DICHOTIC LISTENING AMONG ADULTS WHO STUTTER

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Abstract

Dichotic listening of auditory stimuli is used to assess brain lateralisation by simultaneously presenting different stimuli to the left and right ears to determine which syllable was perceived as being the clearest. There is a limited, albeit dated number of studies that have examined dichotic listening performance in adults who stutter (AWS) and the results remain inconclusive. The aim of this research was to investigate whether AWS show a difference in the magnitude of the right ear advantage (REA) in both undirected and directed attentional tasks when compared with adults who do not stutter (AWNS). There were 14 right-handed participants, consisting of seven AWS and seven age and sex matched AWNS controls. All participants were screened for normal hearing. They completed a dichotic listening task, which included undirected and directed attentional listening tasks. Participants were to select the consonant-vowel (CV) pair they heard the clearest. The interaural intensity difference (IID) was modulated randomly during the undirected attention task. The results for the undirected task revealed: (1) a significant REA for AWS for the IID conditions of 0 to +21 dB and significant left ear advantages (LEA) for IIDs of -15 to -21 dB; (2) a significant REA for AWNS for the IID conditions of -9 to +21 dB and significant LEAs for IIDs of -18 to -21 dB; (3) laterality index scores with a significant IID effect but no significant group or group-by-ear interaction effects using parametric statistics. Further analysis of laterality using non-parametric statistics found significant differences between the fluency groups. In general, the findings in this study were revealing of differences between AWS and AWNS when performing dichotic listening tasks with speech stimuli. The primary difference observed between groups was in regards to the IID point at which a previous REA became a LEA. This "crossing-over" point occurred later for AWNS, indicating a strong left hemisphere advantage for the processing of speech. The earlier "crossing-over" for AWS would indicate that the right hemisphere was activated sooner for the processing of speech compared to AWNS. This

activation of the right hemisphere is assumed to reflect more diffuse cerebral lateralisation for speech processing for the AWS and confirms past brain imaging studies. In the directed attention task, there was no significant difference between AWS and AWNS indicating that instances of stuttering may occur due to more automatic (bottom-up) speech processing. These findings have implications for theories of laterality and hemispheric asymmetry for phonological processing for AWS, which has been suggested to reflect a subgroup of AWS for whom cerebral dominance is related to their disfluency.

Introduction

Dichotic Listening

Dichotic listening is a non-invasive technique used to assess brain lateralisation and asymmetry when processing speech or non-speech auditory signals (Foundas, Corey, Hurley, & Heilman, 2006; Hugdahl, Westerhausen, Alho, Medvedev, & Hamalainen, 2008a). Dichotic listening has been said to literally mean listening to two signals at the same time, with one sound presented into the left ear, while another is simultaneously presented to the right ear (Hugdahl, et al., 2008a). Depending on the type of acoustic signals presented to the listener, an "ear advantage" has been found, with the signal presented to one of the ears perceived as more dominant (Rimol, Eichele, & Hugdahl, 2006). Research has shown that when linguistic stimuli in the form of a consonant-vowel (CV) are simultaneously presented into both ears, there is a right ear advantage (REA). That is, when participants are asked to report back on what they have heard, the signal presented to the right ear is more readily perceived (e.g., Asbjornsen & Helland, 2006; Hugdahl, et al., 2008a; Kimura, 1961; Tallus, Hugdahl, Alho, Medvedev, & Hamalainen, 2007). On the other hand, when non-speech stimuli, such as melodies are presented simultaneously to both ears, a left ear advantage (LEA) is found (Kimura, 1961).

The motivation for early dichotic listening tasks was based on examination of digit span recall in patients who were about to undergo surgery for lesions in various parts of the temporal lobe (left, right & subcortical) (Kimura, 1961). Based on the presentation of strings of differing digits to both ears simultaneously before and after surgery, it was found that the preoperative recall scores were higher for the right ear than for the left ear. This occurred for all groups of participants studied, regardless of the site of the lesion. The postoperative recall scores for those who had lesions in the left temporal lobe were lower for verbal information than that of participants with a right temporal lobe lesion. These findings were taken to indicate that the left temporal lobe is specialised for the recognition of verbal information, at least for the auditory modality. Since the right ear was presumably more strongly connected to the left temporal lobe than was the left ear, this finding suggested verbal material arriving along this auditory pathway had an advantage in being more reliably transmitted to the hemisphere, which was dominant for speech representation. It would then follow that, in participants with speech represented in the left hemisphere, recognition of verbal material arriving at the right ear should be more efficient (Kimura, 1961). This effect was termed a REA.

The findings in Kimura's (1961) study demonstrate that the right ear is more efficient than the left ear for the perception of speech regardless of the site of lesion. This effect was confirmed by the control group, who showed a strong REA in the absence of any brain lesion. Kimura put forward the idea that the REA is caused by several interacting factors. Firstly, monaural auditory input is strongly represented in the contralateral hemisphere. Secondly, the left hemisphere, especially for right-handed individuals is specialised in language processing. It was also postulated that auditory input delivered to the left ear, which is sent along the ipsilateral auditory pathways is suppressed or blocked by the information coming from the contralateral side. Lastly, Kimura suggested that the input to the left ear, which first reaches the contralateral right hemisphere, must be transferred via the corpus collosum to the left hemisphere where the language processing areas are located. The transfer of linguistic information from the right hemisphere to the left hemisphere results in a slight delay in processing. No such transfer/delay is found for the right ear, thereby favouring the right ear for speech processing.

Dichotic listening has also been used to investigate the functional properties of the left and right hemispheres. Kimura (1967) investigated ear superiority for melodies, where two different melodies were presented simultaneously to each ear and participants picked which two they heard from a group of four. Results indicated there were significantly more identifications made for melodies presented to the left ear than for the right ear. The results were taken to indicate a dissociation of auditory asymmetries depending on the type of stimulus presented and these asymmetries, in turn, reflect the functional differences between the left and right hemispheres. The predominance of the right temporal lobe in the integration of melodic patterns is reflected as a LEA.

Since Kimura's (1961, 1967) early work, a LEA has been found for a variety of non-verbal stimuli, such as musical chords, environmental sounds and emotion related sounds (Spajdel, Jariabkova, & Riccansky, 2007). Spajdel et al. (2007) investigated how musical practise effects hemispheric processing in 60 right-handed participants, consisting of 35 females and 25 males. Among the participants were 33 "musicians" (experience with music) and 27 "non-musicians" (no experience with music). The two dichotic listening tasks involved non-verbal stimuli, which consisted of environmental sounds and two-tone sequences. In addition, participants completed a dichotic listening task with CV syllables. Results showed that both musicians and non-musicians had a LEA for environmental sounds and two-tonal sequences (non-verbal stimuli). A REA was found for the CV syllables in both groups. This indicated no effect of musical experience on the LEA as both groups were shown to have a LEA for non-verbal stimuli. This finding was attributed to independent mechanisms that are engaged in the processing of these three stimuli, where a LEA is identified for non-verbal stimuli.

Models of REA

The REA has been explained with two prominent theoretical models concerning the processing of verbal information. These models implicate the role of the corpus collosum in which the left and right hemispheres interact. These theories include the structural model

(Kimura, 1961) and the attentional model (Kinsbourne, 1970), which are explored further in the following sections.

Structural Model

The structural model was postulated by Kimura (1961) where the REA was thought to reflect the asymmetric ascending input of auditory information from the temporal cortex. This auditory input projects from the cochlea of the right ear to brainstem structures and then via contralateral connections through the thalamus to the left temporal cortex. This model holds that the interaction of these symmetric anatomical connections and a left hemisphere processing advantage for language, influences performance in dichotic listening tasks, resulting in a REA. This typical right ear bias is induced by a left hemispheric processing advantage for verbal auditory stimuli, often referred to as a *bottom-up process* (Foundas, et al., 2006; Kimura, 1961, 1967; Satz, Bakker, Teunissen, Goebel, & Van der Vlugt, 1975; Westerhausen & Hugdahl, 2008). An illustration of this concept can be seen in Figure 1.

Penna et al. (2007) used a magnetoencephalogram (MEG), which is an imaging technique for examining the activation of different regions of the brain, to investigate the responses of the primary auditory cortices elicited by dichotic CV syllables in healthy participants (seven females & three males). The researchers sought to evaluate the interactions between ipsilateral and contralateral auditory pathways during a dichotic listening task. All participants showed a REA in the verbal dichotic listening task, as indicated by the MEG. Their results extended the notion put forward by Kimura that an asymmetry occurred between the right and left auditory cortices during a dichotic listening task using CV syllables. The left hemisphere showed a strongly inhibited ipsilateral auditory pathway, thus favouring the perception of the input from the right ear. When examining the right hemisphere, both the ipsilateral and contralateral auditory pathways were inhibited to the same extent. These results provide compelling physiological evidence that the right ear is the advantaged ear. This occurs because the input reaches the left hemisphere (dominant for language) via a preferential route, which suppresses the ipsilateral left auditory pathway.

Bottom-up processing of dichotic listening has also been explored according to sex differences. Weekes, Zaidel and Zaidel (1995) examined polar sex (i.e., male & female) and spectral sex (i.e., masculinity & femininity) differences on hemispheric lateralisation using a dichotic listening task, with CV syllable pairs. Their results found no significant differences across the groups. There were 30 participants, who consisted of 15 females and 15 males. Participants listened to dichotically presented CV pairs and were to select from the cards in front of them what they heard. A percentage was computed for the correctly identified sounds heard in each of the two ears. The overall accuracy scores did not differ significantly between sexes in the high and low masculinity groups. These findings suggested different sex and sex role attribution groups have similar results when processing speech information. They suggested that any group differences in dichotic listening would result from differences in laterality rather than due to polar or spectral sex.

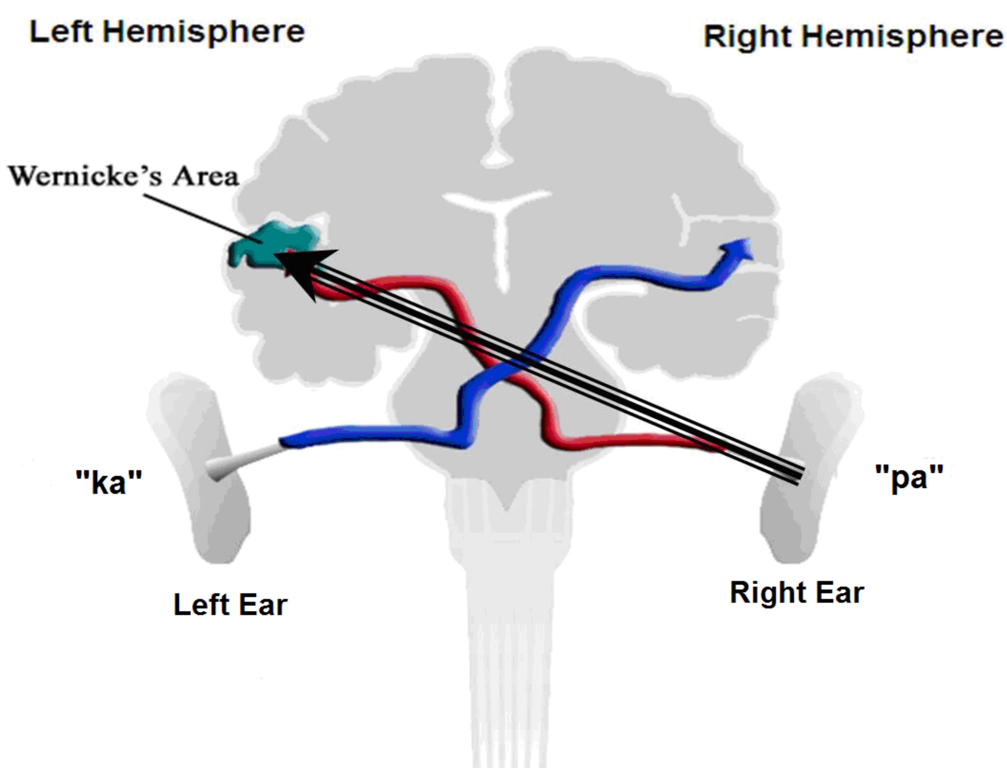


Figure 1. Physiological depiction of bottom-up processing and a right ear advantage (REA) for the perception of "pa" during an undirected dichotic listening task. Messages from the right ear are directly sent to Wernicke's Area, which is important for language. The left ear is projected to the right hemisphere and then needs to cross the corpus collosum to be sent to the language region of the brain (revised from Marek, 2008).

Bellis and Wilber (2001) investigated the effects of age and sex on interhemispheric function across the life span of the normal adult. The main purpose of their study was to determine whether aging and sex effect performance on three measures known to be sensitive to interhemispheric dysfunction, which included a dichotic measure. There were 120 healthy adults who took part in their study, with 15 males and 15 females in four age groups (20–25 years, 35–40 years, 55–60 years & 70–75 years). The dichotic task involved participants listening to dichotically presented digits and selecting what they heard using free recall. This was scored as a function of percent correct per ear. An index of interhemispheric integrity was then calculated by subtracting the left ear percent correct score from the right ear percent correct score, yielding a measure of the REA. Results revealed that for males and females, both right ear and left ear performance on the dichotic listening task decreased with increasing age. However, the decrease in left ear performance was more marked than the right ear, leading to an increase in the REA with advancing age. Their results indicate binaural processing decreases with increasing age and that the decrease in the size of the REA with aging occurs earlier for males than for females, who demonstrate preserved function until the postmenopausal years.

In summary, the structural model of dichotic listening is based on the interaction of cerebral laterality, with the signals from the cochlea being projected to the auditory cortex in the ipsilateral and contralateral cerebral hemispheres. However, the contralateral projections are more robust in the opposite hemisphere to the originating ear. Therefore, there is an advantage for the speech signals presented to the right ear to be transmitted immediately to the language areas in the left hemisphere. This effect is found in both males and females in all age groups. The signals presented to the left ear have been reported to show a delay in transmission to the language areas in the left hemisphere, due to the fact that they need to be transmitted via the corpus collosum before they can be processed (Westerhausen & Hugdahl, 2008).

Attentional Model

The second model of dichotic listening considers the role of attention during participation in a listening task. Kinsbourne (1970) believed that past reports of REA (i.e., Kimura, 1961) may not have been entirely due to bottom-up processing. Kinsbourne (1970) was likely the first to examine the effects of attention on dichotic listening tasks. The aim of Kinsbourne's study was to determine whether deliberate (i.e., directed) attention in a dichotic listening task could either enhance or decrease the REA found in past undirected tasks (Kimura, 1961, 1967). Each hemisphere primarily attends to the contralateral ear. Thus, the simple act of anticipation of verbal stimuli may preferentially activate the left hemisphere, resulting in an enhanced REA. This right ear bias may result from either or both of two processes. These include (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, both resulting in a REA. This process of anticipation by the left hemisphere for speech stimuli is referred to as *top-down processing*. An illustration of this concept is shown in Figure 2.

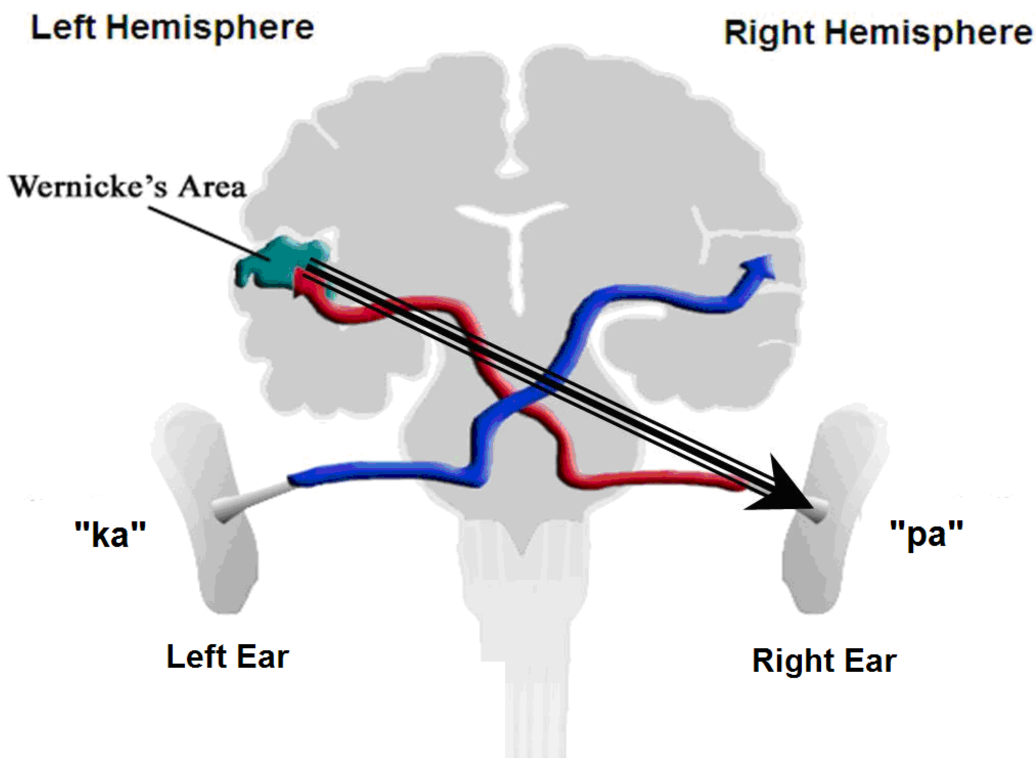


Figure 2. Physiological depiction of a right ear advantage (REA) for "pa" during a directed attention dichotic listening task. When deliberate attention is placed on listening for language, the language region in the left hemisphere (Wernicke's Area) anticipates speech, with the direct pathway being more dominant in the right ear for the processing of syllables (revised from Marek, 2008).

Hugdahl and Anderson (1986) examined dichotic listening in a directed attention task. The aims of the study included comparing instances of a LEA when deliberately attending to the right ear and instances of a REA when deliberately attending to the left ear when recalling CV syllables during a dichotic listening task. If a REA was found to exist in a directed-left task, it would indicate attention alone cannot explain the REA in dichotic listening tasks. In the directed-right attention task, significantly more recalls were from the right ear. In the left-directed attention task, significantly more recalls were from the left ear. Results revealed significantly better recall from the unattended right ear. Therefore, the findings indicate that selected attention to either the right or left during a dichotic listening task served to either enhance or limit the REA. However, in spite of this alteration the REA was found to be intact.

Hugdahl et al. (1999) used the positron emission tomography (PET) technique to evaluate cortical activation under conditions of dichotic presentation of verbal CV syllables versus non-verbal musical instrument stimuli. The PET technique is a form of neuroimaging used to study changes in regional neural activity indexed as regional cerebral blood flow (rCBF) in the critical brain areas during a dichotic listening task (Hugdahl, et al., 1999). A total of 12 right-handed males participated in the study. Two parameters were manipulated, the stimulus (CV syllables or musical instruments) and the direction in which participants were to attend. In the "attend both ears" condition, participants were instructed to attend to both ears and press the button whenever they detected the target stimulus. In the "attend left ear" condition, they were instructed to focus attention to the left ear, and only press the button when they detected the target in the designated ear (left ear). In the "attend right ear" condition, they were instructed to focus attention to the right ear and only press the button when they detected the target in the designated ear (right ear). For each of the three attentional conditions, they were also told before each scan to listen to a specific type of stimuli. Results showed generally larger activation over the contralateral parietal lobe. That is, when attention was directed to the left ear, activity increased over the right hemisphere and visa versa. The results also showed a REA when participants were to "attend both ears" and during the "attend right ear" tasks. However, a LEA was found when participants were instructed to "attend left ear". In the musical stimuli conditions, participants showed a LEA for the "attend both ears" condition, however no significant differences were found for the conditions of "attend right ear" or "attend left ear". These findings indicate that the absence of activation asymmetries in the undirected condition suggests an ear advantage in this condition is not attentional but rather related to speech language dominance and crossed auditory pathways (i.e., bottom-up processing). In contrast, the asymmetric activation seen in the directed condition suggests that an ear advantage is modulated by attention arousal asymmetries (i.e., top-down processing).

Using binaurally presented CV stimuli, Foundas et al. (2006) wanted to determine whether left-handed and right-handed people differed in both the undirected and directed dichotic listening tasks. They also examined the effect of ear report instructions on dichotic listening performance. Binaural presentation of CVs yielded the most robust REA when individuals were to report what they perceived on each trial. The results showed a REA when attention was undirected, with a more robust REA when attention was directed toward the right ear and a LEA was found when attention was directed to the left ear. This pattern did not vary significantly from males and females. The results showed the relationship between attention and change in lateralisation (directed versus undirected) was significantly different for left-handed and right-handed people and therefore indicated the ability to modulate the strength of the REA by using attentional tasks.

The results from Foundas et al. (2006) demonstrate that directing attention can enhance processing of speech stimuli in the attended ear. The researchers concluded that there are a number of explanations for this right ear processing advantage for binaurally presented verbal stimuli, including a combination of anatomical, perceptual and cognitive operations. According to the attentional model, right-handers have a greater rightward attentional bias than do left-handers. Thus, in the left-directed attention condition, right-handers may show a greater right-to-left reversal of their natural bias (i.e., a greater modulation of the REA from the free recall to the directed attention condition). In contrast, left-handers may show less of a rightward bias in the undirected condition than right-handers. In the directed-right condition, left-handers may have a greater shift in laterality compared to right-handers. These findings support the model that attention increases the salience of the stimuli occurring at the directed location and deliberate listening to the left ear may override the right sided attentional bias induced by auditory verbal information, which selectively activates the left hemisphere.

Hugdahl et al. (2001) used the shared database of the Nordic Centre of Excellence Consortium, which consists of 1500 healthy individuals from the ages of five to 89 years, to assess the effects of top-down attention modulation on the strength of the REA. When participants were instructed to focus attention on the right ear, the REA was significantly increased. When they were instructed to focus their attention to the left ear, the REA was significantly decreased and often shifted to a LEA. It was concluded that instructions to focus attention to the left or right ear stimulus modulated the strength of the REA.

In summary, the attentional model assumes that anticipation of incoming verbal signals serves to activate the left hemisphere, where a priming affect occurs for subsequent processing. This activation is automatic and results in a bias favouring the left hemisphere and therefore, the contralateral right ear. This allows acoustic information in the right ear to be processed faster, which was seen with more right ear reports (Westerhausen & Hugdahl, 2008). Directing attention to the right ear typically increases the magnitude of the REA, whereas instructing the participant to attend to their left ear can decrease the magnitude of the REA or result in a LEA (Hugdahl et al., 2008b; Westerhausen & Hugdahl, 2008).

