THE EFFECT OF VOICE-ONSET-TIME ON DICHOTIC LISTENING WITH CONSONANT-VOWEL SYLLABLES: A REPLICATION STUDY

by

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This is a study designed to investigate the influence of voice-onset-time (VOT) on the results of a dichotic listening (DL) test using consonant-vowel (CV) syllables. A previous investigation of the role played by VOT on dichotic CV performance was performed on native-Norwegian speakers with the Norwegian language version of the DCV test (Rimol, Eichele & Hugdahl, 2006). VOT had a significant effect on ear report with three of the pairings (long-long (LL), short-short (SS) and short-long (SL)) resulting in an average right-ear advantage (REA), while the fourth condition, long-short (LS), resulted in an average left-ear advantage (LEA). These results suggested that voice onset duration influenced ear advantage because the ear to which the syllable with the long VOT performed better than the ear to which the syllable with the short VOT was presented, regardless of which ear it was. It was concluded that VOT influences laterality results of DL tests with CVs more than the classic REA which would have predicted a stable advantage for the right ear across all conditions. The purpose of the current study was to evaluate the effect of VOT on native-English speakers using the English version of the DCV test. If the results observed in the Norwegian study were driven by duration of VOT only, it was hypothesized that the long VOT would also enhance performance in the both ears and produce a LEA during the LS condition among listeners performing the test in another language, as long as the relative durations of VOT remained similar to those in the Norwegian

version of the test. It was further hypothesized that if the long VOT does not produce the advantage in left ear performance as seen in the original study, that there may be other factors related to native language that could be influencing laterality during this task.

The results of the current study were similar to those of the original study. The SL, SS, and LL conditions produced an average REA, whereas the LS condition produced an average LEA. The SL condition produced the strongest REA and the LS condition produced the strongest LEA across listeners. The results indicate that relative temporal information between presentations to the two ears plays a significant role in laterality results from DL tests. Differences related to native language cannot be ruled out from this study, however, because relative durations of VOT between the Norwegian and English versions were similar.

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PREFACE

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1.0 INTRODUCTION

1.1 DICHOTIC LISTENING

Dichotic Listening (DL) "involves the simultaneous presentation of different auditory stimulus separately to each ear over headphones, in contrast to the natural binaural listening situation, where the same stimulus is received by both ears" (Ingram, 2007, p. 381). Dichotic listening tests are the most commonly used assessment tasks for clinically diagnosing an auditory processing disorder (APD) (Emanuel, et al., 2011) and are frequently used to study functional brain asymmetry (Berlin et al, 1973; Brancucci et al, 2004; Hugdahl, 2011; Hugdahl & Andersson, 1986; Hugdahl & Wester, 1992; Hynd et al., 1979; Kimura, 1961;). Participants are asked to listen for competing stimuli presented to the right and left ear and to report the sound(s) perceived in each trial. In some DL tests, listeners are directed to listen for and repeat all stimuli that they hear whereas in other tests, they are asked to repeat only one stimulus, i.e. the one that is most "clearly heard" or to ignore one ear and report what is heard in the other ear.

The DL procedure was originally developed by Donald Broadbent (1956) to investigate attention to auditory stimuli. Doreen Kimura adapted the tests over 50 years ago, which have since been used as a means to test auditory laterality (Hugdahl, 2011) and binaural integration (Moncrieff, 2006). Kimura discovered that her patients correctly reported more stimuli, which were presented to the right ear than the left ear, resulting in the theory of the right-ear advantage

(REA) effect (discussed in section 1.2.1). Clinically, DL tests are used to examine impairments in auditory processing, attention, working memory, and executive functioning, as well as hemispheric abnormalities (Emanuel, et al., 2011; Hugdahl, 2011). Outside of audiology, DL tasks are used in psychiatric, neurological and neuropsychological research (Hugdahl, 2011), as a non-invasive way to study brain functions.

