AWS showing similar, poorer or better performance than AWNS depending on attention to a specific ear. The second aim of this study was to further explore whether AWS differed from AWNS on directed attention dichotic listening tasks. Based on the inconsistent findings in past research, we predicted that AWS would not differ from AWNS in their speech processing abilities on these tasks.

Method

Participants

Seven right-handed AWS (two females and five males) took part in the study. A non-probability convenience sampling technique was employed in this study. The AWS participants were accessed by contacting self-help organizations and local speech-language pathologists. Each participant had to meet the following criteria: (1) exhibit more than 3% syllables stuttered in a spontaneous speech sample of 300 words, (2) present with an isolated developmental fluency disorder and be free of any other communication disorder and (3) be classified as an AWS by a speech-language pathologist. The severity of each participant's stuttering ranged from moderate to severe as estimated using the Stuttering Severity Instrument for Children and Adults (SSI-3) (Riley, 1994). Sex, age, amount of previous treatment and stuttering severity were not controlled for in this study. Audiological screening at 500, 1000, 2000 and 4000 Hz was completed, with the inclusion criterion being that the pure tone average of these four frequencies was less than or equal to 20 dB HL and the difference in pure tone average between ears was no more than 5 dB. Handedness for each participant was obtained according to the Edinburgh Handedness Inventory (Oldfield, 1971). The resultant laterality quotient derived from the inventory for the AWS participants indicated all participants were right-handed, although participant AWS2's laterality quotient was 0.50. The general characteristics of the AWS, aside from stuttering, were matched to a control group of AWNS participants. The characteristics of both participant groups are shown in Table 1. The study was given ethical approval by the University of Canterbury Human Ethics Committee and all participants provided written informed consent.

Materials and stimuli

The dichotic listening stimuli consisted of six CV syllables. The vowel /a/ was paired with three voiced stop consonants (/ba/, /da/, /ga/) and three voiceless stop consonants (/pa/, /ta/, /ka/). A recording of each CV type was made using an adult male native speaker of New Zealand English. Dichotic stimuli were delivered through headphones (Sennheiser HD215) driven by a sound card (InSync Buddy USB 6G) attached to a laptop computer. For calibration, the headphones were placed on a Head and Torso Simulator (HATS) (Brüel & Kjær Type 4128) connected to a 5/1-ch input/output controller module (Brüel & Kjær 7539). The 1-second average A-weighted sound level of each syllable sample was measured using a Brüel & Kjær PULSE 11.1 noise and vibration analysis platform. This information was used to adjust the level of each syllable to ensure presentation at 70 dB(A) during subsequent listening tasks.

A specially designed software programme was used for presenting the CV syllables, analyzing the responses and displaying subsequent results. The CVs were paired to create six combinations of the three voiced CVs and six combinations of the three unvoiced CVs (12 stimulus pairs in total). The pseudo-randomization for the IID task was done via a specially designed software programme which used four rules to eliminate learning and order effects and which followed past research (Hugdahl et al., 2008a). The presentation order was pseudo-randomized within and between blocks by applying the following restrictions: (a) not more than two consecutive trials with the same intensity difference condition, (b) not more than three trials in a row with the same direction of intensity advantage, (c) no presentations of the same syllable to the same ear in

Table 1. General characteristics of adults who stutter (AWS) and adults who do not stutter (AWNS) participants. The table includes sex, age, handedness laterality quotient (HLQ), history of speech therapy, family history of stuttering and severity percentile score and rating on the Stuttering Severity Instrument (SSI) (Riley, 1994). All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

						SSI	
Participant	Sex	Age yrs	HLQ (%)	Previous therapy	Family history of stuttering	Score	Rating
AWS1	Female	55	100	Yes	No	46	Moderate
AWS2	Male	57	50	Yes	Yes	24	Mild/moderate
AWS3	Male	39	100	Yes	No	61	Moderate
AWS4	Male	28	100	Yes	No	95	Severe
AWS5	Male	61	100	Yes	No	97	Very severe
AWS6	Female	56	83	Yes	Yes	63	Moderate
AWS7	Male	28	100	Yes	No	75	Moderate
Mean		46	90.4			65.8	
SD		14	18.9			26.0	
AWNS1	Female	56	100	No	No	n/a	
AWNS2	Male	57	100	No	No	n/a	
AWNS3	Male	38	100	No	No	n/a	
AWNS4	Male	26	100	No	No	n/a	
AWNS5	Male	61	83	No	No	n/a	
AWNS6	Female	58	100	No	No	n/a	
AWNS7	Male	26	100	No	No	n/a	
Mean		46	97.5				
SD		15	6.4				