Interaural Intensity Differences

Manipulations of the loudness of CV syllables presented to the left and right ears during a dichotic listening task have been examined. This alteration in sound level has been 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 REA. Tallus et al. (2007) conducted a study in which the aim was to modulate the strength of the REA by manipulating the IID between the right ear and the left ear inputs. Thus, giving the higher intensity speech sounds a better chance of being processed irrespective of ear delivery. Twenty right-handed participants (13 females & seven males) were asked to complete a dichotic listening task where the REA was manipulated by systematically varying the IID. One third of trials were preceded with a greater intensity in the left ear and one third had greater intensity in the right ear. The remaining trials had equal intensity in both ears. The results of the study showed that by manipulating the IID, the strength of the REA could be modulated. Tallus et al. suggested that modulating the strength of the REA through IID manipulation could be a way to explore the nature of impairments in regards to the way the speech is processed in clinical populations (such as those with schizophrenia) since it would allow for more detailed quantification of the auditory processing of these populations.

Hugdahl et al. (2008b) investigated the effects of IIDs in healthy participants, using the well established CV dichotic listening paradigm. By gradually increasing the IID in decibel (dB) increments, they examined the minimum intensity difference required to shift from a REA to a LEA. A total of 33 participants took part in an undirected listening task, where the IID was modulated, either with the left ear being more intense or the right ear being more intense. The data were analyzed in an intensity difference (15 steps) x ear (left or right) repeated measure analysis of variance (ANOVA). The results revealed a clear baseline shift in favour of the right ear at 0 dB (i.e., no IID between the left & right ear intensity), when the intensity was modulated to favour the left ear, a REA persisted until the interaural intensity was 9 dB more intense in the left ear. This showed that there was a preference for selecting speech presented to the right ear up to a sound pressure level IID of 9 dB before yielding a LEA.

Dichotic Listening and Stuttering

Dichotic listening appears to have some value as a means of determining cerebral dominance for language without resorting to somewhat invasive brain imaging procedures or inferring dominance for language on the basis of characteristics such as handedness. A body of research is available regarding the dichotic listening performance of adults who stutter (AWS). This research has been motivated as a result of theories underlying the cause of stuttering. In past research the role of cerebral dominance in AWS has been investigated. The general idea behind these theories is that AWS show atypical cerebral laterality.

Since the early 1920's it was proposed that the cause of stuttering was due to incomplete cerebral dominance, where it was believed that language had not lateralized to the appropriate hemisphere, which therefore caused disfluency. Early research in this area focused on features such as handeness (Bryngelson & Clark, 1933; Orton, 1928; Rosenfield & Jerger, 1984; Travis, 1931). The research related to handeness in stuttering was inconclusive so the cerebral laterality theory lost popularity. Later, Jones (1966 as cited in Rosenfield & Jerger, 1984) was to operate on four AWS patients who had cerebral disease. In order to obtain preoperative information, he injected sodium amytal into the carotid artery, which anesthetizes the ipsilateral hemisphere. This usually results in the patient becoming aphasic (loss of the ability to articulate ideas or comprehend spoken or written language) when the injection is placed into the hemisphere dominant for speech. The four AWS became aphasic when the sodium amytal was injected to both the right and left hemispheres. This suggested that for AWS, both hemispheres were contributing to language production.

More recently Foundas et al. (2003) used volumetric magnetic resonance imaging (MRI) to measure prefrontal and occipital volumes in AWS compared with adults who do not stutter (AWNS). They also examined the association between anatomic measures, severity of stuttering and language abilities to determine if there was a relationship between language processing abilities and anatomic measures. The participants included 16 AWS and 16 AWNS, with an equal number of males and females in each group. The findings showed that AWS had atypical prefrontal and occipital lobe size and asymmetries compared with AWNS. Deficits in language processing were found in AWS, which were associated with reductions in brain volume. Their findings supported the theory that AWS have atypical cerebral dominance which may be due to differences in their anatomical structures. Therefore, the processes which are mediated by these atypical structural areas such as language processing are also likely to be atypical when compared with AWNS.

Dichotic listening techniques have been used to determine cerebral lateralisation for verbal stimuli and non-verbal stimuli for AWS. Curry and Gregory (1969) compared the performance of AWS and AWNS on dichotic listening tasks. Their participants consisted of 20 AWS and 20 AWNS who were identical age and sex controls (19 males & one female). All participants were right-handed and had normal hearing. There were four dichotic listening tests, including the Dichotic Word Test (DWT), where consonant-vowel-consonant (CVC) words of high familiarity were used, the Dichotic Environmental Sounds Test (DEST), where identification of short segments of environmental sounds were used. The third test was the Dichotic Pitch Discrimination Test (DPT), where multi-choice double pitch discrimination tasks were undertaken and the fourth test was the Monotic Word Memory Test (MWMT) using the presentation of groups of words, after which they attempt to recall as many words as possible. Results indicated that of their four tests, only the DWT showed an apparent difference between the two groups in ear superiority. It was found that 75% of AWNS achieved higher scores for their right ear on a verbal task, whereas 45% of AWS had scores higher for their right ear. This difference between groups was shown to be significant. The differences seen between AWS and AWNS were interpreted as reflecting differences within the ipsilateral and contralateral auditory pathways between the fluency groups.

Quinn (1972) investigated dichotic listening performance, replicating Curry and Gregory's (1969) study with a larger sample size. There were 60 right-handed AWS and 60 right-handed AWNS. Participants listened to 144 dichotically presented words. Once they heard the presented words, they wrote down as many as they could recall. The recall scores were noted for each participant, which included their right ear score, left ear score and between-ear score. There was no significant difference in the between-ear scores for AWS and AWNS groups. However, the direction of dominance was reversed in 20% of the AWS group, indicating instances of a LEA for speech processing that was not evident in the AWNS group.

Brady and Berson (1975) examined dichotic listening in 35 AWS and 35 AWNS right-handed participants. Participants were to circle what they heard when presented with CV syllable pairs. The results showed that none of the AWNS showed a LEA (i.e., a reversal of the REA), in contrast to 17 % of AWS who showed a LEA. This investigation indicated that AWS showed a weaker REA and smaller between-ear differences than AWNS. However, these differences were small in magnitude and limit inferences about the role of cerebral dominance in AWS.

Rosenfield and Goodglass (1980) investigated whether AWS differed from AWNS in the degree of lateralisation of left hemisphere dominant (CVs) and right hemisphere dominant (music) stimulus processing. A dichotic listening task was carried out using CV syllables, where participants indicated what they heard. Non-verbal stimuli (music) were also presented with two different melodies presented simultaneously followed by four binaural melodies. Participants were instructed to identify which two passages had been played dichotically. The same tasks were carried out one week later to determine stability of their laterality determinations over time.

Results showed both AWS and AWNS had a significant REA for CVs, while for music the AWS showed a non-significant LEA and AWNS showed a significant LEA. The results revealed that AWS and AWNS did not differ significantly when performing the CV task, however the AWS did perform to a level more inferior to that of AWNS. The finding that more AWS than AWNS show atypical lateralisation, suggests a subgroup of AWS for whom problems of cerebral dominance are related to their disfluency (Rosenfield & Goodglass, 1980).

Blood and Blood (1986) investigated the relationship between stuttering and auditory function using 86 participants, all of whom stuttered. The dichotic listening task involved 120 pairs of synthetically generated stop consonants combined with the /a/ vowel. Results showed that 57% of AWS had a REA, 17% had a LEA and 26 % showed no ear preference. The results of the study were taken to support the theory that among some AWS processing of auditory speech information may invlove diffuse lateralisation across the hemispheres.

Blood, Blood and Newton (1986) examined whether there was a difference in the performance of AWS and AWNS on directed and undirected attention a dichotic listening tasks. Nine male AWS and nine male AWNS engaged in a dichotic listening task consisting of 20 pairs of naturally spoken digits. During the undirected attention task participants were to recall the digits presented to both ears (four numbers). In the directed attention task they were to report the digits in the ear they were instructed to attend to. The AWS group displayed a slightly different pattern of results compared to AWNS. In the undirected attention task, AWS showed no significant difference between the right and left ears. The AWNS participants showed a significantly better right ear score compared to left ear score in the undirected attention task. Both AWS and AWNS had significantly more responses for the right ear in the attentional task. The difference found between the fluency groups was due to significant differences in the left ear scores across conditions, where AWS did more poorly than AWNS on the directed-left task. The results show AWS tend to do more poorly on attending to the left ear. This may indicate that for AWS there is a more even spread of listening in both the right and left ears (both the left & right hemispheres), suggesting that attentional directions may confuse AWS or their processing strategies are incompatible with specific listening directions.

Blood and Blood (1989) investigated ear preference for a group of AWS and AWNS. There were 72 participants, consisting of 18 male and 18 female in each fluency group (AWS & AWNS). The dichotic listening task used 36 word pairs, where participants pointed to one of the cards placed on the table in front of them that reflected what they heard. For male AWNS, results found 78% had a REA, 11% showed no preference and 11% showed a LEA. For the male AWS, results showed that 72% had a REA, 17% showed no ear preference and 11% showed a LEA. For the female AWNS group, 72% showed a REA, 11% showed no ear preference and 17% had a LEA. For the female AWS group 67% had a REA, 11% showed no preference and 22% showed a LEA. No significant differences were found between males and females with each group. Based on the calculation of a laterality quotient, significant differences were found between AWS and AWNS in terms of the strength of the REA. The AWNS participants showed a stronger laterality quotient than the AWS participants. This finding was taken to suggest that AWS and AWNS both show a REA however, AWS had a reduced REA magnitude compared to AWNS during a dichotic listening task using speech stimuli.

Most recently, Foundas et al. (2004) investigated dichotic listening performance in AWS and AWNS participants. It was predicted that in both directed and undirected attention tasks AWS would be more likely to have atypical auditory laterality (reduced REA or a LEA) than AWNS. The study involved 18 AWS and 28 AWNS, who varied in handedness. Participants reported which stimuli they heard in three conditions, which included an undirected attention task, a directed-right attention task and a directed-left attention task. Results indicated that during undirected and directed-left conditions, the AWS group with stronger right hand preferences made left ear responses significantly less frequently than those with stronger left hand preferences. When attention was directed-right, right hand preference was associated with significantly more right ear responses. For AWS, left hand preference was associated with smaller lateralisation shifts in magnitude when attention was directed-right. Perhaps the most important result was that verbal dichotic listening performance was found to differ across fluency groups. While these results show right-handed AWS had a REA, the magnitude of the REA was lower compared to AWNS.

Summary of Dichotic Listening and Stuttering

Past research examining dichotic listening in AWS can be summarised as follows: First, it appears both AWS and AWNS show a REA for the processing of linguistic information. This effect has been evident in undirected and directed attention tasks. Second, while AWS show a REA most research indicates the magnitude (or strength) of the REA is less robust compared to AWNS. This lower magnitude is indicated by greater instances of either a LEA or no ear advantage during dichotic listening of CV stimuli compared to AWNS. Third, the nature of the REA magnitude differences in AWS has not fully been explored. A better understanding of the magnitude differences in dichotic listening of AWS compared with AWNS should assist in clarifying the role of cerebral dominance in AWS. Finally, examination of dichotic listening using IID is uniquely suited to assessing the magnitude differences in REA. To date, there have been no attempts to evaluate AWS using IID in dichotic listening tasks.

Statement of the Problem

Dichotic listening is used to assess brain lateralisation with the structural (bottom-up processing) and attentional models (top-down processing) indicating two different ways in which auditory information is processed. Bottom-up processing occurs when the stimulus presented to the cochlea is projected to the auditory cortex with strong evidence of a REA. This is due to the direct pathway to the language region in the contralateral left hemisphere. Top-down processing occurs when participants are instructed to deliberately attend to a particular ear, which can enhance or reduce the REA. The enhancement of the REA is due to a priming effect of the left hemisphere for speech stimuli. Attempts to examine bottom-up and top-down features of dichotic listening have been made by directed and undirected listening, as well as changing the IID. These studies have shown that the magnitude (or strength) of the REA can be successfully manipulated. Interestingly, past research examining AWS has shown that the magnitude of the REA is less robust compared with AWNS. These findings could be due to the difference in the cerebral lateralisation of AWS compared with AWNS and suggests a reversal in the auditory and motor speech language areas of the brain. Ideally, employing a methodology specifically designed to manipulate the magnitude of the REA would be useful to clarify speech processing differences in AWS and AWNS. The purpose of this study was to investigate cerebral lateralisation of speech stimuli between AWS and AWNS using dichotic listening tasks. The following null hypotheses were proposed:

1. *There will be no significant difference in REA magnitude between AWS and AWNS in an undirected attention dichotic listening task.*
2. *There will be no significant difference in the REA magnitude between AWS and AWNS in a directed attention dichotic listening task.*

To test these null hypotheses, the following research questions were developed:

1. *Do AWS and AWNS differ in the magnitude of the REA in an undirected attention dichotic listening task?*
2. *Do AWS and AWNS differ in the magnitude of the REA in a directed attention dichotic listening task?*

Method

Participants

AWS participants. Seven right-handed AWS, consisting of five males and two females took part in the study. Participants were recruited through the local Christchurch, New Zealand chapter of Speak Easy which is a self-help group designed for those who stutter. The general characteristics of the AWS group can be found in Table 1. The AWS participants ranged in age from 28 to 61 years with a mean of 46 years. An initial criterion for inclusion was the previous diagnosis of a fluency disorder. All AWS participants were self-reported to stutter and were asked to rate their stuttering severity on a scale of 1 (mild) to 10 (severe). All AWS participants indicated no history of neurological disease and all participants reported they had or were currently receiving speech therapy for their disfluency. The researcher also calculated a percentage of stuttering displayed by each AWS participant based on oral reading of 'The Grandfather Passage' (Darley, Aronson, & Brown, 1975). Using the criteria established by Yairi and Ambrose (2004) the presence of stutter like disfluencies (SLD) was determined. A SLD consisted of either a sound/syllable repetition or an (in)audible prolongation. The percent of disfluency at the time of data collection ranged from 1 to 5% for the AWS participants. 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 dBHL 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. A copy of the Edinburgh Handedness Inventory Questionnaire can be found in Appendix I.

AWNS participants. Seven right-handed AWNS participants acted as age and sex matched controls. The AWNS participants were recruited from within the University of Canterbury community, as well as through personal acquaintances. The general characteristics of the AWNS group can be found in Table 2. The AWNS participants ranged in age from 26 to 61 years with a mean of 46 years. Audiological screening at 500, 1000, 2000 and 4000 Hz was also completed, with the inclusion criterion being the same as AWS participants. All AWNS participants were judged as being right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). The AWNS participants indicated no history of neurological disease. None of the AWNS participants reported receiving speech and language therapy. The study was given ethical approval by the University of Canterbury Human Ethics Committee and all participants read the information sheet and provided written informed consent. A copy of the information sheet and consent form can be found in Appendix II.

Table 1. General characteristics of AWS participants. The table includes sex, age, handedness, self-rating of severity, disfluency, footedness, history of speech therapy, family history and age of stuttering onset.

Participant	Sex	Age (Years)	Handedness*	Self Rating of Severity	Disfluency Percent (%)	Footedness	History of Speech Therapy	Family History of Stuttering	Age of onset of disfluency (Years)
1	Female	55	100%	7	3	Right	Yes	No	7
2	Male	57	50%	4	2	Right	Yes	Yes	4
3	Male	39	100%	5	5	Right	Yes	No	8
4	Male	28	100%	5	3	Neither	Yes	No	13
5	Male	61	100%	9	1	Right	Yes	No	4
6	Female	56	83%	4	1	Left	Yes	Yes	13
7	Male	28	100%	7	3	Right	Yes	No	2

* All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

Table 2. General characteristics of AWNS participants. The table includes sex, age, handedness, footedness, history of speech therapy, family history of stuttering.

Participant	Sex	Age (years)	Handedness*	Footedness	History of Speech Therapy	Family History of Stuttering
1	Female	56	100%	Right	No	No
2	Male	57	100%	Right	No	No
3	Male	38	100%	Right	No	No
4	Male	26	100%	Right	No	No
5	Male	61	83%	Right	No	No
6	Female	58	100%	Right	No	No
7	Male	26	100%	Right	No	No

* All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

Materials and Stimuli

A calibrated Grason-Stadler Inc. (GSI) 60 audiometer, using EAR3A insert earphones and pure tone stimuli were used to conduct the hearing screens. The dichotic listening stimuli consisted of six CV syllables. These syallables included /ba/, /da/, /ga/, /pa/, /ta/ and /ka/, thus resulting in three unvoiced (/pa/, /ta/ and /ka/) and three voiced (/ba/, /da/ and /ga/) syllables. A recording of the CV tokens was made using an adult male native speaker of New Zealand English. Adult male speakers have been used to record these same stimuli in past studies examining IIDs in dichotic listening tasks (Tallus, et al., 2007).

Dichotic stimuli were delivered through Sennheiser HD215 headphones driven by an InSync Buddy USB 6G sound card attached to a laptop computer. For calibration, the headphones were placed on a Brüel & Kjær Type 4128 Head and Torso Simulator (HATS) connected to a Brüel & Kjær 7539 5/1-ch. Input/Output Controller Module. The 1-second average A-weighted sound level of each syllable sample was measured using 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 testing.

A specially designed software programme was used for presenting the CV syllables, analysing the responses and displaying subsequent results. The CVs were paired to create all six combinations of the three voiced CVs, and all six combinations of the three unvoiced CVs. The pseudorandomisation 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 pseudorandomised 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 consecutive trials and (d) no repetition of a syllable pair in two consecutive trials.

The randomisation for the directed attention task was also accomplished with this programme. Attention was randomly directed to each ear with no more than two consecutive presentations being to the same ear. There were the same number of trials with attention directed to each ear. Half of the participants started with the right ear and the other half with the left ear, which was again randomised. The hearing screens and dichotic listening tasks took place in a sound-treated booth within the University of Canterbury Speech and Hearing Clinic.

Procedure

Each participant was given an information sheet and consent form regarding the purpose and procedures of the study, which they were asked to read and sign. 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 had an adverse effect on the performance related to the undirected task. That is, performing an attention based task first may have served to prime the participants in later tasks.

All the dichotic listening tasks were digitally controlled using an Acer laptop computer. Each participant was seated in front of the laptop in a relaxed position, where the instructions prior to commencement were given verbally to them. The instructions were as follows:

> *"You will be required to complete some listening tasks, I will go through the instructions at the beginning of each task and you will also have the instructions displayed on the screen in front of you. All tasks should take approximately 40 minutes to complete."*

Undirected Dichotic Listening 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 iterative process, the participant was required to move a linear slide bar 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. The display screen seen by participants for one of the CV stimuli for the perceptual calibration task can be seen in Figure 3. The verbal instructions for the perceptual calibration task were as follows:

> *"You are required to listen to the repeating speech sounds and move the slider to a place where the sounds appear to be coming from both ears equally. The sounds should feel like they are in the centre of your head. The slider may not necessarily be in the centre for each sound. Click 'continue' when you have finished with each speech sound, there are six in total. I will then give you the instructions for the following task."*

Once the interaural intensity balance was complete, participants commenced with the undirected dichotic listening task. During this task, the IID was randomly varied for each ear. Each participant was given verbal instructions and told that the instructions would also be displayed on the screen. The on-screen instructions and the display screen after listening to each presentation of the paired stimuli can be seen in Figure 4. The verbal instructions given to participants are as follows:

"You will hear speech sounds played into both ears at the same time. You are then to select from the screen which sound you heard. If you hear both speech sounds, please indicate which was heard more clearly. There will be breaks in this task, where you can select to have a break or to continue. It may be easier to close your eyes while listening to each presentation. The instructions for this task are displayed on the screen in front of you. Once you have read these, click 'continue' and the first presentation will start immediately. This task will take approximately 20 minutes."

Figure 3. Screenshot of the perceptual calibration task, where participants were to move the slider to a position where the speech sounds sound exactly balanced in both ears i.e., in the centre of their head. This is the screen that appeared for each of the six CV syllables.

Figure 4. Screenshot for the undirected listening task, where participants were instructed to select the sound they had heard (left panel). A screenshot of an example for one of the speech sound combinations (right panel).

Directed Attention Dichotic Listening 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. The calibration was designed to ensure there were no perceptual interaural differences for the CV stimuli for each participant. Once the CV intensity levels were calibrated the directed attention task commenced. This task involved the participants deliberately placing their listening attention 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. The on-screen instructions can be seen in Figure 5. 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. Examples of the screenshots showing the right and left attention conditions can be seen in Figure 6. The verbal instructions given to participants were as follows:

> *"You will again hear speech sounds played into both ears at the same time. In this task you are required to focus your attention to either the left or right ear and then select the speech sound you hear in that ear. When you are required to listen to what is played in your left ear, an arrow will point to the left side of the screen. When you are required to listen to what is played in your right ear, an arrow will point to the right side of the screen. Again there will be breaks in this task, where you can select to have a break or to continue. The instructions for this task are also displayed on the screen in front of you. Once you have read these, click 'continue' and the first presentation will start immediately. This task will take approximately 20 minutes."*

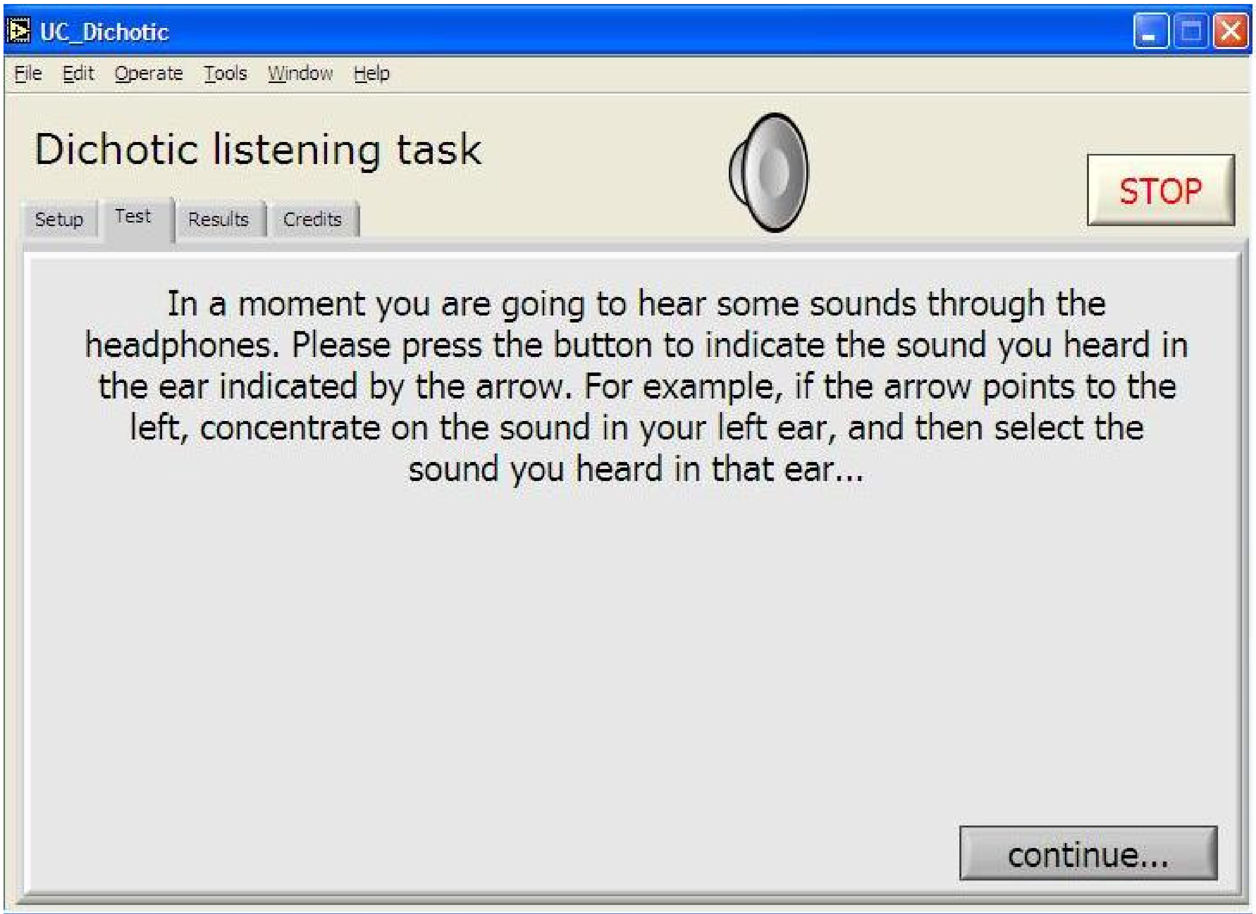


Figure 5. Screenshot of instructions for the directed listening task, where participants were instructed to focus their attention toward the ear indicated by the arrow.