1.1.1 Types of Stimuli

Stimuli for dichotic listening tests include two or more different words, numbers, consonant-vowel syllables (CVs) or other type of speech material. Non-linguistic stimuli, such as musical chords and environmental sounds (a dog barking or running water) can also be used in DL tests. However, most stimuli used are linguistic in nature. During dichotic listening tests, the opposing stimuli are meant to be aligned so that they are presented exactly at the same time. Originally, there wasn't available technology to create this perfect simultaneous presentation, but the stimuli was aligned to be as close to the same time as possible. Today, this feat is far more achievable. Under some DL conditions, the stimuli also have the same duration, but that cannot always be achieved with each type of stimulus. A DL task with words is a test of binaural integration because the listener must process competing stimuli from both ears and then repeat either what is heard in both ears or what is heard most clearly after the processing has occurred. Digits, or numbers, are verbal material and a part of every language. Competing digits, such as "one" and "six" are presented simultaneously in opposing ears ("seven" is not used because it contains two syllables). Similarly, syllables, such as /ta/ and /ka/ are presented simultaneously in opposing ears (see Figure 1 below). The Dichotic Fused Words Test (DFWT) presents pairs of monosyllabic rhyming consonant-vowel-consonant (CVC) words, such as /coat/ and /goat/, to the participants. Dichotic listening tests with words don't have to rhyme and most often vary in the initial and final consonant and medial vowel. Other words tests include the Dichotic Words Test (DWT) (Moncrieff, 2011) and the Dichotic Nonsense Words Test (DNWT) (Cheyney & Moncrieff, in preparation). The DWT pairs monosyllabic meaningful words such as "bean", "king" and "toad", while DNWT pairs monosyllabic, nonsense words, such as "meb", "tep", and "sus". The Staggered Spondaic Words (SSW) test is another DL word test in which spondaic words (two syllables with equal stress) are presented in an overlapped manner, meaning the second half of the first spondee occurs at the same time as the first half of the second spondee. In this way, the listener hears half of each spondaic word monaurally and the other half of each word dichotically. The Screening Test for Auditory Processing Disorders (SCAN) Competing Words (CW) subtest is part of an APD screening battery that also uses CVC competing words. Sentences can also be used in a DL test mode but the task is a binaural separation task. In this type of DL task, the listener is instructed to completely ignore what is being presented to one ear and to only identify material presented to the other ear. This type of presentation can also be used with shorter stimuli such as words, but it is essential during the presentation of longer material such as sentences. The SCAN – Competing Sentences (CS) uses pairs of sentences that have similar word length, semantic content and duration. The Dichotic Sentence Identification (DSI) test dichotically presents 10 nonsense-like sentences, which are called "third-order approximation" sentences and are comprised of real words in irregular syntactic arrangement that carry no semantic information. The listener must identify both sentences from a printed list of all 10 sentences, but the task involves a small number of sentences so the listener is able to identify most of the sentences simply by identifying one of the key words in it.

Figure 1. Dichotic Listening Test using CV syllables schematic

Courtesy of Kenneth Hugdahl, PhD, University of Bergen, Norway

1.1.2 Testing Conditions

Testing conditions can vary depending on the stimuli and experiment. The presentation level used is a typically comfortable listening level, normally ~50 dB HL. Dichotic listening stimuli are presented via earphones or headphones to the listener in a sound-treated or soundproof booth. Stimuli may be presented from a compact disc player via an audiometer or through a laptop or desktop computer. Participants are given verbal instructions on how to respond. During a free recall mode, the listener is directed to repeat either one or both of the stimuli from memory. This mode is considered a divided attention mode of listening. In a forced response mode, the listener is asked to attend to a specific ear (left or right) and ignore presentations made to the opposite ear. This is considered more of a selected attention paradigm. Under either of these conditions, the listener will be asked to either provide a verbal response by repeating the stimulus or stimuli heard or to choose the stimulus or stimuli from a group of options provided to them in writing on a piece of paper or on a computer screen.