consecutive trials and (d) no repetition of a syllable pair in two consecutive trials. The dichotic listening tasks took place in a sound-treated booth within the University of Canterbury Speech and Hearing Clinic.

Procedures

Every participant performed the undirected task first, followed by the directed attention task. This approach was taken because it was assumed that completion of the directed task first may have served to prime the participants in later tasks (Hugdahl & Andersson, 1986). Half of the participants were randomly selected to start with the right hear while the other half started with the left ear. All the dichotic listening tasks were controlled using a laptop computer. Each participant was seated in front of the laptop in a relaxed position.

Undirected Task

In preparation for the undirected task, participants were required to first complete a perceptual calibration listening task. This task was designed to establish the interaural intensity balance for each individual to account for any audiometric asymmetries of individual participants. To complete the task, participants were fitted with headphones while facing the laptop computer. Each CV was presented to the participants simultaneously via the headphones and repeated continuously at two second intervals. During this process, the participant was required to move a slider on a linear scale to a location where the CV was heard equally in both ears. This was completed for each of the six CVs. The median score of the slider position was used as the interaural intensity balance for that participant. Once the interaural intensity balance was completed, participants commenced with the undirected dichotic listening task. Similar to

Westerhausen et al. (2009), each of the 12 CV pairs were presented at 15 different IIDs, resulting in 180 intensity-stimulus pairs. During this task, the IID was randomly varied for each ear. The IID was varied using a range of −21 dB to 21 dB, where −3 to −21 dB indicated greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicated greater intensity in the right ear. Each participant was given verbal instructions and told that the instructions would also be displayed on the screen. Each CV pair was presented via earphones and also displayed orthographically on the laptop monitor. Participant responses were collected on the basis of a mouse-pointer selection of the corresponding orthographic display. The intensity-stimulus pairs were presented in blocks of 45 presentations, followed by a short 3–5 min break.

Directed Task

Prior to completing the directed attention task another perceptual calibration task was undertaken. The identical procedures used in the initial calibration task were performed. Once the CV intensity levels were calibrated the directed attention task commenced. The IID was not manipulated for the directed attention task. This task involved the participants deliberately attending to either their right or left ear and report what they heard. Each participant was given verbal instructions and told the instructions would also be displayed on the screen. After listening to each presentation of the paired stimuli, participants were required to select what they heard in the ear they were instructed to attend to. Attention was randomly directed to each ear with no more than two consecutive presentations delivered to the same ear. The 12 stimulus pairs were presented four times (48 trials in total) with same number of trials with attention directed to each ear (24 trials per directed ear).

Data analysis

Group means for each presentation type (undirected & directed attention tasks) were obtained for each participant group. For the undirected attention paradigm, the magnitude of these differences was compared in two ways. The first analysis involved determining the cross-over level (dB) at which the REA shifted to a LEA. This cross-over level was estimated by fitting a first-order polynomial (linear regression) to each participant's right and left ear IID data plots. The point at which these data plots intersected was taken as the cross-over level. Cross-over levels ranging from −21 dB to −1 dB indicated greater intensity in the left ear, 0 dB being equal intensity levels in both ears and 1 to 21 dB indicating greater intensity in the right ear. The second analysis involved a series of planned comparison Mann–Whitney *U* tests to determine whether AWS differed from AWNS at each IID. A similar test was used to evaluate group differences in the directed attention task

Results

The results are presented in two sections. The first section contains the results for the undirected task and the second section contains the results for the directed attention task.