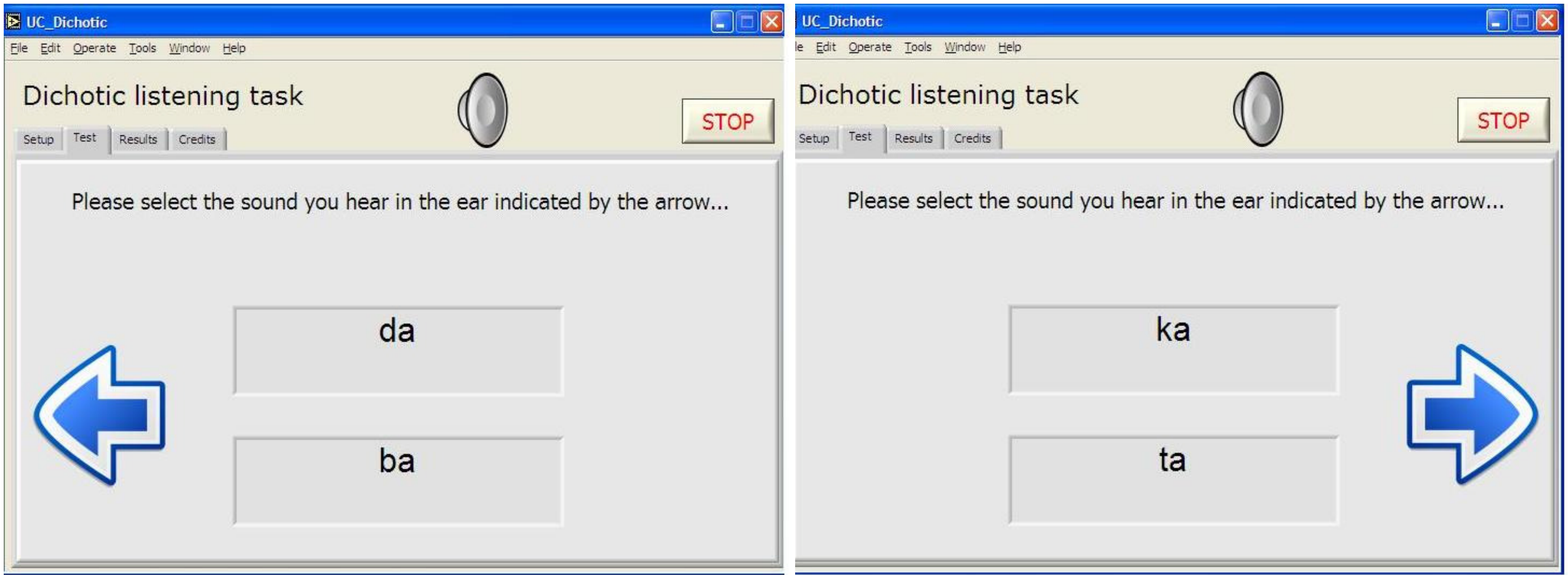


Figure 6. The screenshot for the directed attention task, where the options of speech sounds are shown after presentation and the participants are required to select the sound they hear in the attended ear. An example of the screenshot for the directed-left attention task is shown in the left panel and an example of the screenshot for the directed-right task is shown in the right panel.

Data Analysis

Group means for each presentation type (undirected & directed attention tasks) were obtained for each fluency group. The magnitude of these differences was compared, using the correct report of responses for the right ear and those obtained for the responses for the left ear. The IID was varied using a range of -21 dB to 21 dB, where -3 to -21 dB indicated greater intensity 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. A laterality index was also used for the analysis of the IID, using the formula [(RE-LE)/(RE+LE)] x 100, where RE and LE stand for the number of responses reporting the right or left ear speech stimuli, respectively. This analysis shows the change in the degree of REA between two intensity levels, where there is a reduction in the magnitude of REA as the stimulus intensity level is increased for the left ear. In the same respect, there is an increase in the magnitude of the REA when the right ear stimulus is more intense.

A combination of parametric and non-parametric statistics were used to evaluate the dichotic listening task performance according to "ear" differences (left & right) and "fluency group" differences (AWS & AWNS). Parametric statistics, such as independent *t*-tests and a repeated measures two-way analysis of variance (ANOVA) examining differences across settings and differences across each group were employed. For the undirected attention dichotic listening task, the within group factor was IID (15 conditions) and the between group factor was ear (left & right). Non-parametric statistics, such as a Mann-Whitney U-test was used to directly evaluate differences between the AWS group and the AWNS group in the various dichotic listening tasks.

Results

The results are presented in three sections. The first section contains the results for the absolute differences in the undirected task. The second section shows the results for the laterality index score derived from the undirected task. The last section contains the results for the directed attention task.

Undirected Attention Task: Absolute Differences

AWS. The individual results of the undirected attention task for the AWS participants are shown in Appendix III. The combined results for the AWS group are displayed in Figure 7. The largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB, indicating that a REA persisted until the CV in the left ear was 12 dB more intense than the right ear. To evaluate whether there was a significant ear difference in the undirected attention task, a two-way repeated measures analysis of variance (ANOVA) was performed. The within group factor was IID (15 conditions) and the between group factor was ear (left & right). There was no significant IID effect [F (1, 12) =0, p=1, η_p^2=0.00][1] but a significant ear effect [F (1, 12) =22.49, p<0.01, η_p^2 =0.65] and a significant ear by IID effect [F (1, 12) =126.05, p<0.01, η_p^2=0.91] for AWS. The significant ANOVA effects were followed with Turkey's honest significant difference (HSD) post-hoc t-tests. Multiple t-test comparisons were undertaken using a Bonferroni adjustment procedure (criterion p<0.05). Results of follow-up t-tests identified a total of 11 comparisons

[1] The partial eta statistic (η_p^2) provides an estimate of overall effect size. The value can range from 0 (no effect) to 1 (large effect).

yielding significant ear differences at IIDs of -21, -18, -15, 0, 3, 6, 9, 12, 15, 18 and 21 dB. There were no significant differences between ear selection for IIDs of -12, -9, -6 and -3 dB.

AWNS. The individual results of the undirected attention task for the AWNS participants are shown in Appendix IV. The combined results for the AWNS group are displayed in Figure 8. The largest REA was found at the IID of 21 dB and the smallest REA was found at -12 dB. A reversal of the REA to a LEA was found at the IID of -15dB, indicating that a REA persisted until the CV in the left ear was 15 dB more intense than the right ear. To evaluate whether there was a significant ear difference in the undirected attention task, a two-way repeated measures ANOVA was performed. The within group factor was IID (15 conditions) and the between group factor was ear (left & right). There was no significant IID effect [F (1, 12) =0, p=1, η_p^2=0.00] but a significant ear effect [F (1, 12) =31.70, p<0.01, η_p^2=0.72] and a significant ear by IID effect [F (1, 12) =145.81, p<0.01, η_p^2=0.92] for AWNS. Results of follow-up Turkey's HSD t-tests, using an adjusted alpha level identified a total of 13 comparisons yielding significant ear differences at -21, -18, -9, -6, -3, 0, 3, 6, 9, 12, 15, 18 and 21 dB. There were no significant differences between ear selection for IIDs of -15 and -12 dB. The combined results for the AWS and AWNS can be seen in Figure 9.

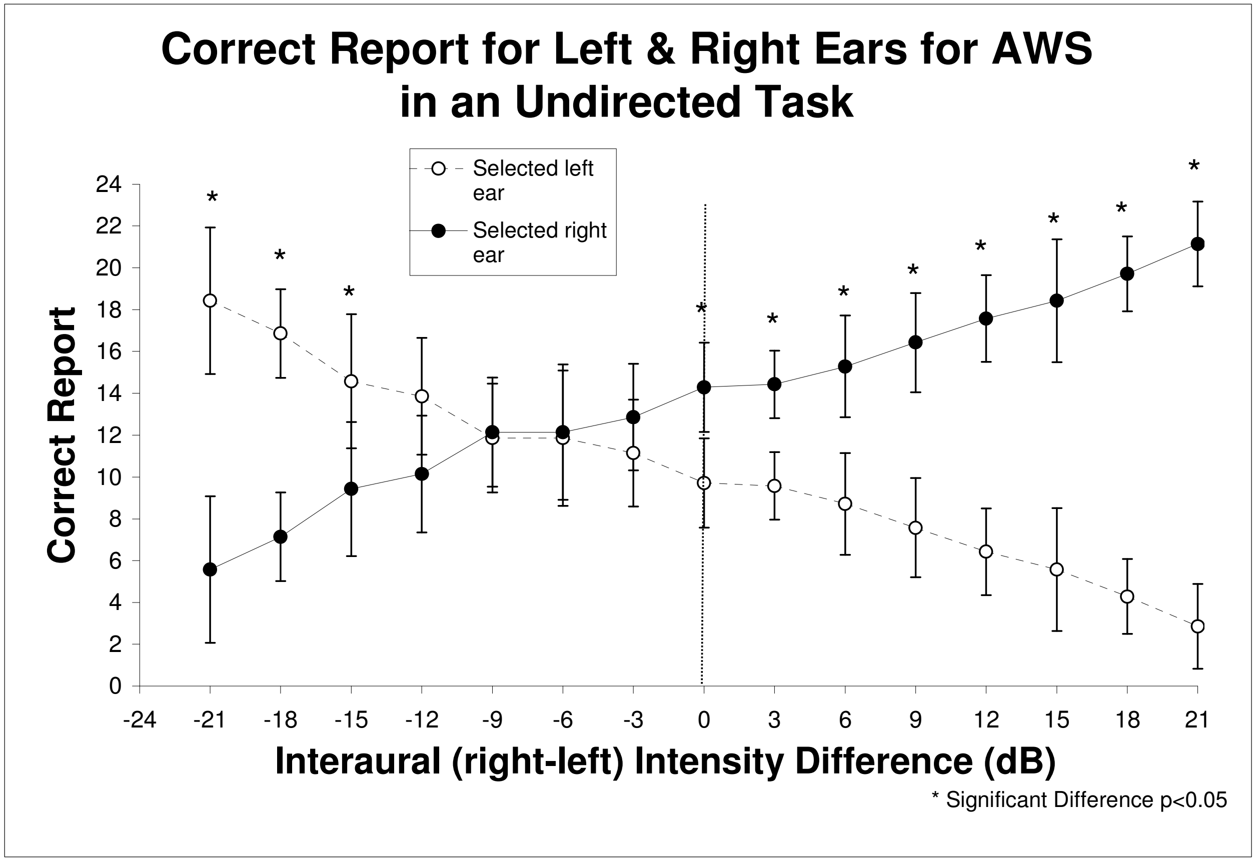


Figure 7. Correct report for AWS participants for the left and right ear CV stimuli as a function of changing the interaural intensity difference (IID) (dB).An IID of -3 to -21 dB indicates greater intensity the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear.

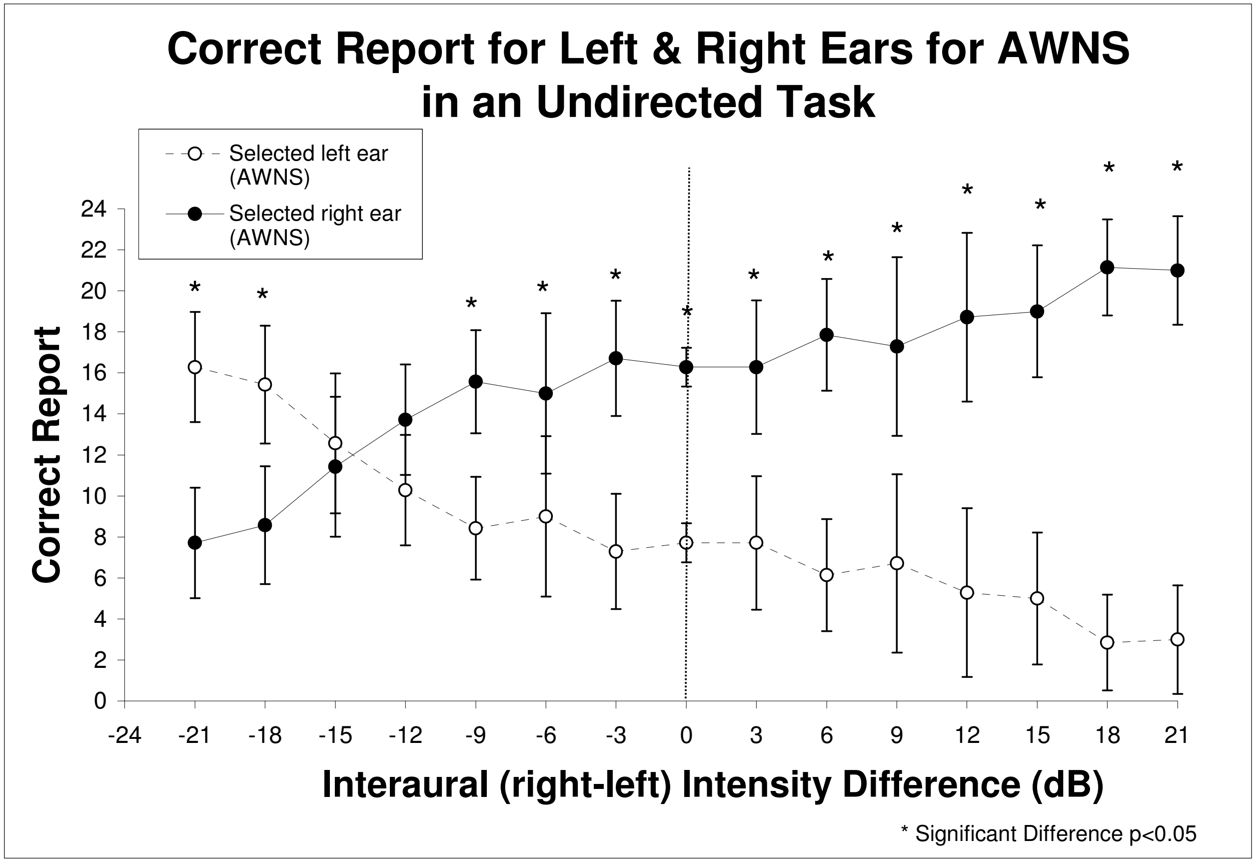


Figure 8. Correct report for AWNS participants for the left and right ear CV stimuli as a function of changing interaural intensity difference (IID) (dB). An IID of -3 to -21 dB indicates greater intensity the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear.

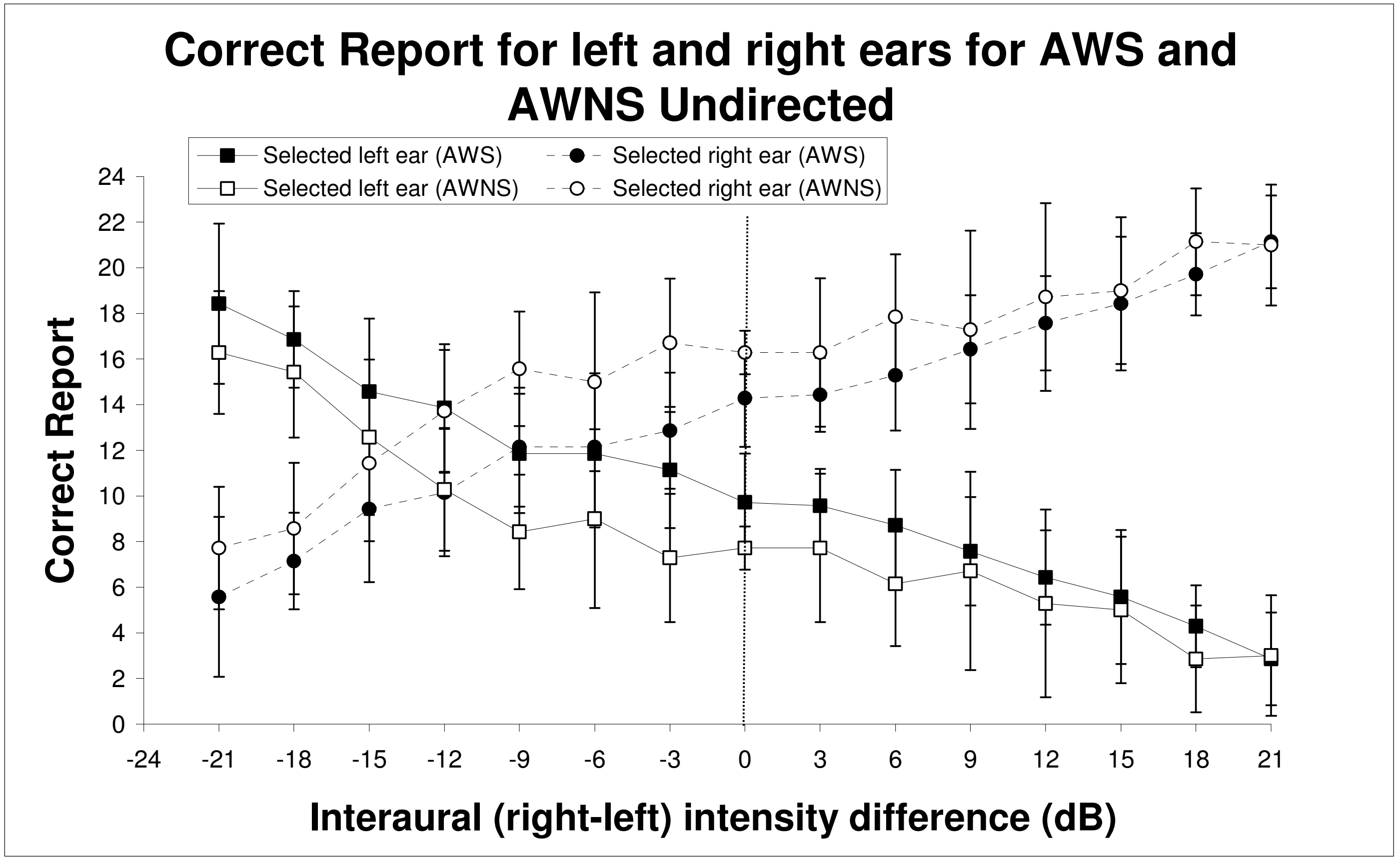


Figure 9. Correct report comparison of AWS and AWNS participants for the left and right ear CV stimuli as a function of changing the interaural intensity difference (IID) (dB). An IID of -3 to -21 dB indicates greater intensity the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear.

Undirected Attention Task: Laterality Index Score

AWS. The individual results of the laterality index score for the AWS participants are shown in Appendix V. The group results can be found in Figure 10. The analysis for the laterality index score was based on the formula [(right ear-left ear)/(right ear + left ear)] x 100, with the ear reports relating to the number of responses reported by the participant for the right and left ear CV stimuli. This analysis shows the degree of change of the ear advantage across IIDs, with the positive percentages indicating the degree of REA and the negative percentages indicating the degree of LEA. Mean results for AWS participants indicate that a REA was first evident for the IID of 21 dB and persisted until -9 dB. A LEA was evident for IIDs from -12 to -21 dB.

AWNS. The individual results of the laterality index for the AWNS participants are shown in Appendix VI. The group results are shown in Figure 11. Mean results of the laterality index score for AWNS participants indicate that a REA was first evident for the IID of 21 dB and persisted until -12 dB. A LEA was evident IIDs from -15 to -21 dB.

AWS and AWNS. The comparison of group mean results can be seen in Figure 12. To evaluate whether there was a significant difference between the AWS group and the AWNS group for the laterality index score, a two-way repeated measures ANOVA was performed. The within group factor was IID (15 conditions) and the between group factor was fluency group (AWS & AWNS). There was a significant IID effect [F (1, 12) =132.68, $p<0.01$, η_p^2 =0.91] but no significant group effect [F (1, 12) =3.32, $p= 0.09$, η_p^2=0.217] and no significant group by IID effect [F (1, 12) = 0.92, $p= 0.35$, η_p^2=0.07]. Results of follow-up Turkey's HSD *t*-tests, using an adjusted alpha level identified a total of 74 comparisons yielding significant differences for the IID effect. There were no significant differences between 31 comparisons of IIDs which included 21 dB versus (vs.) 15 dB, 21 vs. 18 dB, 18 vs. 12 dB, 18 vs. 15 dB, 15 vs. 6 dB, 15 vs. 9 dB, 15 vs. 12 dB, 12 vs. 6 dB, 12 vs. 9 dB, 9 vs. -3 dB, 9 vs. 0 dB, 9 vs.3 dB, 9 vs.6 dB, 6 vs. -3 dB, 6 vs. 0 dB, 6 vs. 3 dB, 3 vs. -6 dB, 3 vs. -9 dB, 3 vs. -3 dB, 3 vs. 0 dB, 0 vs. -6 dB, 0 vs. -9 dB, 0 vs. -3 dB, -3 vs. -6 dB, -3 vs. -9 dB, -9 vs. -12 dB, -9 vs. -6 dB, -6 vs. -12 dB, -12 vs. -15 dB, -15 vs. -18 dB and -18 vs. -21 dB.

Due to the small participant sample size and the subsequent large variability noted at each IID, an exploratory analysis was pursued using non-parametric statistics. A series of planned comparison Mann-Whitney U-tests were performed to determine whether AWS differed from AWNS at each IID. The results can be found in Table 3. 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, $p<0.05$]. Mann Whitney U-tests were also performed to examine the difference in mean laterality index scores of the two fluency groups. The results can be seen in Table 4 and Figure 13 . Significant differences in the magnitude of REA were found to occur at IIDs of 0 dB, -3 dB, -9 dB and -12 dB. In these cases, larger laterality index scores were found for the AWNS participants. This indicates a weaker REA for AWS participants at these IID levels. When the IID reached -15 dB both groups performed similarly, with the magnitude difference being smaller between the fluency groups.