1.2 STRUCTURAL THEORY OF THE RIGHT-EAR ADVANTAGE (REA)

1.2.1 Basic Assumptions

In 1961, Doreen Kimura performed the first dichotic listening study on patients with epileptic seizures (Kimura, 1961). She simultaneously presented as many as four pairs at a time of different digits to her subjects' ears before and after a temporal lobectomy. Patients with a left temporal lobectomy showed poor performance in the dichotic digits test postoperatively, but good scores for tests with nonverbal auditory stimuli, indicating that the left temporal lobe must be necessary to normally process verbal stimuli. Kimura developed the structural theory of the REA from her work testing patients with dichotic listening tests. It had previously been shown that monaural presentation of speech resulted in no difference between the two ears, but dichotically presented stimuli creates a competition between the ears that often results in enhanced performance in one ear over the other (Kimura, 1967). The contralateral auditory pathway has a greater number of neural fibers than the ipsilateral pathway and suppresses the ipsilateral pathway ascending from the opposite ear, leading to the contralateral pathway dominance and the REA (Kimura, 1967). Berlin and colleagues reiterated the assertion that the contralateral path is stronger, consequently leading, in most listeners, to the typical REA. Berlin also suggested that the right ear "may simply perform better during competition" during DL tasks, an assertion that has been documented in a majority of listeners across decades of research

(Berlin et al, 1973). Kimura then used DL to investigate whether speech and music would result in the same lateralization effect by testing individuals with both digits and melodies. Digits produced the usual right-ear superiority, but the melodies produced a left-ear superiority (Kimura, 1967). This result added support to the structural theory in that the right ear superiority during DL tests with speech stimuli may be due to left hemisphere dominance for language, whereas left ear superiority during DL tests with tonal stimuli may be due to right hemisphere dominance for nonverbal auditory stimuli such as tonal patterns in melodies (Kimura, 1967).

In 2011, Kimura published a paper reflecting on the REA effect she originally reported. She concluded that "right-ear effect was due to the fact that in people also, the crossed auditory pathways were more effective than the uncrossed. This gave the right-ear input an advantage in accessing areas in the left hemisphere critical for speech perception," (Kimura, 2011, p. 214).

1.2.2 Evidence

1.2.2.1 Post-mortem dissections

In a review of lateralization written by Tervaniemi and Hugdahl (2003), the anatomical structures of the auditory cortex reveal the evidence for hemispheric asymmetry leading to the REA. The planum temporale, located in the upper posterior section of the temporal lobe between Heschl's gyrus and the Sylvian fissure, is larger in the left hemisphere than in the right. Geschwind and Levitsky (1968) examined the temporal lobes in 100 human brains post mortem. Handedness was not controlled for, but it was assumed that since as many as 96 percent of humans have a left-hemisphere dominance for speech, that the overwhelming majority of the subjects would also have greater structural mass in the left cerebral hemisphere. Geschwind and Levitsky (1968) reported that the planum temporale was larger in the left hemisphere in 65% of the brains, whereas it was larger in the right hemisphere in 11% of the brains and symmetrical in the remaining 24% (Geschwind & Levitsky, 1968). Furthermore, the left planum temporale was, on average, longer than the right planum temporale (Geschwind & Levitsky, 1968). The planum temporale is thought to be involved in processing verbal and non-verbal stimuli and is the principal structural component of the auditory "where" pathway for processing and integrating the location of auditory signals (Ahveninen et al., 2006).