Undirected attention task

AWS

For each participant, first-order polynomials were fit to the right ear and left ear IID data points, respectively, to identify the cross-over level. Across the AWS participants, the cross-over levels

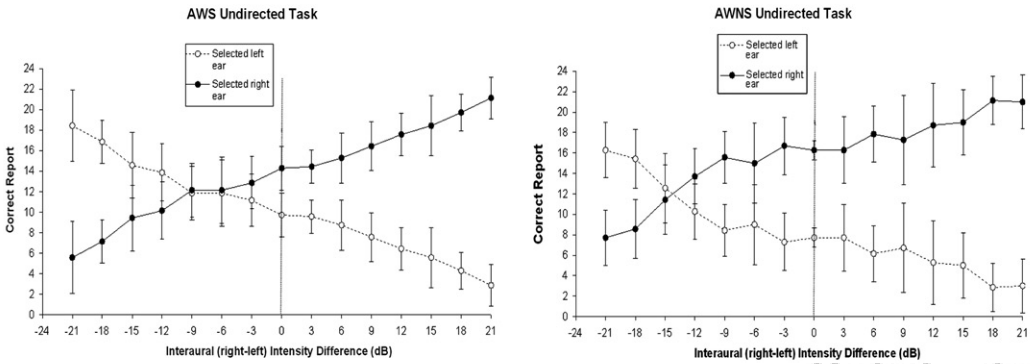

Figure 1. The left panel shows the correct report for AWS participants for the left and right ear CV stimuli as a function of changing the interaural intensity difference (IID) (dB). An IID of −3 to −21 dB indicates greater intensity the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear. The right panel shows the correct report results for AWNS participant.

ranged from 2 dB to −14 dB and averaged −6 dB for the group (SD = 5.28), indicating that a REA persisted until the CV presented in the left ear was 6 dB more intense than the right ear. The combined results for the AWS group are displayed in Figure 1.

AWNS

Across the individual AWNS participants, the cross-over levels ranged from −4 dB to −21 dB with a group average of −12 dB (SD = 6.55). The −12 dB cross-over value indicated a persistent REA until the left ear stimulus was 12 dB more intense than the right ear. The combined results for the AWNS group are displayed in Figure 1.

AWS versus AWNS

To evaluate whether overall group differences existed in the magnitude of REA, a two-tailed student *t*-test for paired samples was performed using the individual cross-over (dB) levels. The test approached significance $t(5) = 2.41$, $p = 0.06$.* A series of planned comparison Mann–Whitney *U* tests were also performed to determine whether AWS differed from AWNS at each IID. Significant differences between AWS and AWNS were found at the IIDs of 0 dB [$U(n_1 = 7, n_2 = 7) = 39.5$, $p < 0.05$], −3 dB [$U(n_1 = 7, n_2 = 7) = 40.0$, $p < 0.05$], −9 dB [$U(n_1 = 7, n_2 = 7) = 40.0$, $p < 0.05$] and −12 dB [$U(n_1 = 7, n_2 = 7) = 41.5$, $p < 0.05$]. This indicates a weaker REA for AWS participants at these IID levels. When the IID reached −15 dB both groups performed similarly.

*A further analysis of the group results was performed by removing participant AWS2 and the corresponding control participant, AWNS2. The AWS2 participant was found to have a Handedness Laterality Quotient of 50% (see Table 1), indicating no clear hand dominance. Removing this participant from the re-analysis allowed for an examination of AWS and AWNS group differences with less dextral ambiguity, particularly in regard to speech-language dominance. Results of the re-analysis indicated a significant difference between groups on the undirected attention task ($t = 2.64$, $p < 0.02$). A similar analysis was performed for the directed attention task; however, the re-analysis revealed no significant differences between the AWS and AWNS groups.

Directed Attention Task

AWS and AWNS

In the directed-right task, AWS participants scored 66.6% correct (i.e. they accurately reported the CV stimuli presented to the right ear). AWNS participants scored 69.0% correct on the directed-right task. In the directed-left task, AWS participants scored 51.7% correct and AWNS scored 48.2% correct. In general, both AWS and AWNS participants showed better identification of CVs when directed to the right ear compared with directing attention to the left ear. To evaluate whether there was a significant difference between the AWS group and the AWNS group for the directed attention tasks, Mann–Whitney U tests were performed. There were no significant differences between the AWS and the AWNS groups for either the right-directed attention condition [$U(n_1 = 7,\ n_2 = 7) = 25.5,\ p = 0.45$] or the left-directed attention condition [$U(n_1 = 7,\ n_2 = 7) = 30.5,\ p = 0.228$].