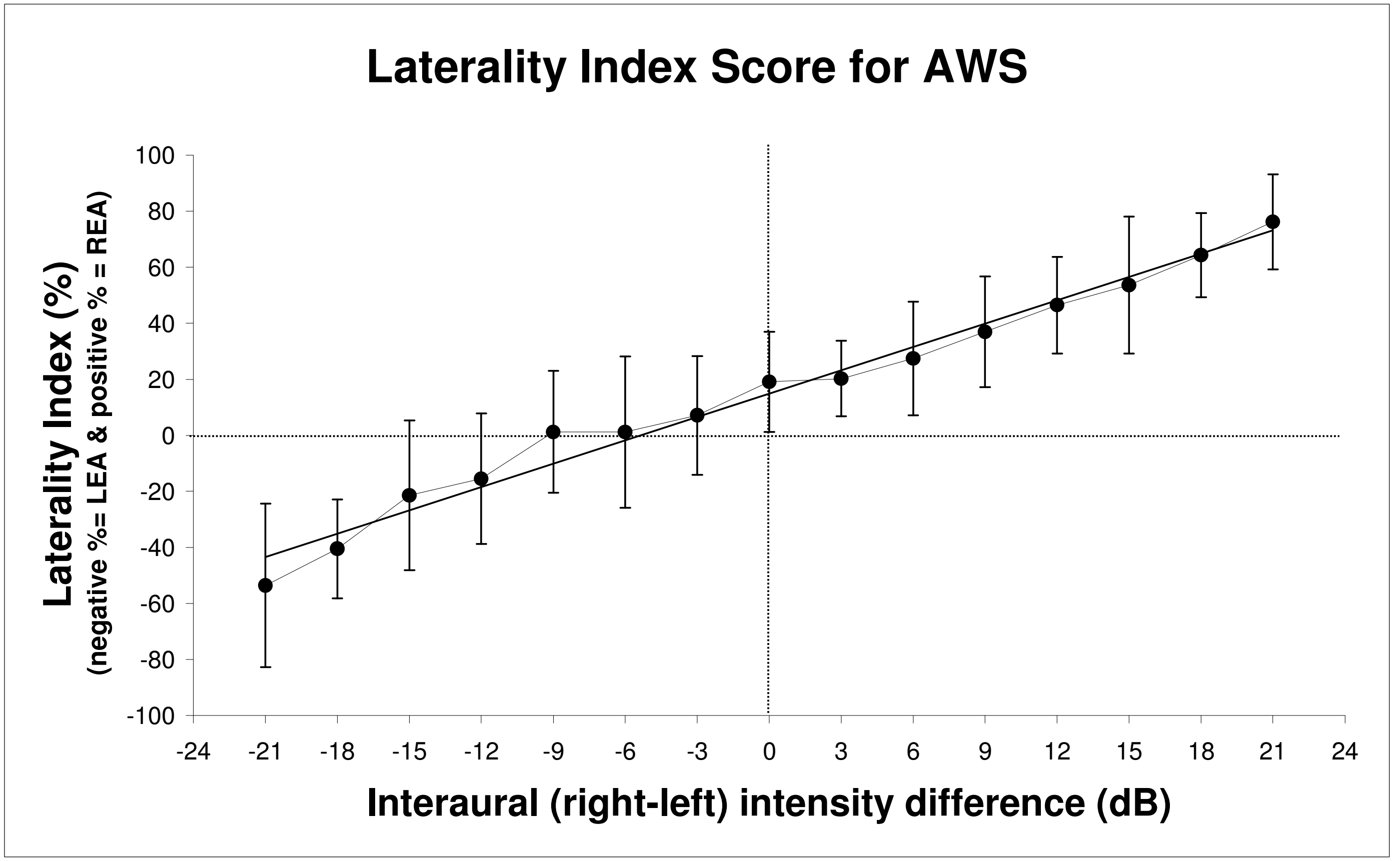


Figure 10. Laterality Index Score for AWS participants as a function of interaural intensity difference (IID) (dB). An IID of -3 to -21 dB indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear. Maximum laterality index scores can range from -100 (100% left ear advantage) to 100 (100% right ear advantage).

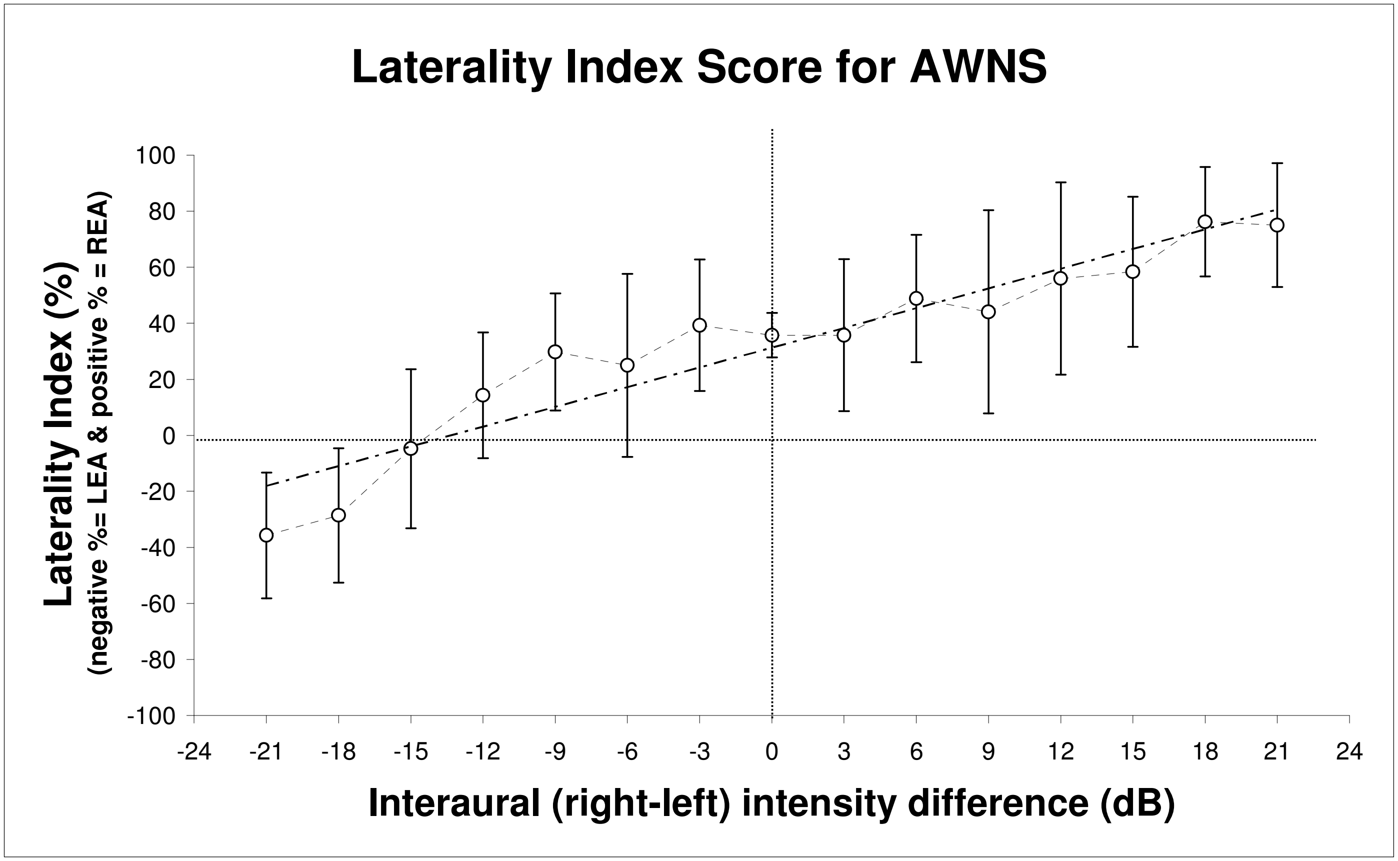
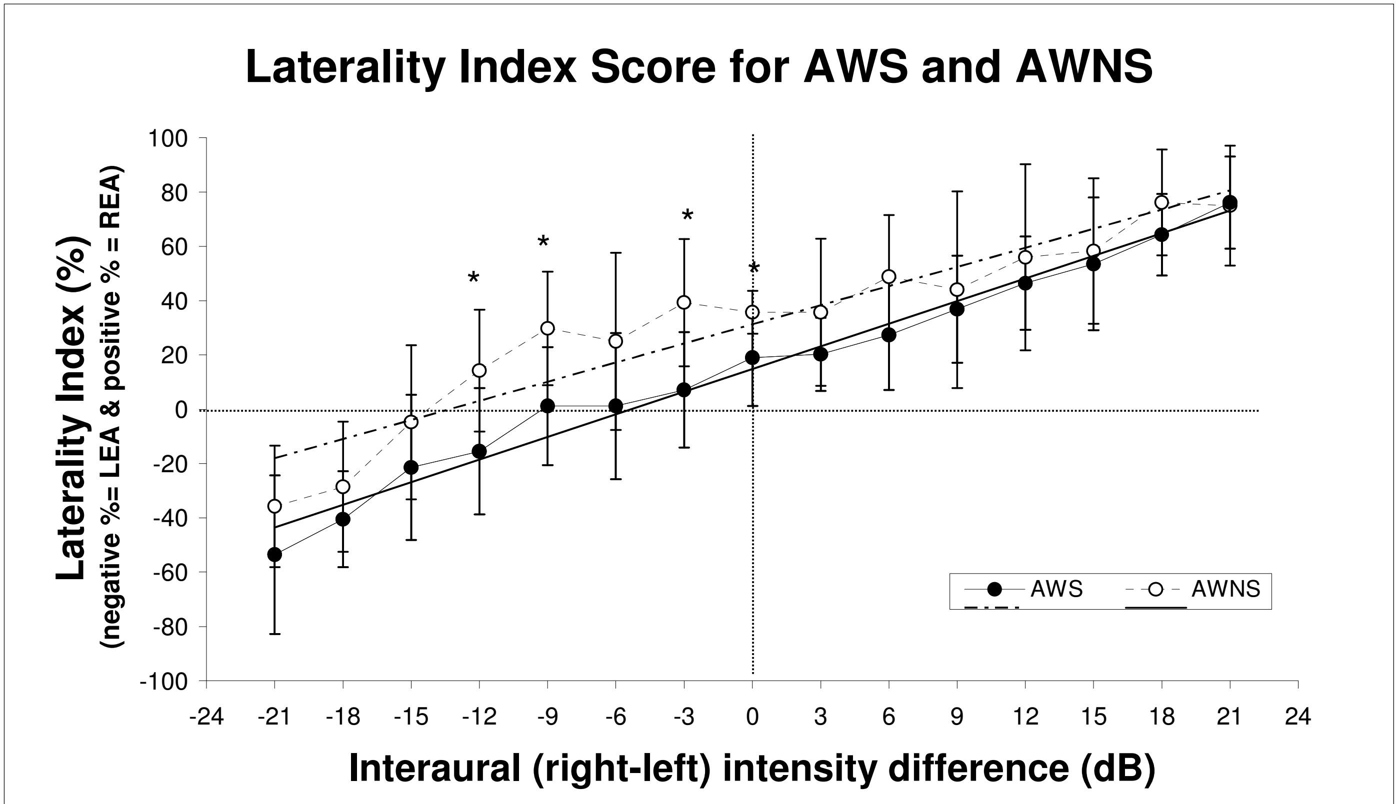


Figure 11. Laterality Index Score for AWNS participants as a function of interaural intensity difference (IID) (dB An IID of -3 to -21 dB indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears and, 3 to 21 dB indicates greater intensity in the right ear. Maximum laterality index scores can range from -100 (100% left ear advantage) to 100 (100% right ear advantage).



* Significant Difference *p*<0.05 using non parametric Mann Whitney U-tests.

Figure 12. Laterality Index Score for AWS and AWNS as a function of interaural intensity difference (IID) (dB). An IID of -3 to -21 dB indicates greater intensity in 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. Maximum laterality index scores can range from -100 (100% left ear advantage) to 100 (100% right ear advantage).

Table 3. Results using planned comparison non-parametric Mann-Whitney U-tests for the laterality index score between AWS participants and AWNS participants.

Laterality Index Score: AWS compared with AWNS		
Interaural Intensity Difference (IID) (dB)	U Value	*p* (one-tailed)
-21	33.5	0.130
-18	28.0	0.355
-15	31.5	0.191
-12	41.5	0.031*
-9	40.0	0.265*
-6	33.5	0.130
-3	40.0	0.265*
0	39.5	0.027*
3	31.0	0.228
6	37.0	0.064
9	26.0	0.451
12	30.0	0.276
15	27.0	0.402
18	35.0	0.104
21	25.0	0.500

* Denotes significant difference $p<0.05$

Table 4. Mean Laterality Index Score (%) for AWS and AWNS, indicating the magnitude difference between the fluency groups. A positive magnitude difference indicates a higher laterality index score for AWNS and a negative magnitude difference indicates a higher laterality index score for AWS.

Mean Laterality Index Score (%)			
Intensity Difference (dB)	AWNS	AWS	Magnitude Difference (%) (AWNS- AWS)
-21	-35.71	-53.57	17.86
-18	-28.57	-40.48	11.9
-15	-4.76	-21.43	16.67
-12	14.29	-15.48	29.76*
-9	29.76	1.19	28.57*
-6	25.00	1.19	23.81
-3	39.29	7.14	32.14*
0	35.71	19.05	16.67*
3	35.71	20.24	15.48
6	48.81	27.38	21.43
9	44.05	36.90	7.14
12	55.95	46.43	9.52
15	58.33	53.57	4.76
18	76.19	64.29	11.9
21	75.00	76.19	-1.19

* Denotes significant difference $p<0.05$

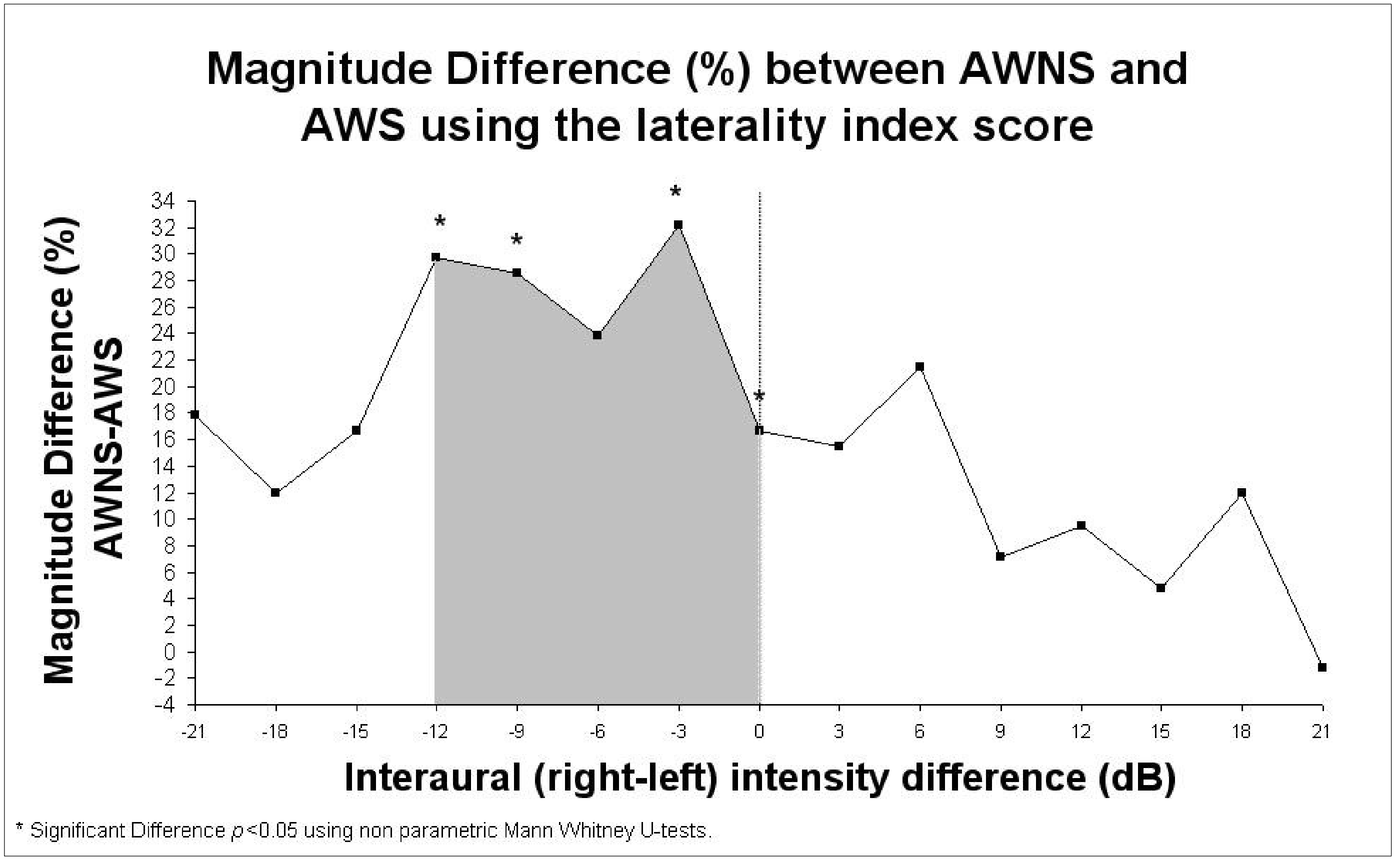


Figure 13. Mean Laterality Index Score (%) indicating the absolute magnitude difference between AWS and AWNS. A positive magnitude difference indicates a higher laterality index score for AWNS and a negative magnitude difference indicates a higher laterality index score for AWS. Significant differences can be found within the shaded region, indicated a strong REA among the AWNS participants.

Directed Attention Task

AWS. The individual results of the directed attention task for the AWS participants are shown in Appendix VII. The group results can be found in Figure 14 and in Table 5. In the directed-right task, participants scored 66.6% correct (i.e., they accurately reported the CV stimuli presented to the right ear). In the directed-left task, participants scored 51.7% correct (i.e., they accurately reported the CV stimuli presented to the left ear). In general, the AWS participants showed better identification of CVs when directed to the right ear compared with directing attention to the left ear.

AWNS. The individual results of the directed attention task for the AWNS participants are shown in Appendix VIII. The group results can be found in Figure 14 and in Table 5. In the directed-right task, participants scored 69.0% correct. In the directed-left task, participants scored 48.2% correct. In general, the AWNS participants showed better identification of CVs when directed to the right ear compared with directing attention to the left ear.

AWS and AWNS. The comparison of group mean results can be seen in Figure 14 and in Table 5. Examination of the results indicate that AWS scored a slightly lower percentage correct (66.6%) compared with the AWNS (69.0%) in the right-directed task. On the other hand, AWS demonstrated a higher percentage correct (51.7%) compared to AWNS (48.2%) in the left-directed task. Both AWS and AWNS groups scored higher when instructed to direct their attention to the right ear compared with when instructed to attend the left ear. To evaluate whether there was a significant difference between the AWS group and the AWNS group for the directed attention tasks, two-tailed independent *t*-tests were performed. For the right attention task, there was no significant difference between the AWS and the AWNS groups [t (12) = -0.47, p= 0.59, d=0.26] and no significant difference between the AWS and

AWNS groups in the left attention task [t (12) = 0.392, p= 0.81, d=0.22] [2]. An additional analysis using non-parametric statistics (Mann-Whitney U tests) found that there was no significant difference between AWS performance compared with AWNS in the directed-right condition [U (n_1=7, n_2=7) =25.5, p=0.45]. Furthermore, there was no significant difference in the directed-left attention condition between AWS and AWNS groups [U (n_1=7, n_2=7) =30.5, p=0.228].

[2] The Cohen's d statistic (*d*) provides an estimate of overall effect size when comparing populations. The value can range from 0 to 1, with 0.2 being a small effect, 0.5 being a medium effect and 0.8 being a large effect size.

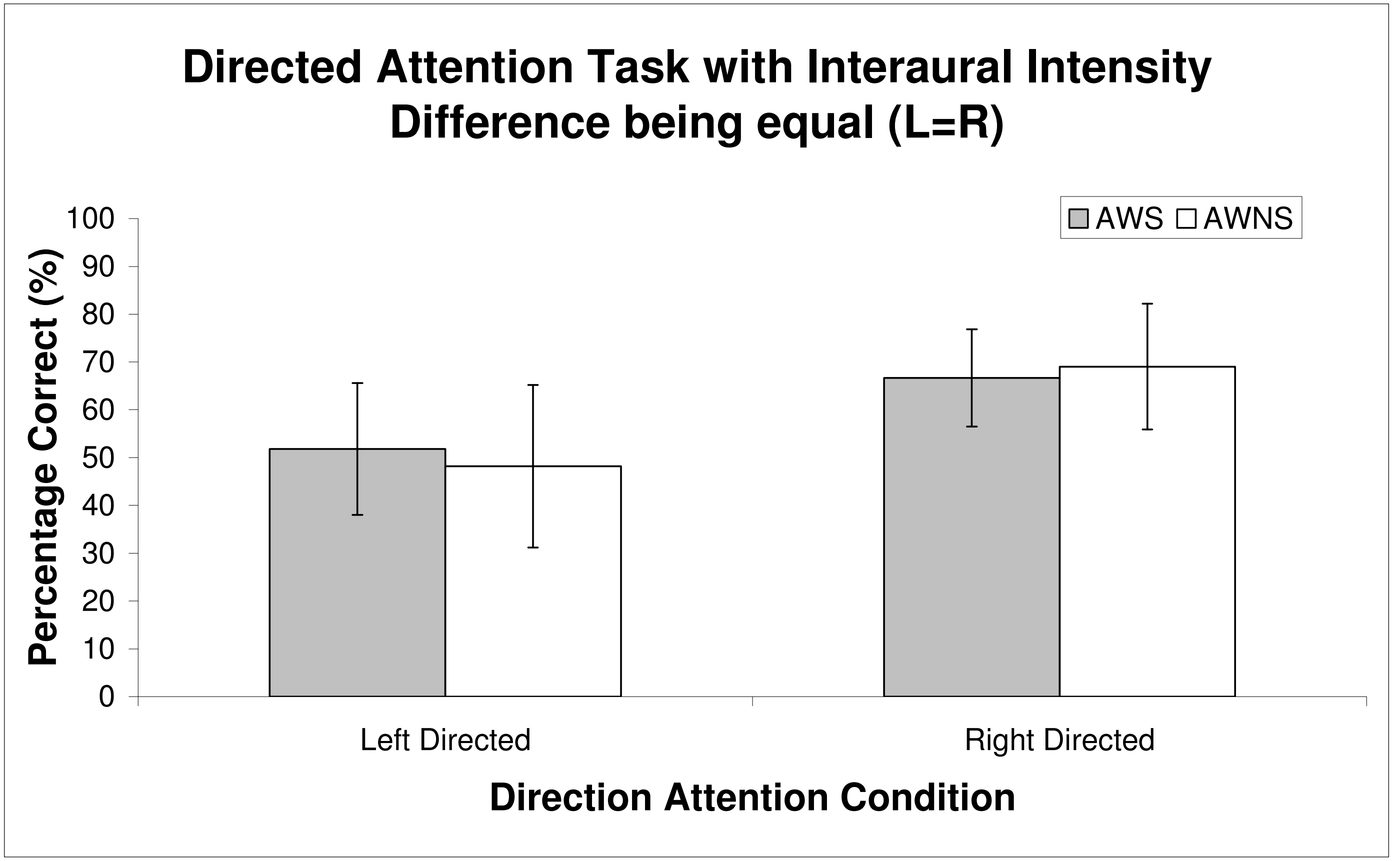


Figure 14. Percent correct for AWS and AWNS participants in the directed attention tasks (directed-left & directed-right). The results indicate the percentage correct when participants are instructed to direct their attention to the left or right (i.e., a correct response is the reporting of the stimuli that was presented in the ear they were instructed to attend to).