Discussion

The purpose of this study was to explore possible laterality differences in auditory processing of speech stimuli between AWS and AWNS using a combination of undirected and directed attention tasks. A discussion of the participants' performance for each of these tasks follows.

Undirected attention task

No previous studies comparing AWS to AWNS have examined dichotic listening using an IID format. Instead, an equal binaural intensity (IID of 0 dB) has been used. While past studies examining dichotic listening in AWS and AWNS have noted that the magnitude of the REA is less robust in AWS, there have been no attempts to directly examine the strength of the REA. This study is a departure from past dichotic listening studies of AWS by examining performance according to IID. Based on alteration of the intensity level of the CV stimuli presented to the left and right ears, the AWNS participants *crossed* at an IID of −12 dB. That is, a shift from a REA to a LEA was not evident until the CV stimuli were 12 dB more intense in the left ear. In contrast, the AWS participants crossed at an IID of −6 dB. The difference between groups approached statistical significance ($p < 0.06$) in the full group comparative analysis. Upon removal of AWS2, whose handedness laterality quotient was 0.50, the group differences were significant at the $p < 0.02$ level. Further, group differences were evident at several IID levels (IID = 0, −3, −9, −12 dB), whereby the AWNS group showed a stronger REA compared to AWS group. Hugdahl et al. (2008a) referred to this cross-over effect as reflecting a REA ''resistance'', due to the left hemisphere dominance in speech processing.

The present findings lend additional, albeit inferential, support to past studies exploring cerebral laterality and activation among AWS (Biermann-Ruben, Salmelin, & Schnitzler, 2005; Blomgren, Nagarajan, Lee, & Alvord, 2003; Braun et al., 1997; Cykowski et al., 2008; Foundas et al., 2003; Neumann et al., 2003; Preibisch et al., 2003; Salmelin, Schnitzler, Schmitz, & Freund, 2000; Van Borsel, Achten, Santens, Lahorte, & Voet, 2003; Walla, Mayer, Deecke, & Thurner, 2004). The combined results from these studies suggest the left-laterality of the speech motor system is incomplete for AWS, where there is an overactivity of pre-motor areas, which have an important role in speech and language formation (Fox et al., 2000). These brain imaging findings reveal reduced left hemisphere activation, bilateral activation or widespread right hemisphere bias for AWS when listening to verbal information (Braun et al., 1997; De Nil, Kroll, Lafaille, & Houle, 2003; Fox et al., 2000). Interestingly, the pattern of neural overactivation that is seen in AWS and not in AWNS is thought to reflect the lack of automatization normally observed in

AWNS (De Nil, Kroll, & Houle, 2001; De Nil et al., 2003). The findings from the current study using dichotic listening infer the same findings of this widespread right hemisphere activation for AWS. Furthermore, the recent findings by Choo et al. (2011) seem particularly relevant to the present results. These researchers found the overall size of the corpus callosum to be large in AWS compared to AWNS. A larger callosa presumably contains more white matter that would allow for more efficient interhemispheric processing, including dichotic listening tasks.

Directed attention task

There are limited studies on the effects of directed attention in dichotic listening tasks among AWS participants. Blood et al. (1986) examined the influence of attention during a dichotic listening task between AWS and AWNS. They found that both groups had an overall better performance (in excess of 98% accuracy) when attention was directed to the right ear. The groups differed in regard to the left ear with the AWS participants showing slightly poorer accuracy (still in excess of 92% accuracy) in identifying stimuli presented to the left ear. The present results partially agree with those of Blood et al. Our AWS and AWNS participants likewise performed better on right-directed attention tasks; however, performance accuracy did not reach 70%. Both groups showed poorer performance on the left-directed task (less than 52% accuracy) but did not differ significantly. Two possible reasons for the difference between Blood et al. and the current results are offered. First, Blood et al. required recall of spoken digits, while the current study used CV stimuli. It is possible that recall of spoken digits may allow for clearer processing of linguistic stimuli compared to CV stimuli. Second, the mean age of the participants used in Blood et al. were younger ($M = 24$ years) compared to the present participants ($M = 46$ years). There is research that indicates that right and left ear performance on dichotic listening tasks decrease with increasing age (Dolcos, Rice, & Cabeza, 2002; Jerger, Chmiel, Allen, & Wilson, 1994). Results from Jerger et al. showed that for males and females, right and left ear performance on dichotic listening tasks decreased with increasing age, with the decrease in left ear performance being significantly worse than right ear performance. The authors interpreted their findings to mean that binaural processing decreases with increasing age. A similar pattern was apparent for the AWS and AWNS participants in this study.