Table 5. Means and percentages for AWS and AWNS participants for the directed attention tasks (directed-left & directed-right). These indicate which ear participants reported hearing the stimuli (left or right) when instructed to direct their attention to either the left or right.

		Ear in which reported stimulus was heard							
		Left				Right			
Attention	Group	Mean	(%)	SD	(%)	Mean	(%)	SD	(%)
Directed-Left	AWS	12.43	(51.79)	3.31	(13.79)	11.57	(48.21)	3.31	(13.79)
	AWNS	11.57	(48.20)	4.08	(16.98)	12.43	(51.80)	4.08	(16.98)
Directed-Right	AWS	8.00	(33.34)	2.45	(10.19)	16.00	(66.66)	2.25	(10.19)
	AWNS	7.42	(30.96)	3.15	(13.12)	16.57	(69.04)	3.15	(13.12)

Summary of Major Findings

Undirected Attention Task

1. A significant REA was found for AWS in the IID conditions of 0 to +21 dB and a significant LEA was found for AWS in the IID conditions of -15 to -21 dB.
2. A significant REA for was found for AWNS in the IID conditions of -9 to +21 dB and a significant LEA was found in the IID conditions of -18 to -21 dB.
3. The laterality index score showed a significant IID effect but no significant group or group by ear interaction effects using parametric statistics (i.e., two-way ANOVA).
4. A further analysis of laterality using non-parametric statistics (i.e., Mann Whitney U-test) found significant differences between AWS and AWNS at 0 dB, -3 dB, -9 dB and -12 dB.

Directed Attention Task:

1. AWS performed slightly better in left-directed condition and slightly poorer in the right-directed condition compared with AWNS. However, the these differences were not statistically significant.

Discussion

The purpose of this study was to investigate possible differences in cerebral lateralisation of speech stimuli between AWS and AWNS using various dichotic listening tasks. Based on examination of seven AWS and seven AWNS participants, the following research questions were posed: Firstly, do AWS and AWNS differ in the magnitude of the REA during an undirected attention dichotic listening task? Secondly, do AWS and AWNS differ in the magnitude of the REA during a directed attention dichotic listening task? A discussion of each of these research questions follows.

Undirected Attention Dichotic Listening Task

Do AWS and AWNS differ in the magnitude of the REA during an undirected attention dichotic listening task?

AWNS. The results obtained for the present group of AWNS participants can be compared to the findings of Hugdahl et al. (2008a). Hugdahl et al. examined dichotic listening in a group of 33 adults using an IID testing format. The participants crossed at an IID of -6 dB. That is, a LEA was not evident until the CV stimuli were 6 dB more intense in the left ear. However, they found a slight deviation across participants, with a cross-over occurring from -3 to -9 dB. The researchers referred to this cross-over effect as reflecting a “resistance” by the REA, due to the left hemisphere dominance in speech processing. Among the present group of AWNS, the cross-over point occurred at an IID of -15 dB with a slight deviation across participants ranging from -9 to -18 dB. Therefore, the present group of AWNS appeared to show a stronger REA “resistance” compared to Hugdahl et al. This later point in cross-over indicates that a more intense stimulus was required in the left ear before a significant LEA was yielded.

Several possibilities are offered for the apparent differences in performance of the present group of AWNS compared to Hugdahl el al. (2008a). First, Hugdahl et al. used a sample size over four times the size of the current study and thus there may have been more variability associated with the present group of AWNS, leading to a later cross-over point. It is also interesting to consider the language backgrounds when comparing the results of the present study to Hugdahl et al. The researchers used CV stimuli spoken by a native Norwegian male speaker, which were presented to Norwegian listeners. In contrast, the present study used CV stimuli spoken by a native New Zealand male speaker, which were presented to New Zealand listeners. The Norwegian language may have a different pronunciation of the CV stimuli compared with New Zealand English and therefore the results may have been influenced by different sounding CV stimuli. Finally, it is important to note that participants in the Hugdahl et al. study did not complete a baseline perceptual calibration of IID prior to performing the listening tasks. They used the mean of two audiograms to determine inclusion, whereas the current study used one audiogram and a perceptual listening calibration task. This calibration was performed in the present study to account for any perceptual asymmetries in the participants hearing, which would influence the results when changing the IID.

AWS. No previous studies examining dichotic listening in AWS have assessed REA/LEA differences using an IID format. All previous studies have used equal binaural intensity (IID of 0 dB). Based on the performance of the present group of AWS at 0 dB IID, the results obtained for AWS showed similarities, as well as differences compared to past dichotic listening tasks among AWS. For example, it has been found that both AWS and AWNS show a REA, however the magnitude of the REA is reduced for AWS when compared with AWNS (Blood & Blood, 1986, 1989; Blood, et al., 1986; Brady & Berson, 1975; Curry & Gregory, 1969; Foundas, et al., 2004; Rosenfield & Goodglass, 1980). The results from the present study are consistent with these findings. Upon examination of the results for AWS and AWNS participants at an IID of 0 dB, both groups showed a significant REA ($p<0.05$). In addition, the

AWNS had a significantly higher laterality index score compared with AWS at 0 dB, suggesting a larger REA magnitude for AWNS.

Slight differences can be found between the results from the current study and Quinn (1972), who found no significant ear differences between AWS and AWNS. However, Quinn's results are similar to the current study in regard to instances of LEAs, where AWS had more instances of a LEA for speech processing compared with AWNS (Blood & Blood, 1986, 1989; Blood, et al., 1986; Brady & Berson, 1975; Curry & Gregory, 1969; Foundas, et al., 2004; Rosenfield & Goodglass, 1980). These results along with present study suggest the right hemisphere has a role in the processing of speech for AWS, indicating a difference in hemispheric dominance for linguistic information. Past investigations found a weaker REA for AWS compared with AWNS. The current study supports the finding that AWS show a less robust REA compared to AWNS, when examining responses obtained at the IID condition of 0 dB.

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 magnitude of the REA. The present study is a departure from past dichotic listening studies of AWS by examining performance according to IID. By adjusting the IID, the magnitude of the REA could be directly examined. Based on alteration of the intensity level of the CV stimuli presented to the left and right ears, a larger proportion of IID conditions with no significant differences between the ears for AWS were found compared to AWNS. These "no ear" preference conditions occurred for IIDs from -3 to -12 dB, revealing right hemisphere involvement for the processing of linguistic information as soon as the stimuli were more intense in the left ear.

The present findings lend additional support to past brain imaging research noting more diffuse brain lateralisation for CV stimuli among AWS (Foundas, et al., 2003). Studies exploring cerebral laterality and activation using MRI, PET and MEG have found atypical laterality and activation among AWS as initially speculated by Orton (1928) and Travis (1931) and more recently by a number of researchers (Biermann-Ruben, Salmelin, & Schnitzler, 2005; Blomgren, Nagarajan, Lee, & Alvord, 2003; Braun et al., 1997; De Nil, Kroll, Kapur, & Houle, 2000; 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 over-activity of pre-motor areas, which have an important role in speech and language formation (Fox et al., 2000). These brain imagining 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 over-activation that is seen in AWS and not in AWNS is thought to reflect the lack of automatisation 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.

In summary, the results from the current study using an undirected dichotic listening task are consistent with those found in past brain imaging studies, indicating diffuse lateralisation for AWS. The findings from this study suggest activation of the right hemisphere earlier (i.e., earlier "cross-over") for AWS compared to AWNS. The performance of the AWS participants indicates a lack of REA resistance to bottom-up processing that has previously been described in studies looking at AWNS (Hugdahl, et al., 2008a). The findings of the present study therefore agree with the statement by Rosenfield and Goodglass (1980) that there is a subgroup of AWS whom the problems of their disfluency may be due to differences in cerebral dominance. Based on the combined results from the absolute ear differences and the laterality index score, the first research question posed in this study can be answered in the affirmative. AWS and AWNS differ in the magnitude of the REA in an undirected dichotic listening task.

Directed Attention Dichotic Listening Task

Do AWS and AWNS differ in the magnitude of the REA in a directed attention dichotic listening task?

AWNS. Foundas et al. (2006) examined dichotic listening using three conditions (undirected, directed-right & directed-left) and examined recall responses according to the attended ear. The researchers found a pronounced REA in the directed-right task. Similarly, a strong LEA was found for the directed-left task. Directing attention was thought to demonstrate enhancement of speech processing which can occur for the directed ear. In the current study, AWNS showed better (but non-significant) identification of CVs when attention was directed to the right ear compared to when attention was directed to the left ear. This follows past studies where there was a more pronounced REA in the directed-right condition and a less robust REA in the directed-left condition (Foundas, et al., 2006; Hugdahl & Anderson, 1986).

The present study provides partial support for past research using brain imagining which examines the effects of attention on cerebral activation. Studies using PET have found that directing attention to either the right or left ear influenced the activation when listening to speech stimuli (Alho et al., 1999; Hugdahl, et al., 1999; O'Leary et al., 1996). The collective result from past studies is that there is more activation over the contralateral hemisphere when participants attend to a particular ear. The findings from the present study are slightly different from past research. In particular, there was a less prominent LEA in the present study during directed-left tasks. There are two possible explanations for the lack of a strong LEA in the present study. Firstly, the differences in the findings may be due to the smaller sample size.

Past studies have used up to 15 participants compared to the seven in the current study (Alho, et al., 1999). A second possible explanation is that participants showed a resistance to the LEA in a left-directed attention task. This suggestion comes about from examination of results from the IID tasks. The AWNS group crossed-over at an IID of -15 dB in the current study, while past studies have found this cross-over to occur at an IID of -6 dB (Hugdahl, et al., 2008a). This resistance to the LEA in the undirected task may explain the reduced LEA in the directed-left task compared with past studies.

AWS. 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 when AWS participants were instructed to attend to the right ear, they correctly recalled 98% of the right ear stimuli. When participants were instructed to attend to the left ear, they correctly identified 93% of left ear stimuli. AWNS correctly identified 99.5% of right ear stimuli and 95.7% of left ear stimuli. In the present study, when AWS participants were asked to direct their listening attention to the right ear, they correctly identified 67 % of right ear stimuli. When participants were asked to direct their attention to the left ear, they correctly identified 52% of left ear stimuli. In the present study, AWNS correctly identified 69% of right ear stimuli and 30% of left ear stimuli. These present findings are consistent with Blood et al. in that AWS and AWNS had higher correct scores when attention was directed to the right and left ears, respectively. However, the results from the current study are reduced in magnitude compared to Blood et al.'s study. The methodology in the present study was not similar to Blood et al. which may explain the difference in the magnitude of responses. The current study differed from Blood et al. in that they used spoken digits and had participants recall two digits played into the attended ear for the directed attention task. Whereas, in the present study participants were presented with single CV syllables into each ear and they were required to select the CV they heard the clearest. It is possible that recall of the digits may allow for clearer processing of linguistic stimuli (i.e., less resistance) compared to CV stimuli. Although the findings in the current directed attention tasks were not significant, the results together with Blood et al. support the contention of different cerebral activation which results from directed dichotic listening tasks (Foundas, et al., 2006; Hugdahl, et al., 1999).

Foundas et al. (2004) used a dichotic listening task to determine whether AWS and AWNS differ in the way they process binaurally presented speech stimuli according to handedness. The researchers found when attention was directed to the right, hand preference was associated with more responses to the right ear. However, it is difficult to compare results from Foundas et al. with the current study as handedness was not examined, with participants in the present study all being right-handed. Only findings from their right-handed participants can be compared. This comparison provides results similar to those obtained in the current study that more right ear responses were made in the directed-right condition. Furthermore, both the current study and Foundas et al. found that AWS did not differ compared to AWNS in directed attention tasks.

Recent work using directed attention dichotic listening tasks have found that attention tasks may require different cognitive processes compared to undirected attention task. Directed listening tasks require processing that is more demanding than undirected listening tasks and possibly evoke aspects from executive cognitive control processing (Westerhausen et al., 2009). Directed attention tasks are designed to specially assess dichotic listening tasks 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 influences a stronger REA. Another explanation for this REA is the suppression of the LEA, due to the activation of the left hemisphere in anticipation of speech information in a directed attention task (Kinsbourne, 1970). This top-down processing may not be apparent in undirected listening tasks, due to this type of processing being less revealing of diffuse cerebral activations or it may “mask” any differences between AWS and AWNS. This top-down processing may involve a different type of speech processing that is perhaps less automatic. Interestingly, in the present study it was the “automatic” (or bottom-up) speech processing which was revealing of laterality differences between AWS and AWNS. This same type of automatic speech processing may be responsible for moments of stuttering. Further research is needed to support this possible explanation.

In summary, AWS and AWNS 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 indicate a different type of speech processing that is less discriminating of group differences in cerebral activation. This suggests that the disorder of stuttering may be more evident in dichotic listening tasks reflective of automatic (bottom-up) speech processing. This type of processing is used in the undirected dichotic listening tasks. Therefore, based on the results from the directed attention task, the second research question posed in this study can be answered in the negative. AWS and AWNS do not differ in the magnitude of the REA in a directed attention dichotic listening task.

Limitations

The limitations of the present study are discussed in the following sections, which include issues related to participant recruitment, stuttering severity, fluency treatment effects and a possible ordering effect.

Participant Recruitment

In the present study, seven participants comprised each group, with a total of 14 participants. The sample size was likely to yield low statistical power and contribute to large variability. Past research investigating cerebral lateralisation using dichotic listening tasks and AWS and AWNS participants enlisted up to 120 participants, with 60 in each fluency group (Quinn, 1972) or as few as 18 participants, with 9 in each fluency group (Blood & Blood, 1986). Although significant differences were found using non-parametric statistics, caution should be taken when generalising the results to the broader population.

Participants in the present study were all right-handed, with no evaluation of left-handed AWS. Investigations examining handedness have found differences in regards to the processing of speech stimuli between right and left-handed participants. For example, right-handed AWNS have been shown to have a greater shift in listening bias when completing a directed attention task (Foundas, et al., 2006). Research with AWS and handedness found AWS who were right-handed made less left-ear responses than AWS who were left-handed during a dichotic listening task (Foundas, et al., 2004). Therefore, it is important to stress that the results of the present study are confined to right-handed AWS and AWNS participants.

No attempt was made to examine performance according to sex differences. Past research has found no differences in the processing of speech stimuli between males and females during traditional dichotic listening tasks (Blood & Blood, 1989; Weekes, et al., 1995). The examination of sex differences in an IID dichotic listening task has yet to be explored.

Participants in this study were older than that of other studies which could therefore be a confounding factor. The mean age of the participants in the present study was 46 years. In past studies, mean ages have ranged from 12 years to 27 years (Blood & Blood, 1986, 1989; Blood, et al., 1986; Brady & Berson, 1975; Curry & Gregory, 1969; Foundas, et al., 2004; Hugdahl, et al., 2008a; Rosenfield & Goodglass, 1980). Research examining age effects during dichotic listening has found that both right and left ear scores decrease with increasing age (Bellis & Wilber, 2001). Recruitment of the current study was guided primarily by availability at the commencement of the study. The only criteria were that participants were right-handed, had normal hearing and were individuals who stutter. Examination of age effects was thus not a primary objective.

Severity of Stuttering

The current study did not directly consider differences in the severity of stuttering among AWS participants. The inclusion criteria of the AWS participants in this study were based on the presence of SLD noted during oral reading of the 100-word Grandfather Passage (Darley, et al., 1975). In addition, each participant was asked to judge the severity of their stuttering using a 10-point self report scale. Studies investigating stuttering severity using MRI have reported greater activation in the right inferior frontal cerebral regions for AWS who had moderate disfluency compared with those had severe disfluency (Neumann, et al., 2003; Preibisch, et al., 2003). Based on the 10-point self report scale, the current AWS participants ranged from mild to moderately severe, therefore generalizations may not be drawn about the affect of stuttering severity during dichotic listening tasks.

Treatment Effects

The effects of prior treatment for stuttering were not examined in the present study. A prior study by Neumann et al. (2003) found stuttering treatment influenced the cerebral activation in

AWS. Neumann et al. reported an increase in the cerebral activation after therapy in the left hemisphere in AWS, indicating that therapy may have an affect on the way the brain is able to process speech. De Nil et al. (2003) used PET to examine cerebral activation of AWS pre- and post-treatment, and also compared PET scans to AWNS controls. They found that AWS had decreased overall activation in the post-treatment scan compared to the pre-treatment scan. Interestingly, the findings of their study also revealed an increase in the activation of the left hemisphere post-treatment, although the pattern of results did not indicate normalisation in the post-treatment and one year follow-up scans. Further research looking into the effects of treatment on dichotic listening would be beneficial especially as to why some AWS are able to become fluent and others only seem to be partially fluent after treatment (De Nil, et al., 2003).

Order Effects

An ordering effect is a testing phenomenon in which measures are consistently given in the same sequence, creating possible influences on subsequent responses (Portney & Watkins, 2000). In the current study an ordering effect may have arisen due to all participants starting with the undirected dichotic listening task followed by the directed dichotic listening task. By undertaking the undirected task first, participants were kept naïve in their listening. This was done to ensure that during the undirected task no attentional effects occurred. If the directed attention task had been completed first, participants may have been attending to specific ears unintentionally in the following undirected attention task. In spite of this rationale, it is possible that the performance shown in the present group of AWS and AWNS participants were affected by the sequence of dichotic listening tasks.

Clinical Implications

The first clinical implication of the current study is the use of dichotic listening as a means for diagnosis of AWS. Currently disfluency diagnosis is often made on the basis of collecting speech samples and noting the number and types of disfluencies. Adjacent to collection and evaluation of speech samples, performance on dichotic listening could be used as a supplement to the diagnosis of stuttering. Perhaps the underlying mechanism responsible for the differences in dichotic listening tasks is somehow related to disruption of critical feedback processes that permit the uninterrupted forward flow of speech (Curry, 1969). Determining whether this auditory feedback pathway is atypical may help in the creation of speech therapy techniques for AWS.

The second implication of this study is the use of dichotic listening to explore laterality and cognitive impairments in clinical populations, other than those with a communication disorder. Past research has supported that dichotic listening can be used to examine these populations, such as those with schizophrenia (Hugdahl et al., 2003; Loberg, Hugdahl, & Green, 1999). These studies found that patients with schizophrenia who were asked to direct their attention and to report only the stimuli in the left ear were unable to modulate the REA. However when instructed to report only what was heard in the right ear, they were able to modulate the REA. The controls in these studies were able to modulate the REA by increasing the response when attending to the right ear and decreasing the effect when attending to the left ear. This finding is thought to reflect a difficulty in the ability for those with schizophrenia to use top-down cognitive control. However, it is unknown why this difficulty only occurs when attention is directed to the left ear even when the demands in attending to each ear are the same (Bryden, Munhall, & Allard, 1983; Hugdahl, et al., 2003; Hugdahl, et al., 2008b; Loberg, et al., 1999).

Directions for Future Research

Past research using dichotic listening tasks to examine cerebral lateralisation of AWS and AWNS participants enlisted up to 120 participants, with 60 in each fluency group (Quinn, 1972). A larger sample size would be beneficial to decrease the variability and increase the statistical power found in the present study. This would allow for the ability to generalize to the AWS population. Future studies should also include right- and left-handed participants and males and females so further analysis can be made into the effects using an IID paradigm with the AWS population.

Using dichotic listening tasks with children may be a useful diagnostic tool. However, due to the need for concentration and motivation to complete the listening tasks, children need to be at an age where they have the ability to complete the tasks. Some past studies have suggested that cerebral lateralisation for speech information may be present in the first few years of life (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Moffitt, 1971). Therefore, if children who stutter were found to have less hemispheric sensitivity for speech compared with children who do not stutter, listening tasks could serve as a diagnostic tool to select children who are at risk for stuttering. If dichotic listening tasks could be completed in children, early detection can be made and appropriate therapy can take place. Cimorell-Strong, Gilbert and Frick (1983) examined dichotic listening in children aged five, seven and nine years and found that those children who stutter had similar results to AWS, where a reversal of the REA (i.e., LEA) and no ear preferences were found compared with children who do not stutter. This is an interesting finding as it demonstrates further evidence for atypical lateralisation for speech information from younger years. Therefore, further research using dichotic listening as a means of early diagnosis of stuttering would be extremely beneficial.

Past research has shown differences within the brain when AWS are processing speech using brain imaging techniques after receiving therapy for their disfluency (Alm, 2004; De Nil, et al., 2003; Fox, et al., 2000; Neumann, et al., 2003). Future research could examine treatment effects using dichotic listening task to determine if the same effects seen in imagining studies occur when completing dichotic listening tasks. It has been found in these brain imagining studies that AWS individuals have increased left cerebral activation after therapy (Neumann, et al., 2003). Using dichotic listening tasks to examine the magnitude of the REA and looking into the effects of IID would allow for a cost effective, less invasive examination of cerebral lateralisation. Types of treatment could also be investigated to determine whether various treatment programmes show differences in the way the brain processes linguistic information.

Further studies could explore the degree of stuttering severity on cerebral activation to determine if cerebral lateralisation is even more diffuse for those whose speech disfluency is more severe. Studies investigating stuttering severity using MRI have reported greater activation for AWS who had moderate disfluency compared with those had severe disfluency (Neumann, et al., 2003; Preibisch, et al., 2003). Dichotic listening could be used to determine if the same effects from past studies using MRI occur. The degree of severity may have an impact on the degree to which the diffuse cerebral activation occurs, therefore could be used to understand the differences in cerebral activation of AWS.

Conclusion

Using dichotic listening to determine cerebral laterality for speech processing found that AWS participants differed significantly in an undirected attention dichotic listening task compared with AWNS. The undirected attention results indicated that both AWS and AWNS have a REA for processing speech information, however the REA is less robust for AWS. The primary difference observed between the groups was in regards to the IID point at which a previous REA became 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 that the right hemisphere was activated sooner for the processing of speech compare to AWNS. These overall findings from the undirected listening task support past brain imaging studies showing diffuse cerebral activation for AWS, involving both the left and right hemispheres for speech.

In the directed attention dichotic listening task, no significant differences were found when comparing AWS with AWNS. The overall finding that AWS do not differ from AWNS in the directed attention task may indicate that the form of speech processing during this task is not discriminatory of those who stutter and those who do not stutter.

In summary, the results from the present study provide partial support for the hypothesis that AWS will show a less robust REA compared with AWNS when undertaking a dichotic listening task using speech stimuli. A difference between groups was found for the undirected task but not for the directed attention task.

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Appendix I

Edinburgh Handedness Inventory (Oldfield, 1971)

The Edinburgh Handedness Inventory Questionnaire

Date:

Time:

Participant:

Age:

Please check the box that applies to you.

		Which hand do you prefer?			Do you ever use the other hand?	
		LEFT	RIGHT	EITHER	YES	NO
1	Writing					
2	Drawing					
3	Throwing					
4	Scissors					
5	Toothbrush					
6	Knife (without a fork)					
7	Spoon					
8	Rake (upper hand)					
9	Striking a match or lighter					
10	Opening a box (lid)					

a	Which foot do you prefer to kick with?			
b	Which eye do you use when using only one?			

Appendix II

University of Canterbury Information Sheet and Consent Form

Department of Communication Disorders
Project Information Sheet

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

PARTICIPANT INFORMATION

You are invited to participate in the research project entitled *Dichotic Listening among Adults who Stutter.*

The aim of this project is to evaluate the effects of listening to different speech sounds presented into each ear at the same time and determining which of these sounds is heard most clearly. We are interested in determining whether people who stutter differ from people who do not stutter in their perception of speech sounds.

Your involvement in this project will involve one session, lasting approximately 1½ hours, which includes a hearing test, to ensure normal hearing. In the event that you are found to have hearing levels that fall outside the normal hearing range, you will be unable to participate in the study and a follow up referral to the University of Canterbury Speech and Hearing Clinic will be made. After completion of the hearing screen you will then be required to listen to various speech sounds presented to both ears simultaneously and indicate what you have heard. You have the right to withdraw from the project at any time, including withdrawal of any information provided. If you are currently receiving services at the University of Canterbury Speech and Hearing Clinic and decide to withdraw from this study, your services will not be discontinued or affected due to this decision.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, the information gathered will be assigned a number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders.

The project is being carried out as a requirement for a Masters of Audiology by Wanita Lynn under the supervision of Professor Michael Robb. The project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee. If you have any further questions about the research project, please do not hesitate to contact either my supervisor or myself at the University of Canterbury. Thank you once again.

Sincerely,

Wanita Lynn B.Sc.
Master of Audiology Student
Ph: 3418479
Mob: 027 6306503
Email: wll25@student.canterbury.ac.nz

Professor Michael Robb
Dept of Communication Disorders
Ph: 364 2987 extn 7077
Email: michael.robb@canterbury.ac.nz

Department of Communication Disorders

Wanita Lynn
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch
13 January 2009

Consent Form

Dichotic Listening among Adults who Stutter.

I have read and understood the description of the above-named project. On this basis, I agree to take part as a participant in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

NAME (please print): …………………………………………………………….

Signature:

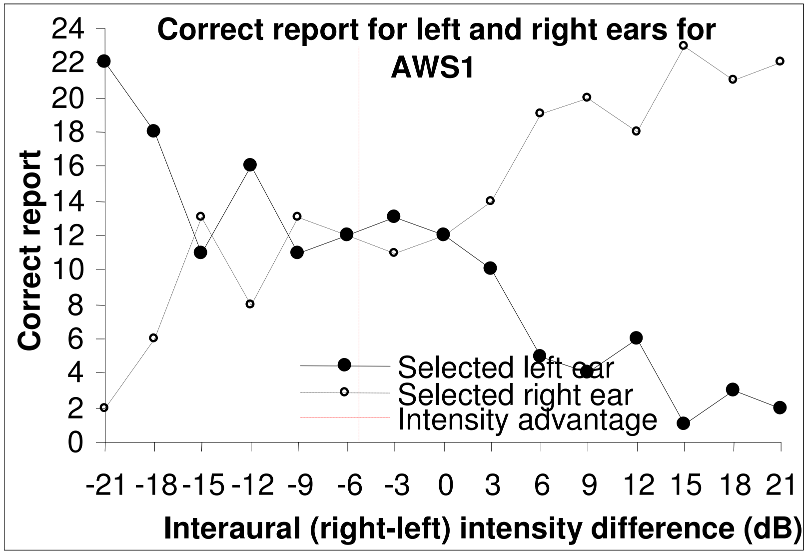
Date:

University of Canterbury Private Bag 4800, Christchurch 8020, New Zealand.
Tel: +64 3 364-2987 x7077, Fax: +64 3 364 2260
www.cmds.canterbury.ac.nz

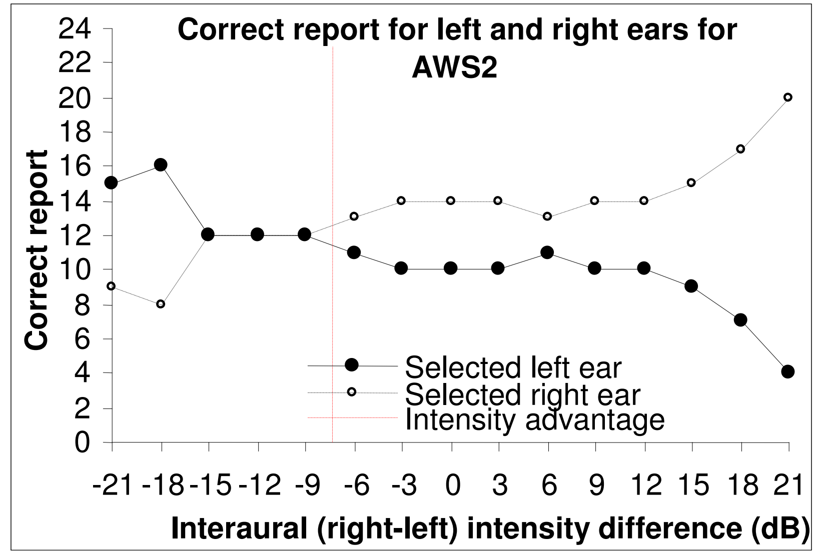
Appendix III

Individual Results of AWS Participants in the Undirected Attention Dichotic Listening Task:

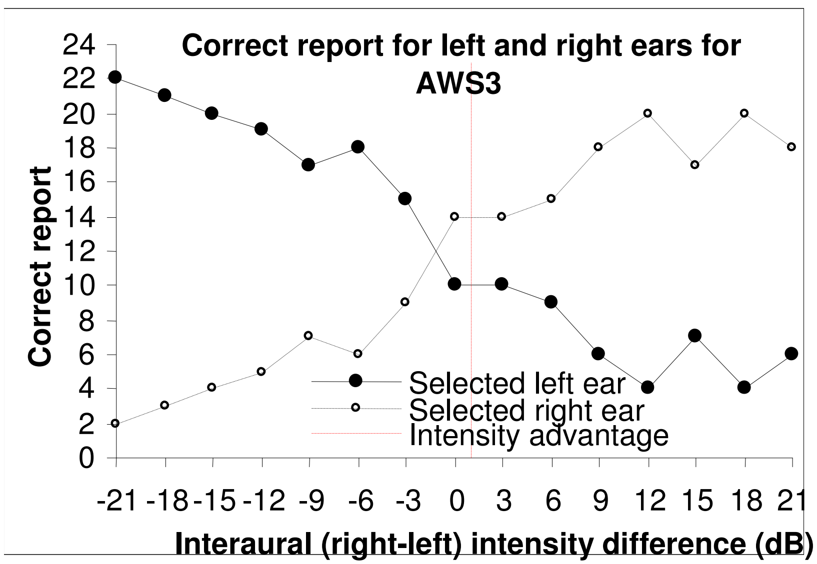
Absolute Differences



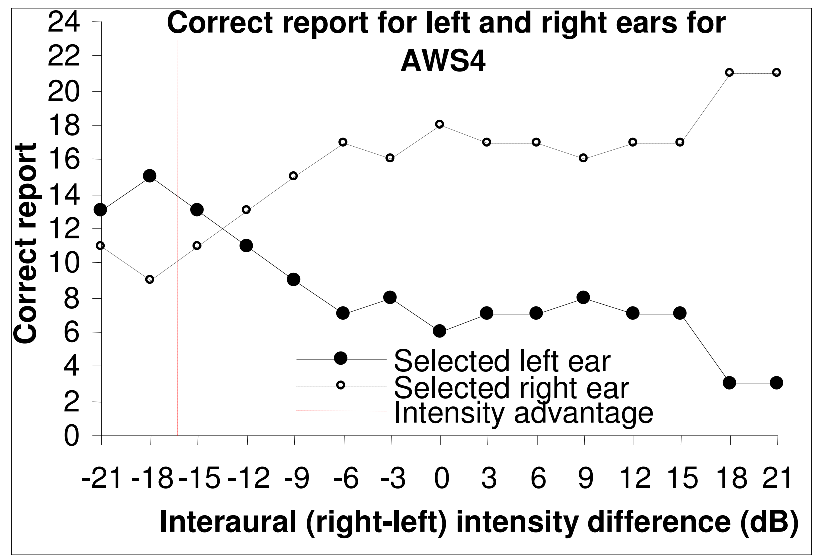
Correct report for left and right ears for AWS1
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage



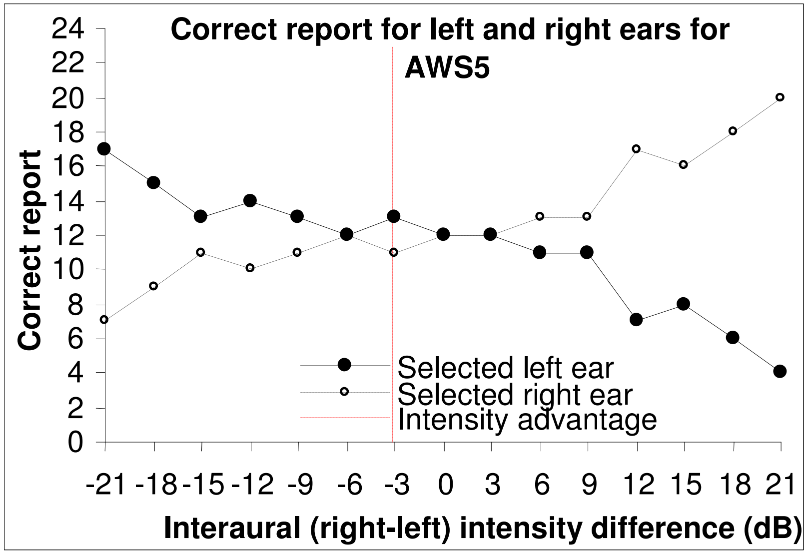
Correct report for left and right ears for AWS2
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

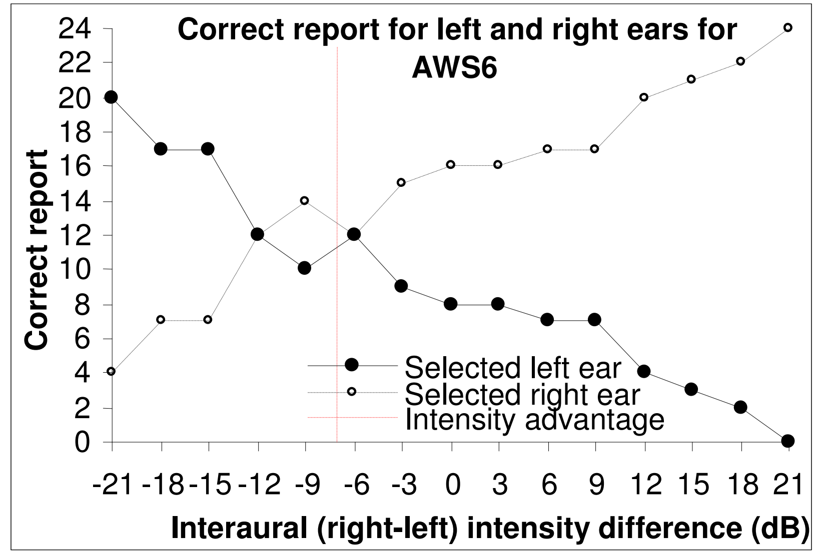


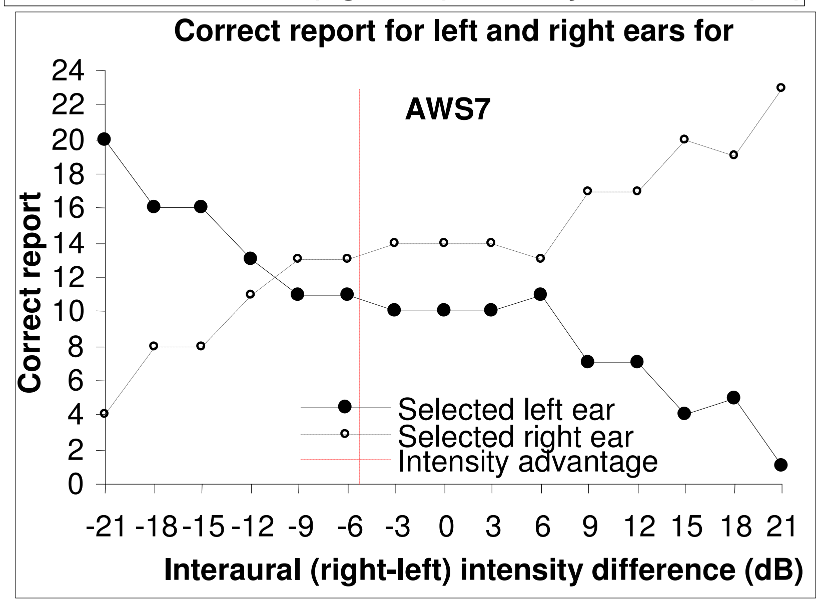
Correct report for left and right ears for AWS3
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage



Correct report for left and right ears for AWS4
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

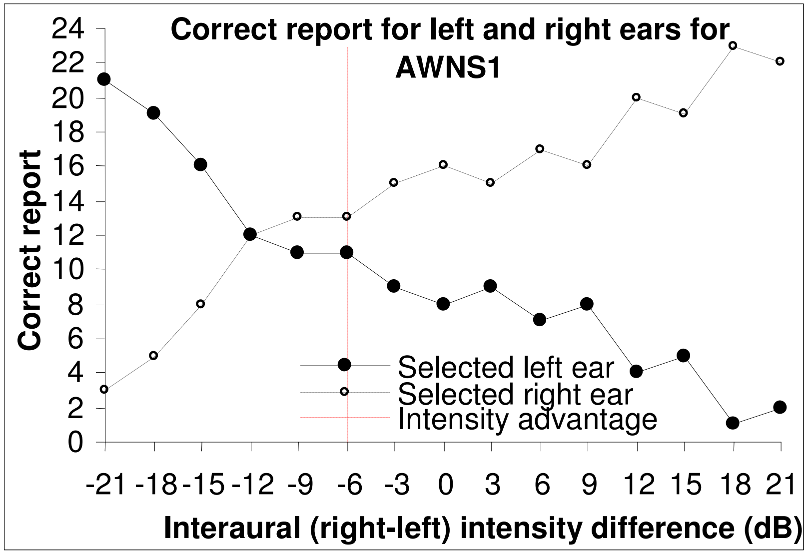

Correct report for left and right ears for
AWS5
Correct report
Selected left ear
Selected right ear
Intensity advantage
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)

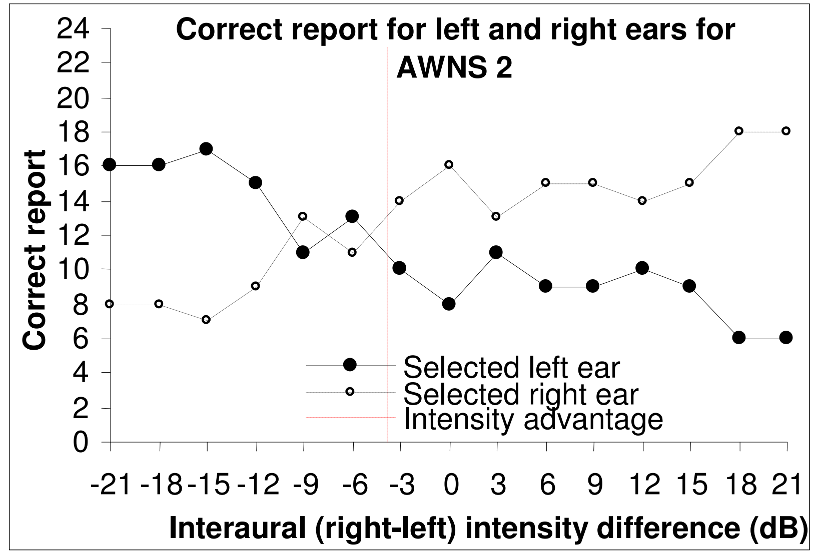

Correct report for left and right ears for
AWS6
Correct report
Selected left ear
Selected right ear
Intensity advantage
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)

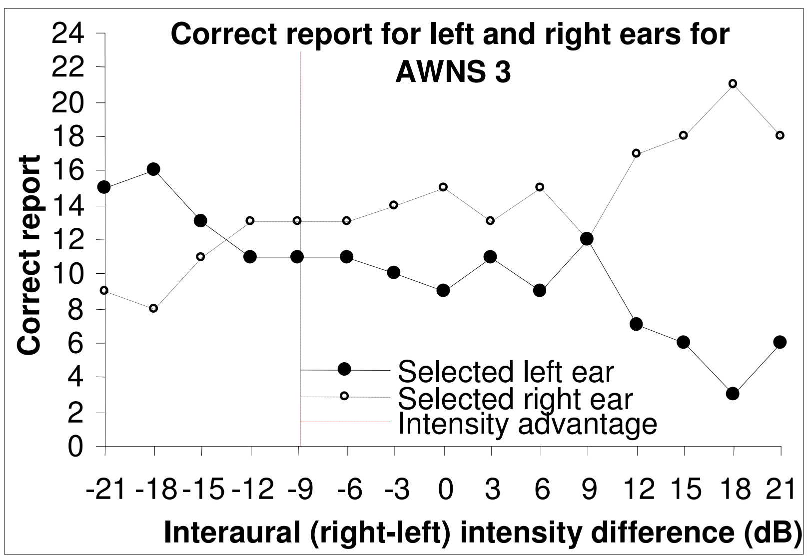

Correct report for left and right ears for
AWS7
Correct report
Selected left ear
Selected right ear
Intensity advantage
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)

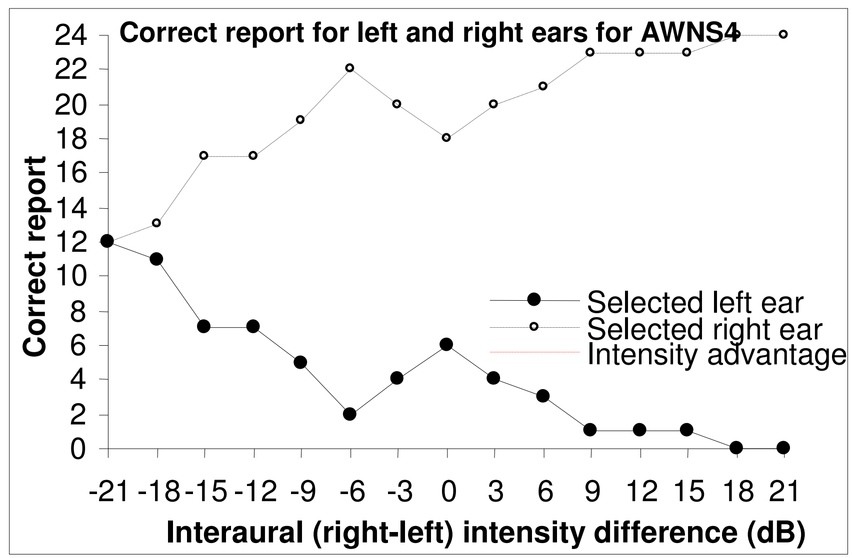
Appendix IV

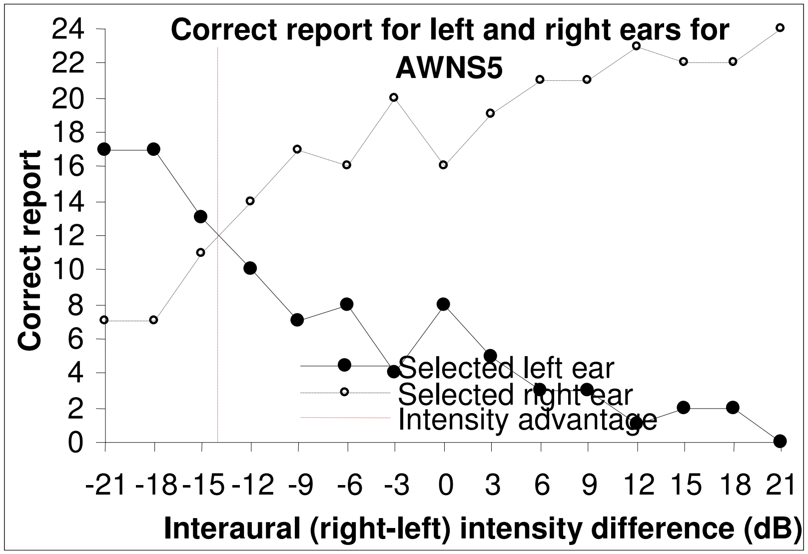
Individual Results of AWNS Participants in the Undirected Attention Dichotic Listening Task: Absolute Differences.