Foundas et al. (2004) used a direct attention CV task to determine whether AWS and AWNS differ in the way they process binaurally presented speech stimuli according to gender and handedness. These researchers found that among right-handed males, there was no significant difference between groups on directed attention tasks. These findings align with the present group of participants, all of whom were right-handed. However, Foundas et al. also noted that right-handed AWS females showed difficulty in being able to selectively attend to the right or left ear. Two right-handed females participated in this study. Examination of the individual results for these two participants indicated they were not noticeably different from the male participants; therefore, we are unable to confirm the gender-related differences reported by Foundas et al. It is of interest to note that the overall performance accuracy values for the AWS and AWNS participants reported by Foundas et al. ranged from approximately 25% to 70%, which nicely align with the present values (as opposed to Blood et al., 1986) and provide further support for the suggestion that digit recall dichotic listening tasks may provide clearer auditory processing than tasks using CV stimuli.

Conclusion

Westerhausen et al. (2009) suggest that directed attention tasks involve executive cognitive control processing that is not required of undirected attention tasks. Directed attention tasks are designed to specially assess dichotic listening in a top-down processing format. That is, when the participant anticipates verbal stimuli, there may be a priming effect, which activates the left hemisphere and therefore contributes to a stronger REA (Kinsbourne, 1970). The directed attention task was not revealing of laterality differences in AWS compared to AWNS. So it seems likely that the executive cognitive control required of these tasks may mask any essential laterality differences between AWS and AWNS. Interestingly, in this study it was the undirected attention task that was most revealing of laterality differences between AWS and AWNS. Undirected attention tasks presumably reflect bottom-up processing (Foundas et al., 2006; Kimura, 1967). Therefore, it is possible that this form of speech processing may be discriminating of AWS and AWNS.

In summary, the results from the present study provide support for our first prediction that AWS will show a less robust REA compared to AWNS when processing CV stimuli in an undirected attention task. The undirected attention results indicated that both AWS and AWNS have a REA for processing speech information, with a primary difference observed between groups in regard to the IID point at which a REA shifts to a LEA. This crossing-over point occurred later for AWNS indicating a strong left hemisphere advantage for processing speech. The earlier crossing-over for AWS would seem to indicate a stronger right hemisphere involvement for the processing of speech compared to AWNS. The results obtained for the directed attention task served to confirm our second prediction that AWS would not differ from AWNS. Both groups were highly similar in their performance on dichotic listening tasks when asked to deliberately direct their attention to a specific ear. The finding that AWS do not differ from AWNS during a directed attention task may reflect a different type of speech processing that is less discriminating of group differences in cerebral activation. Finally, the pattern of performance observed in this study generally confirmed our original predictions. Still, these results should be considered preliminary until validated by a larger sample size of AWS participants.

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Declaration of interest

The authors report no conflict of interest.

References

Asbjornsen, A., & Helland, T. (2006). Dichotic listening performance predicts language comprehension. *Laterality*, *11*, 251–262.

Biermann-Ruben, K., Salmelin, R., & Schnitzler, A. (2005). Right rolandic activation during speech perception in stutterers: A MEG study. *Neuroimage*, *25*, 793–801.

Blomgren, M., Nagarajan, S., Lee, J., & Alvord, L. (2003). Preliminary results of a functional MRI study of brain activation patterns in stuttering and nonstuttering speakers during a lexical access task. *Journal of Fluency Disorders*, *28*, 337–356.

Blood, G., & Blood, I. (1986). Relationship between specific disfluency variables and dichotic listening in stutterers. *Perceptual and Motor Skills*, *62*, 337–338.

Blood, G., & Blood, I. (1989). Laterality preferences in adult female and male stutterers. *Journal of Fluency Disorders*, *14*, 1–10.

Blood, G., Blood, I., & Newton, K. (1986). Effect of directed attention on cerebral asymmetries in stuttering adults. *Perceptual and Motor Skills*, *62*, 351–355.

Brady, J., & Berson, J. (1975). Stuttering, dichotic listening and cerebral dominance. *Archives of General Psychiatry*, *32*, 1449–1452.

Braun, A., Varga, M., Stager, S., Schulz, G., Selbie, S., Maisog, J., et al. (1997). Altered patterns of cerebral activity during speech and language production in developmental stuttering. An H2(15)O positron emission tomography study. *Brain*, *120*, 761–784. Q1

Broadbent, D. (1954). The role of auditory localization in attention and memory span. *Journal of Experimental Psychology*, *47*, 191–196.

Bryden, M., Munhall, K., & Allard, F. (1983). Attentional biases and the right-ear effect in dichotic listening. *Brain and Langauge*, *18*, 236–248.

Choo, A. L., Kraft, S. J., Olivero, W., Ambrose, N. G., Sharma, H., Chang, S. E., & Loucks, T. M. (2011). Corpus callosum differences associated with persistent stuttering in adults. *Journal of Communication Disorders*, *44*, 470–477.

Curry, F., & Gregory, H. (1969). The performance of stutterers on dichotic listening tasks thought to reflect cerebral dominance. *Journal of Speech and Hearing Research*, *12*, 73–82.

Cykowski, M., Kochunov, P., Ingham, R., Ingham, J., Mangin, J., Riviere, D., Lancaster, J., & Fox, P. (2008). Perisylvian sulcal morphology and cerebral asymmetry patterns in adults who stutter. *Cerebral Cortex*, *18*, 571–583.

De Nil, L., Kroll, R., & Houle, S. (2001). Functional neuroimaging of cerebellar activation during single word reading and verb generation in stuttering and nonstuttering adults. *Neuroscience Letters*, *302*, 77–80.

De Nil, L., Kroll, R., Lafaille, S., & Houle, S. (2003). A positron emission tomography study of short- and long-term treatment effects on functional brain activation in adults who stutter. *Journal of Fluency Disorders*, *28*, 357–380.

Dolcos, F., Rice, H. J., & Cabeza, R. (2002). Hemispheric asymmetry and aging: right hemisphere decline or asymmetry reduction. *Neuroscience and Biobehavioural Reviews*, *26*, 819–825.

Foundas, A., Corey, D., Angeles, V., Bollich, A., Crabtree-Hartman, E., & Heilman, K. (2003). Atypical cerebral laterality in adults with persistent developmental stuttering. *Neurology*, *61*, 1378–1385.

Foundas, A., Corey, D., Hurley, M., & Heilman, K. (2004). Verbal dichotic listening in developmental stuttering: Subgroups with atypical auditory processing. *Cognitive behavioural Neurology*, *17*, 224–232.

Foundas, A., Corey, D., Hurley, M., & Heilman, K. (2006). Verbal dichotic listening in right and left-handed adults: Laterality effects of directed attention. *Cortex*, *42*, 79–86.

Fox, P. T., Ingham, R. J., Ingham, J.C., Hirsch, T. B., Hunter Downs, J., et al. (1996). A PET study of the neural systems of stuttering. *Nature*, *382*, 158–162. Q2

Fox, P., Ingham, R., Ingham, J., Zamarripa, F., Xiong, J., & Lancaster, J. (2000). Brain correlates of stuttering and syllable production. A PET performance-correlation analysis. *Brain*, *123*, 1985–2004.

Hugdahl, K. (2011). Fifty years of dichotic listening research – still going and going and …. *Brain and Cognition*, *76*, 211–213.

Hugdahl, K., & Andersson, L. (1986). The ‘‘forced attention paradigm’’ in dichotic listening to CV syllables: A comparison between adults and children. *Cortex*, *22*, 417–432.