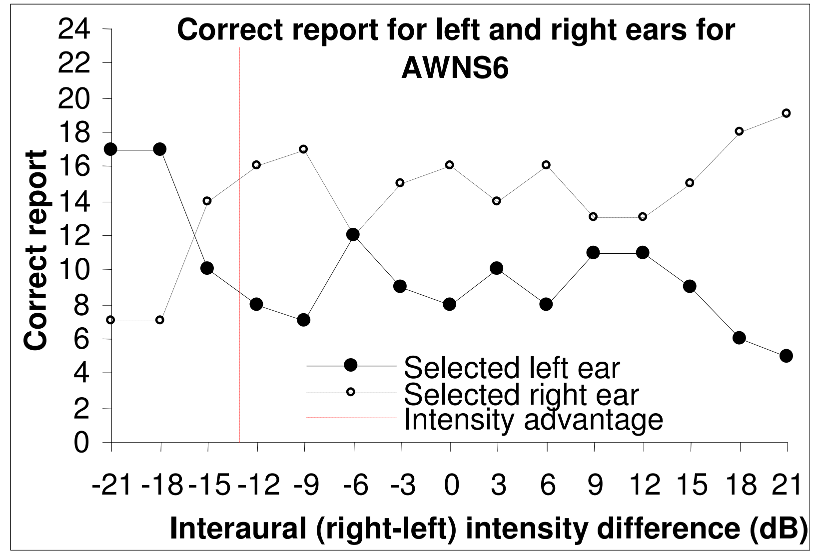

Correct report for left and right ears for AWNS1
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

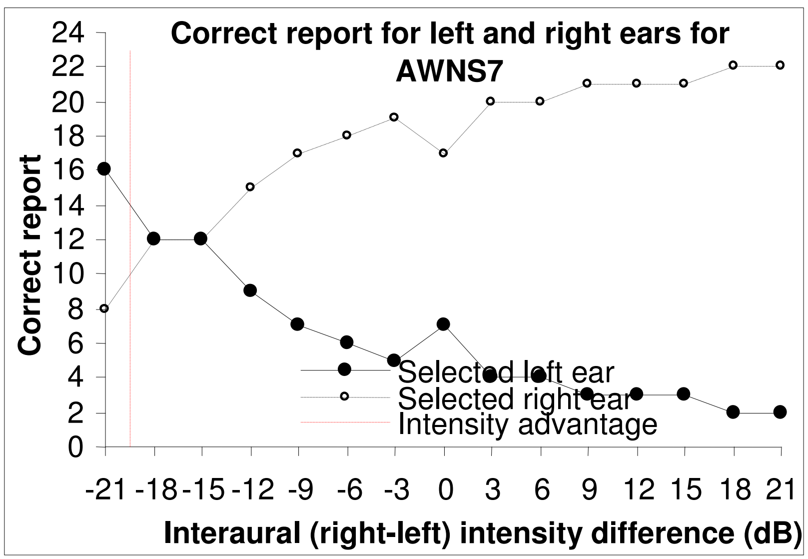

Correct report for left and right ears for AWNS 2
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage


Correct report for left and right ears for AWNS 3
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage


Correct report for left and right ears for AWNS4
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage


Correct report for left and right ears for AWNS5
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

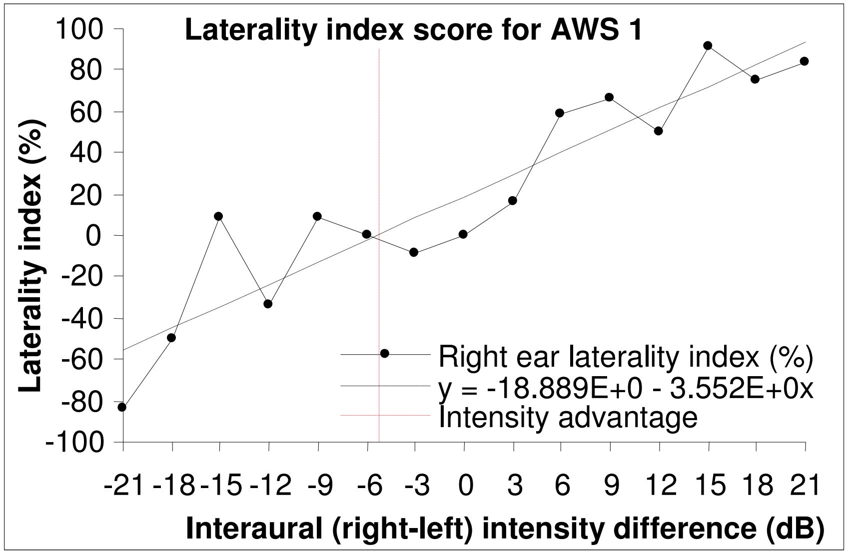

Correct report for left and right ears for AWNS6
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

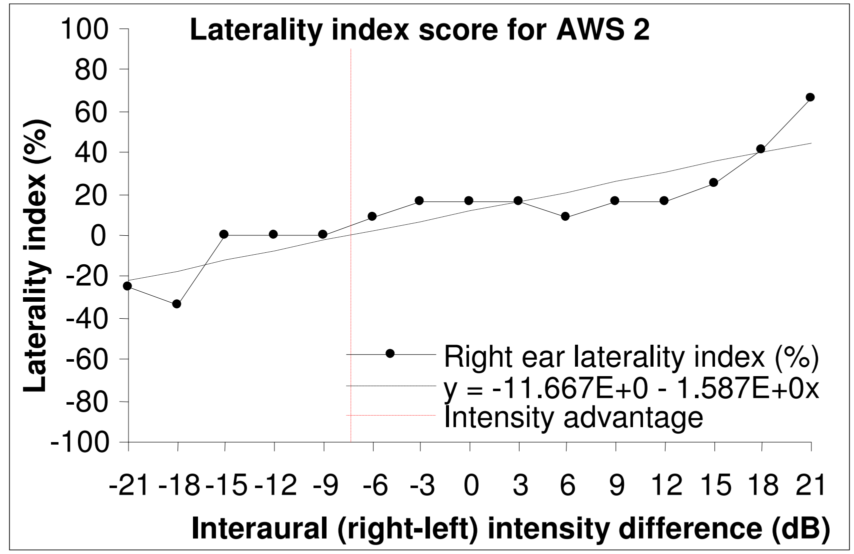

Correct report for left and right ears for AWNS7
Correct report
Interaural (right-left) intensity difference (dB)
Selected left ear
Selected right ear
Intensity advantage

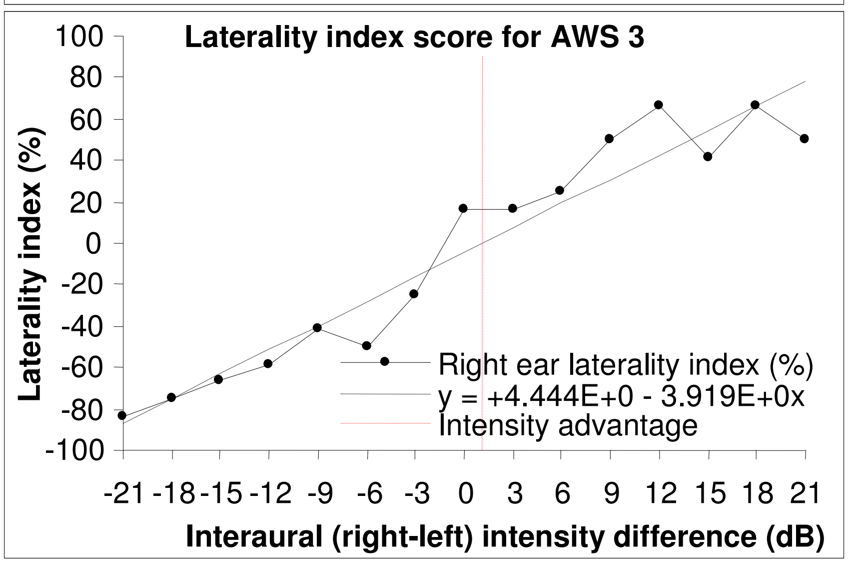
Appendix V

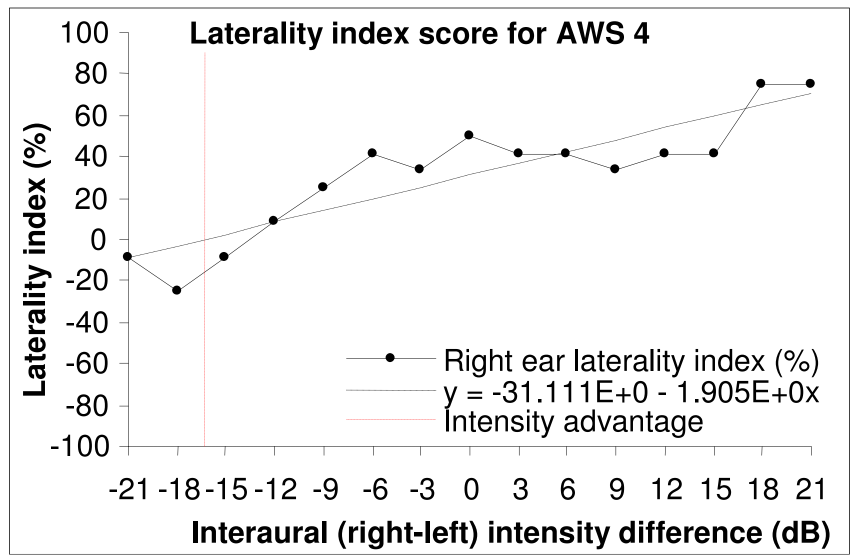
Individual Results of AWS Participants in the Undirected Attention Dichotic Listening Task:

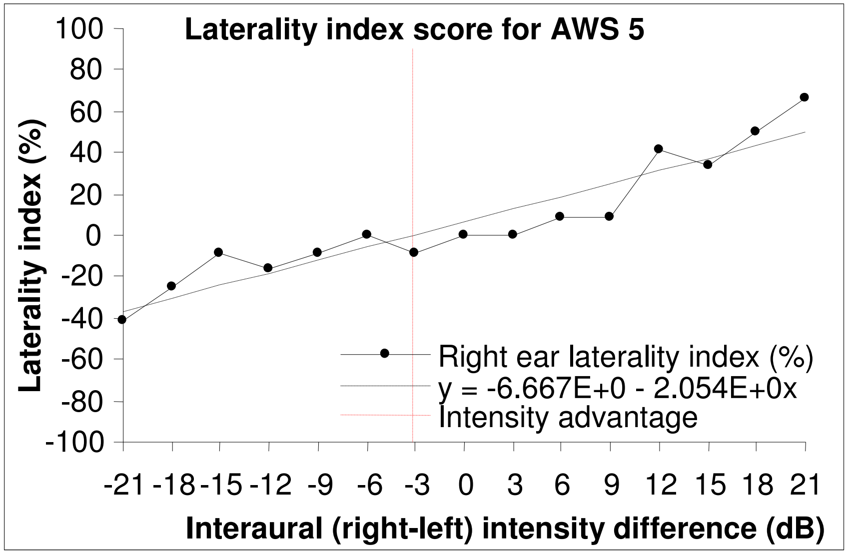
Laterality Index Score

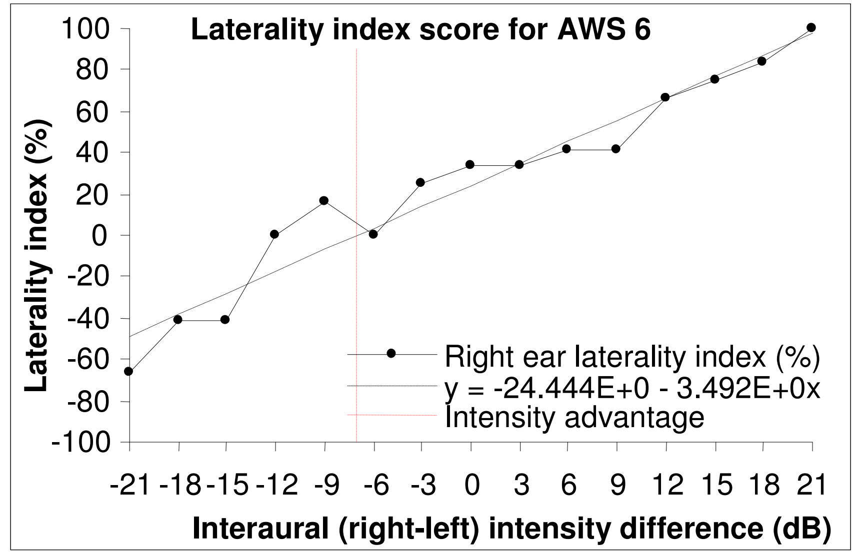

Laterality index score for AWS 1
Laterality index (%)
Right ear laterality index (%)
y = -18.889E+0 - 3.552E+0x
Intensity advantage
Interaural (right-left) intensity difference (dB)

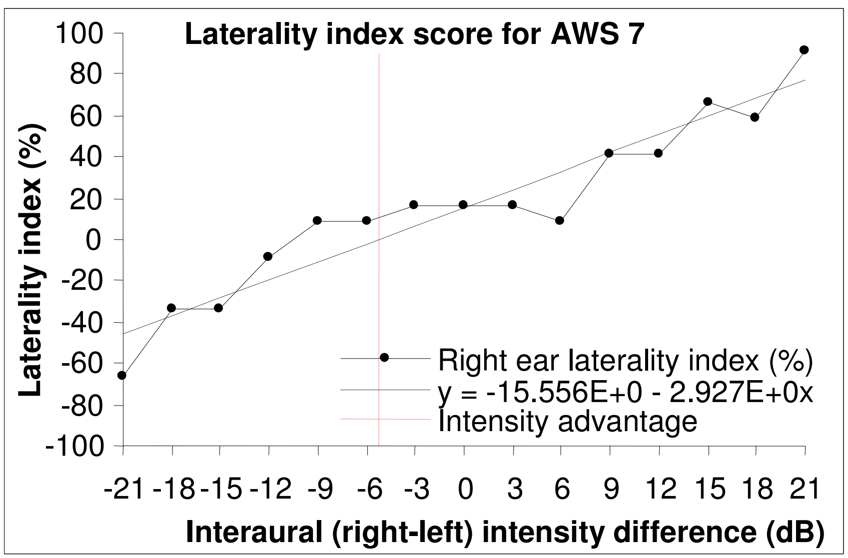

Laterality index score for AWS 2
Laterality index (%)
Right ear laterality index (%)
y = -11.667E+0 - 1.587E+0x
Intensity advantage
Interaural (right-left) intensity difference (dB)


Laterality index score for AWS 3
Laterality index (%)
Right ear laterality index (%)
y = +4.444E+0 - 3.919E+0x
Intensity advantage
Interaural (right-left) intensity difference (dB)


Laterality index score for AWS 4
Laterality index (%)
Right ear laterality index (%)
y = -31.111E+0 - 1.905E+0x
Intensity advantage
Interaural (right-left) intensity difference (dB)

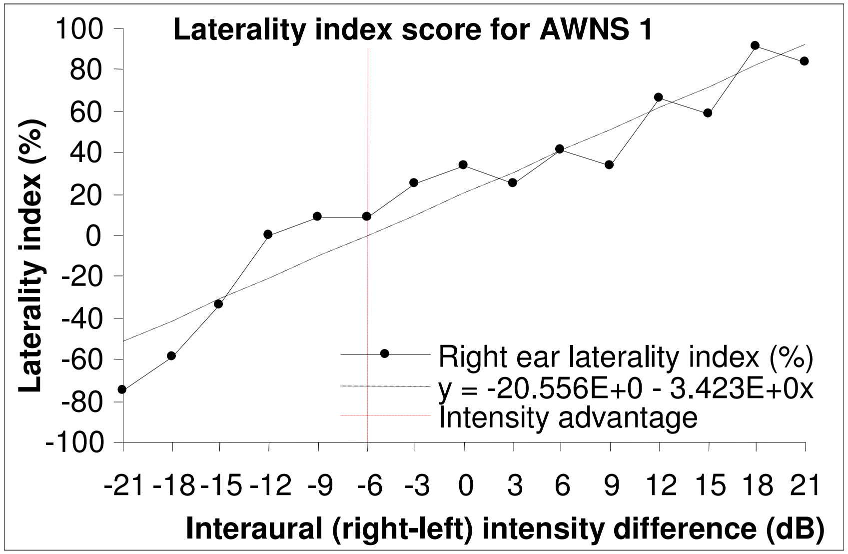

Laterality index score for AWS 5
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -6.667E+0 - 2.054E+0x
Intensity advantage

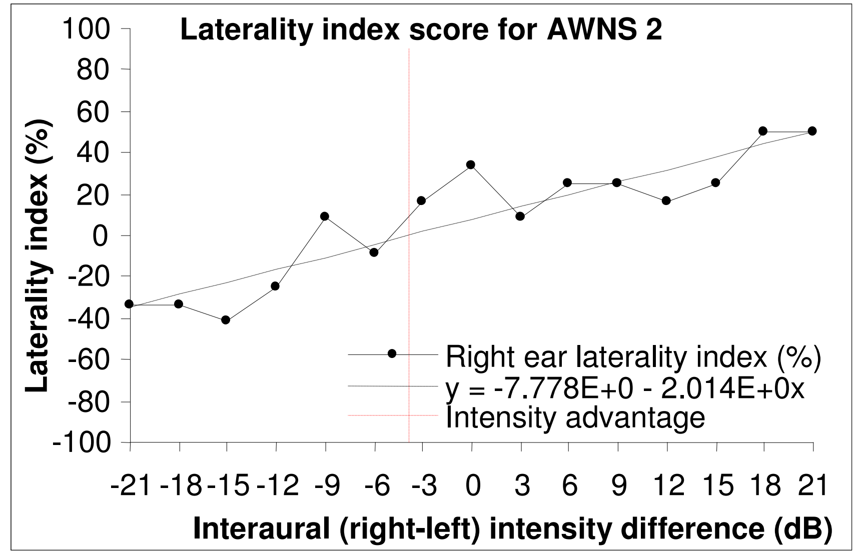

Laterality index score for AWS 6
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -24.444E+0 - 3.492E+0x
Intensity advantage

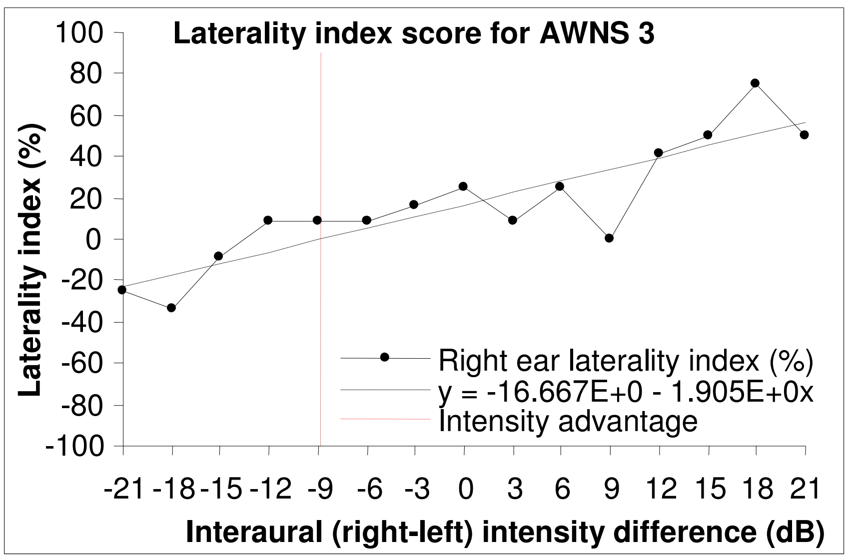

Laterality index score for AWS 7
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -15.556E+0 - 2.927E+0x
Intensity advantage

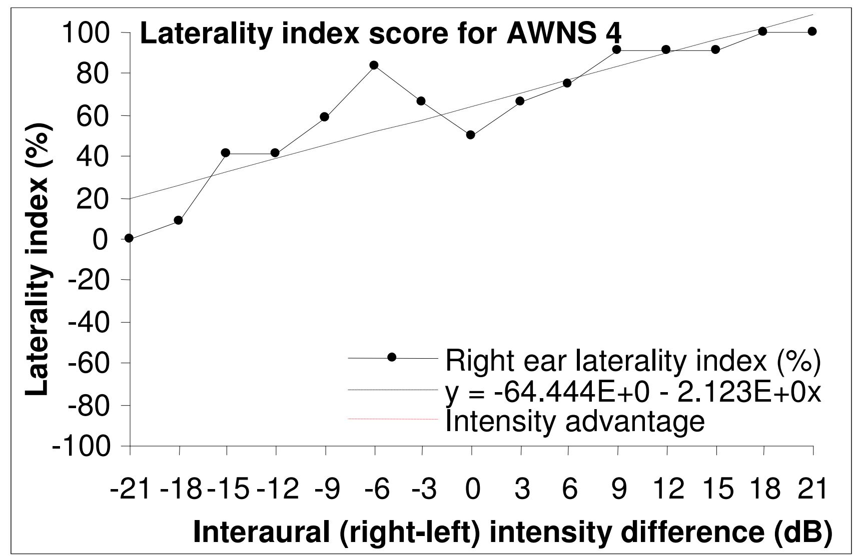
Appendix VI

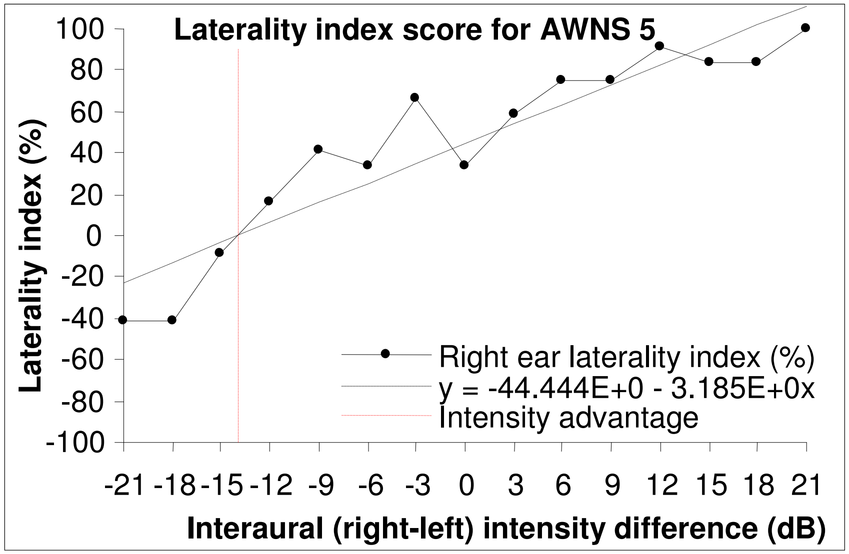
Individual Results of AWNS Participants in the Undirected Attention Dichotic Listening Task: Laterality Index Score