Hugdahl, K., Westerhausen, R., Alho, K., Medvedev, S., & Hamalainen, H. (2008a). The effect of stimulus intensity on the right ear advantage in dichotic listening. *Neuroscience Letters*, *431*, 90–94.

Hugdahl, K., Westerhausen, R., Alho, K., Medvedev, S., Laine, M., & Hamalainen, H. (2008b). Attention and cognitive control: Unfolding the dichotic listening story. *Scandinavian Journal of Psychology*, *50*, 11–22.

Jancke, L., Hanggi, J., & Steinmetz, H. (2004). Morphological brain differences between adult stutterers and non-stutterers. *BMC Neurology*, *4*, 23–28.

Jerger, J., Chmiel, R., Allen, J., & Wilson, A. (1994). Effects of age and gender on dichotic sentence identification. *Ear and Hearing*, *15*, 274–286.

Kimura, D. (1961). Cerebral dominance and the perception of visual stimuli. *Canadian Journal of Psychology*, *15*, 166–177.

Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. *Cortex*, *3*, 163–168.

Kinsbourne, M. (1970). The cerebral basis of lateral asymmetries in attention. *Acta Psychologica*, *33*, 193–201.

Neumann, K., Euler, H., von Gudenberg, A., Giraud, A., Lanfermann, H., Gall, V., et al. (2003). The nature and treatment of stuttering as revealed by fMRI: A within- and between-group comparison. *Journal of Fluency Disorders*, *28*, 381–410. Q3

Oldfield, R. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.

Orton, S. (1928). A physiological theory of reading disability & stuttering in children. *New England Journal of Medicine*, *199*, 1045–1052.

Preibisch, C., Neumann, K., Raab, P., Euler, H., von Gudenberg, A., Lanfermann, H., et al. (2003). Evidence for compensation for stuttering by the right frontal operculum. *Neuroimage*, *20*, 1356–1364. Q4

Quinn, P. (1972). Stuttering: Cerebral dominance and the dichotic word test. *The Medical Journal of Australia*, *2*, 639–643.

Riley, G. (1994). *Stuttering severity instrument for children and adults* (3rd ed.). Austin, TX: PRO-ED.

Rimol, L., Eichele, T., & Hugdahl, K. (2006). The effect of voice-onset-time on dichotic listening with consonant–vowel syllables. *Neuropsychologia*, *44*, 191–196.

Rosenfield, D., & Goodglass, H. (1980). Dichotic testing of cerebral dominance in stutterers. *Brain and Language*, *11*, 170–180.

Salmelin, R., Schnitzler, A., Schmitz, F., & Freund, H. (2000). Single word reading in developmental stutterers and fluent speakers. *Brain*, *123*, 1184–1202.

Satz, P., Bakker, D., Teunissen, J., Goebel, R., & Van der Vlugt, H. (1975). Developmental parameters of the ear asymmetry: A multivariate approach. *Brain and Language*, *2*, 171–185.

Tallus, J., Hugdahl, K., Alho, K., Medvedev, S., & Hamalainen, H. (2007). Interaural intensity difference and ear advantage in listening to dichotic consonant-vowel syllable pairs. *Brain Research*, *1185*, 195–200.

Travis, L. (1931). *Speech pathology*. New York: Wiley-Liss.

Van Borsel, J., Achten, E., Santens, P., Lahorte, P., & Voet, T. (2003). fMRI of developmental stuttering: A pilot study. *Brain and Language*, *85*, 369–376.

Walla, P., Mayer, D., Deecke, L., & Thurner, S. (2004). The lack of focused anticipation of verbal information in stutterers: A magnetoencephalographic study. *Neuroimage*, *22*, 1321–1327.

Westerhausen, R., & Hugdahl, K. (2008). The corpus callosum in dichotic listening studies of hemispheric asymmetry: a review of clinical and experimental evidence. *Neuroscience and Biobehavioural Reviews*, *32*, 1044–1054.

Westerhausen, R., Moosmann, M., Alho, K., Medvedev, S., Hamalainen, H., & Hugdahl, K. (2009). Top-down and bottom-up interaction: Manipulating the dichotic listening ear advantage. *Brain Research*, *1250*, 183–189.