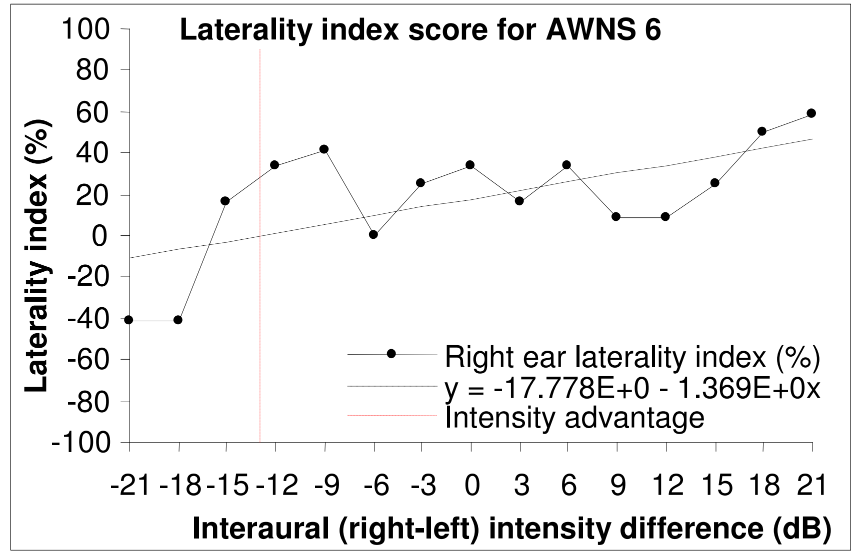

Laterality index score for AWNS 1
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -20.556E+0 - 3.423E+0x
Intensity advantage

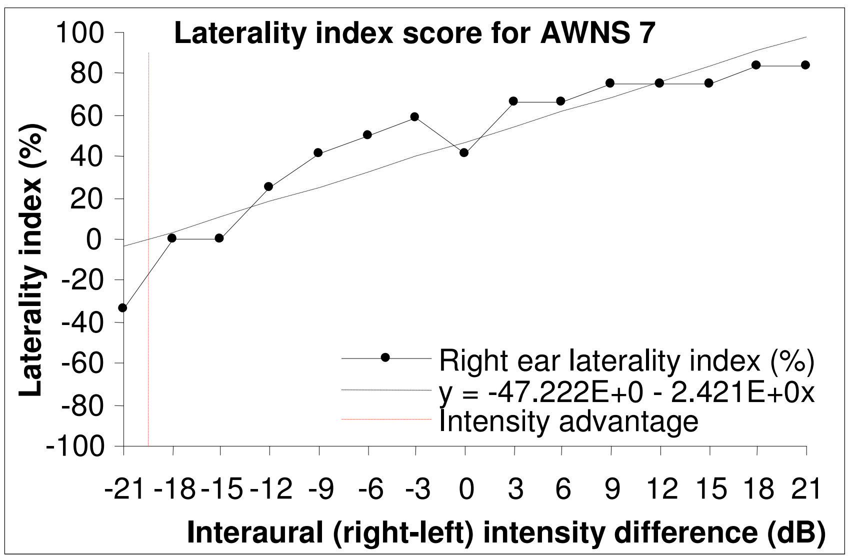

Laterality index score for AWNS 2
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -7.778E+0 - 2.014E+0x
Intensity advantage


Laterality index score for AWNS 3
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -16.667E+0 - 1.905E+0x
Intensity advantage


Laterality index score for AWNS 4
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -64.444E+0 - 2.123E+0x
Intensity advantage

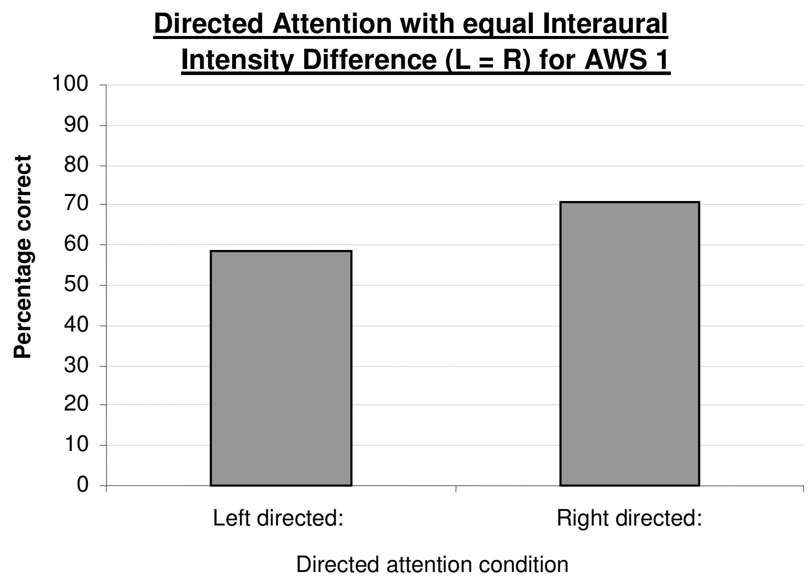

Laterality index score for AWNS 5
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -44.444E+0 - 3.185E+0x
Intensity advantage

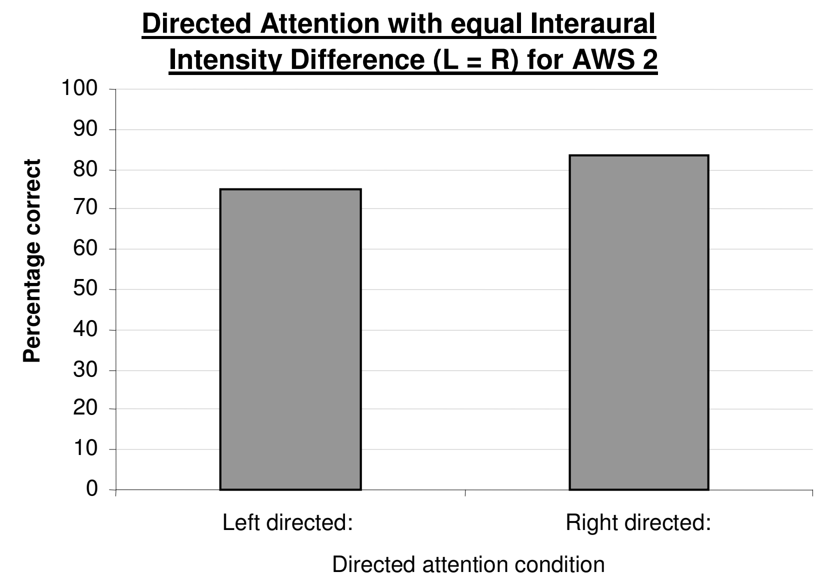

Laterality index score for AWNS 6
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -17.778E+0 - 1.369E+0x
Intensity advantage

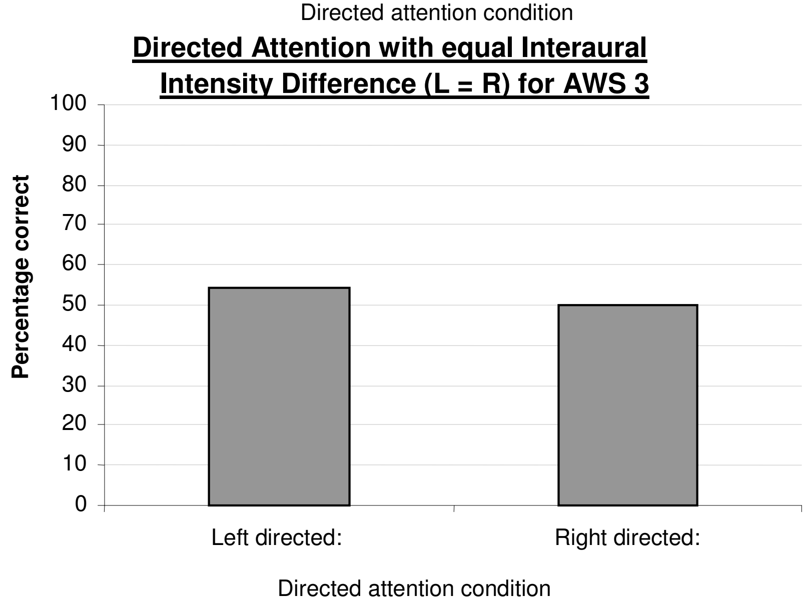

Laterality index score for AWNS 7
Laterality index (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21
Interaural (right-left) intensity difference (dB)
Right ear laterality index (%)
y = -47.222E+0 - 2.421E+0x
Intensity advantage

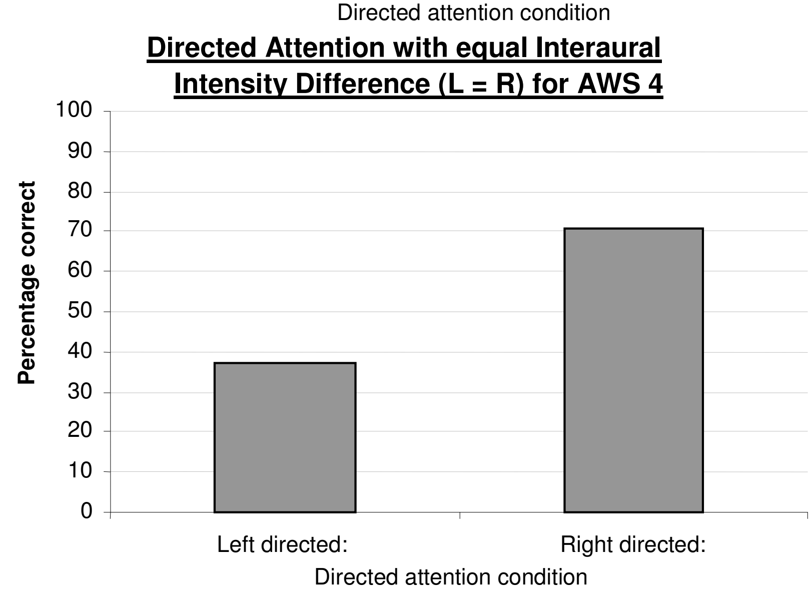
Appendix VII

Individual Results of AWS Participants for the Directed Attention Dichotic Listening Task

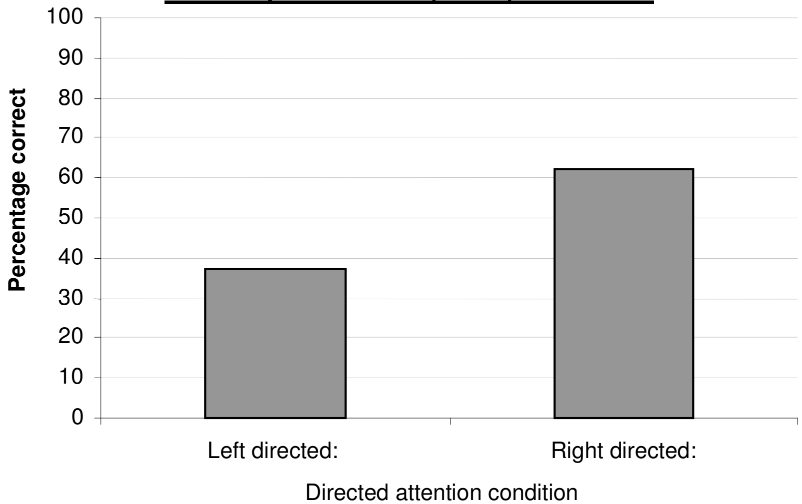

Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 1
Percentage correct
0
10
20
30
40
50
60
70
80
90
100
Left directed:
Right directed:
Directed attention condition


Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 2
Percentage correct
0
10
20
30
40
50
60
70
80
90
100
Left directed:
Right directed:
Directed attention condition

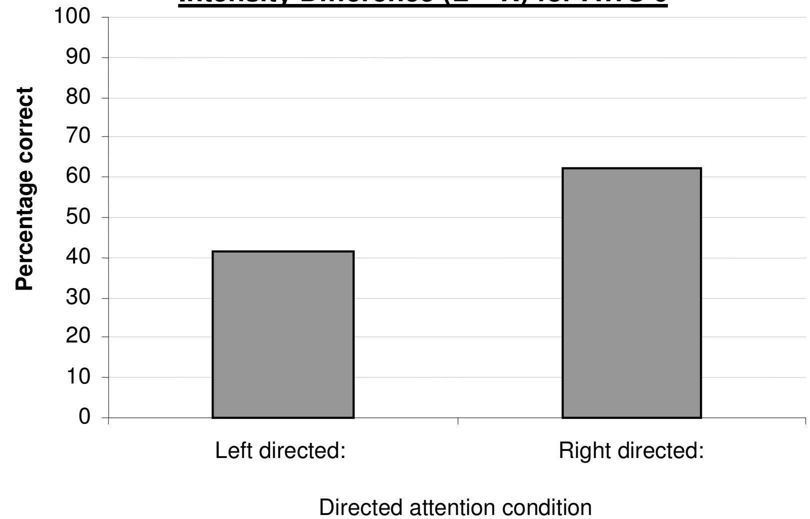

Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 3
Percentage correct
0
10
20
30
40
50
60
70
80
90
100
Left directed:
Right directed:
Directed attention condition


Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 4
Percentage correct
0
10
20
30
40
50
60
70
80
90
100
Left directed:
Right directed:
Directed attention condition

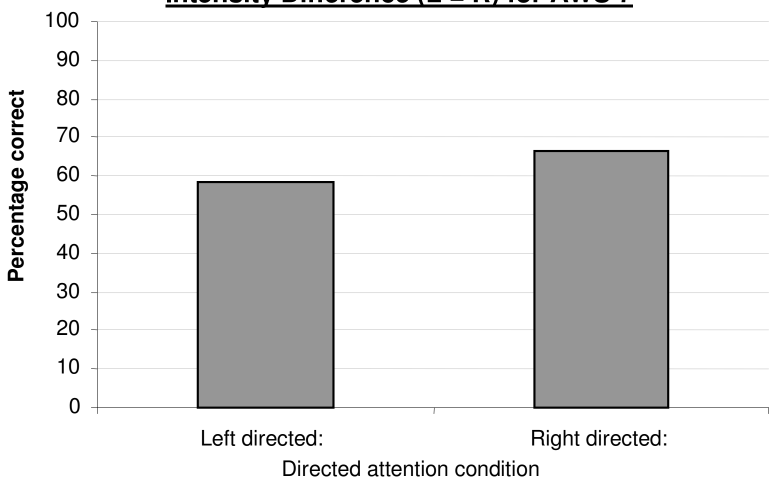
Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 5



Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 6



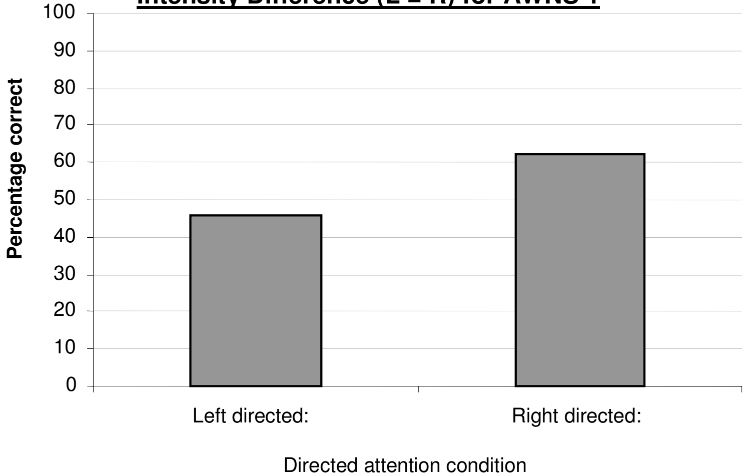
Directed Attention with equal Interaural Intensity Difference (L = R) for AWS 7



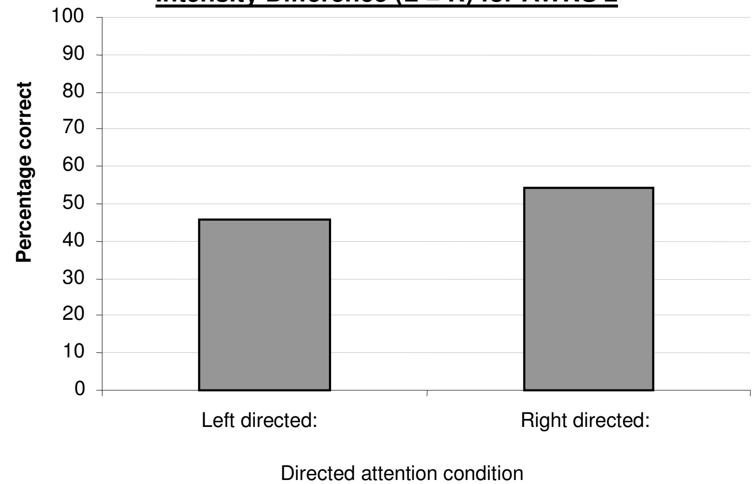
Appendix VIII

Individual Results of AWNS Participants for the Directed Attention Dichotic Listening Task

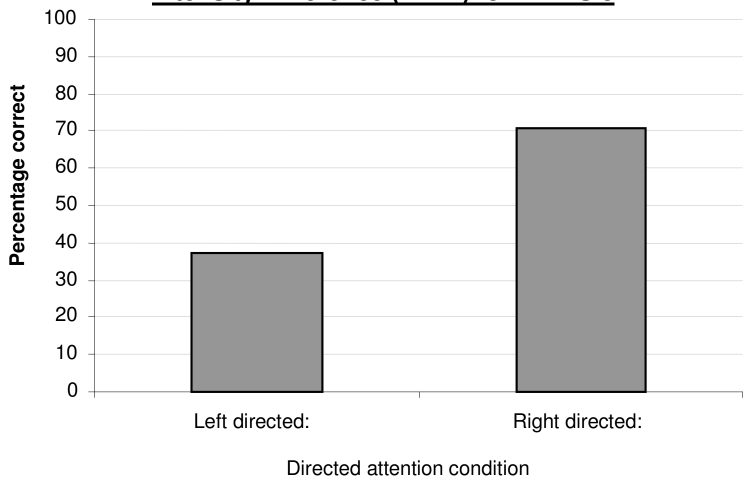
Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 1



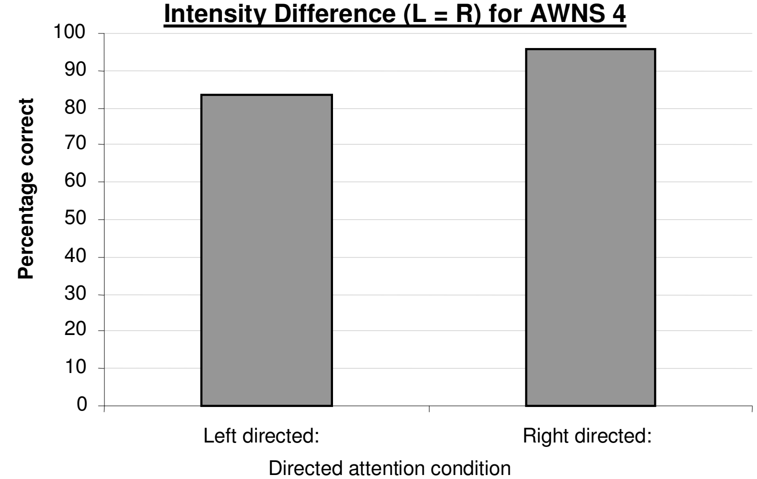
Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 2

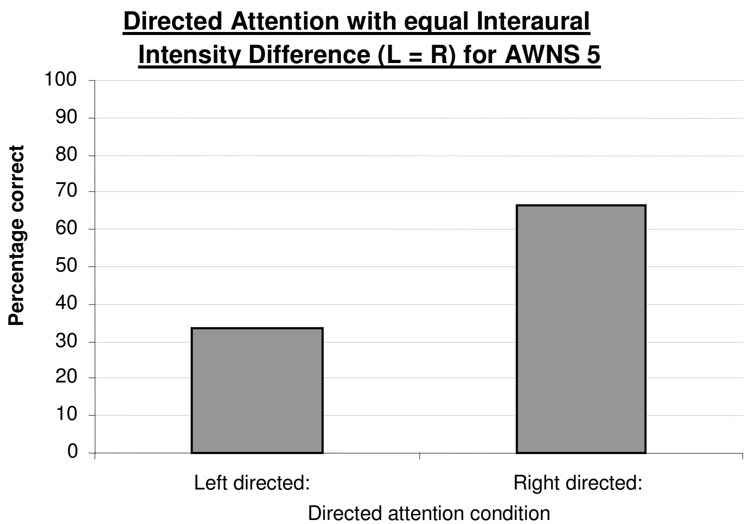


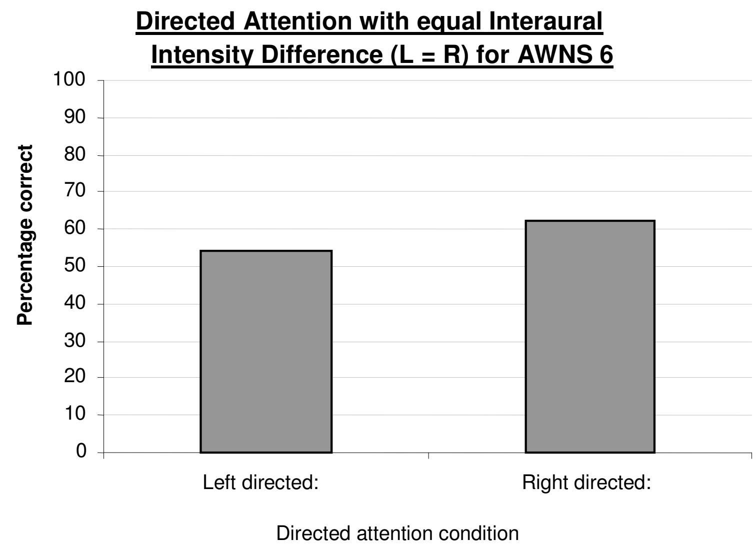
Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 3

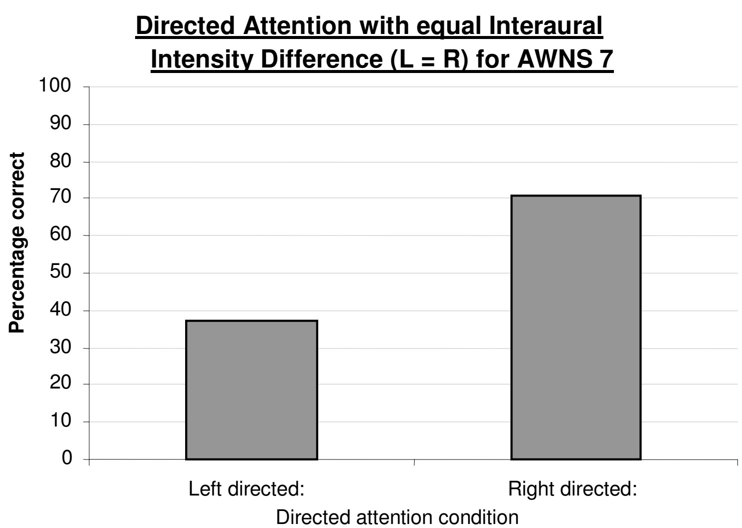


Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 4




Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 5
Percentage correct
100
90
80
70
60
50
40
30
20
10
0
Left directed:
Right directed:
Directed attention condition


Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 6
Percentage correct
100
90
80
70
60
50
40
30
20
10
0
Left directed:
Right directed:
Directed attention condition


Directed Attention with equal Interaural Intensity Difference (L = R) for AWNS 7
Percentage correct
100
90
80
70
60
50
40
30
20
10
0
Left directed:
Right directed:
Directed attention condition