1.2.2.2 Lesion Studies with DL Tests

Hugdahl and Wester (2000) examined the role of the thalamus for language processing and analyzed lesions in the left vs the right thalamus. Dichotic listening tests were conducted before, after, and during the introduction of the lesion. Hugdahl and Wester (2000) predicted that a left thalamus lesion would lead to increased REA while a lesion on the right thalamus would lead to a decreased REA or a left-ear advantage (LEA). A less-than-normal REA was found in all patients prior to surgery. During the surgery, patients who received stereotactic electric stimulation to their left hemisphere had a significant increase in their right ear scores, while there was no significant difference in the scores of right-stimulated patients. Finally, after the surgery, left-lesioned patients had a significant drop in correct scores with almost little to no REA whereas, the scores of the right-lesioned patients did not change. Hugdahl and Wester (2000) postulated that the ventrolateral thalamic nucleus "gates" information in the left hemisphere, allowing a facilitation of a REA. When signals are presented to the contralateral right ear, the gate is "on." Lesions interfere with the normal function of the gate, thereby creating a decreased REA.

Sparks and Geschwind (1968) examined the effects on DL tests after the severance of neocortical commissures in a 52-year old male (WJ) to treat a seizure disorder. The patient received preliminary dichotic testing with digits and words at a comfortable listening level. The same tests were also performed on left brain-damaged aphasic and right brain-damaged non-aphasic patients. All of the patients also received DL listening tests with 25 infrequently used words, such as “thwart” or “mauve,” to the right ear and 25 frequently used words, such as “south” and “nose,” to the left ear. In the digits test, WJ was unable to correctly repeat any of the stimuli presented to the left ear, while he correctly repeated all of the stimuli presented to the right ear. In the common and uncommon words tests, WJ revealed complete extinction in the left ear. For the right ear, he repeated 44% of the words correctly and 44% incorrectly with 12% not repeated. Sparks and Geschwind (1968) hypothesized that the callosal pathway has an important role in the REA. Typically, it is assumed that the temporal lobe receives its stronger connection via the direct contralateral pathway. However, Sparks and Geschwind (1968) noted that the stronger contralateral pathway transmits directly to the opposite temporal lobe and the information can then travel via the corpus callosum to the ipsilateral temporal lobe. WJ’s interhemispheric pathway was severed, so information from his left ear went directly to the right hemisphere but was then unable to cross over to the left hemisphere for linguistic processing. This study suggests the importance of the corpus callosum in the processing of linguistic information presented in competition to both ears which affects all DL test results.

1.2.2.3 Imaging Studies

The review by Tervaniemi and Hugdahl (introduced in section 1.2.2.1) discussed the evidence found from EEG, MEG, fMRI and PET scans performed during dichotic listening studies, which showed activation in the neural pathways of the left-hemisphere with speech sound stimuli, while music stimuli elicited activation in the neural pathways of the right-hemisphere (Tervaniemi and Hugdahl, 2003). These results provided functional evidence in support of Kimura’s structural theory with evidence that linguistic information activates the brain bilaterally but activates the left hemisphere to a larger degree than the right and that non-linguistic information produces the opposite pattern.

Magnetoencephalography (MEG) studies also support the hypothesis that the dominant contralateral pathway from the right ear to the cortex inhibits the ipsilateral pathway, resulting in left hemisphere dominance (Brancucci et al., 2004; Kimura, 1967). Brancucci et al. (2004) performed MEG tests on 10 subjects during a DL task using eight tones and found a significant response at the cortical level at the planum temporale of the Heschl's gyrus, which contains the primary auditory cortex. Hertrich, Mathiak, Lutzenberger, and Ackermann (2002) also used MEG and found the left hemisphere to be better at encoding formant transitions. Left lateralization was indicated in evoked magnetic fields when stop consonant-vowel stimuli was used. Stop consonants, such as those used in DL tests with CVs (/ba/, /da/, /ga/, /pa/, /ta/, /ka/), contain frequencies which change rapidly over time (Tallal et al., 1993). These results suggest that the left hemisphere may also preferentially process the rapid temporal changes in speech and that temporal processing therefore also favors a REA. Tallal et al. (1993) found that when she lengthened the formant transitions in the CV syllables, the magnitude of the REA was significantly reduced (see section 1.4.2 below for further discussion of this study).

In a study looking at ear advantage in children with focal epilepsy in the left-hemisphere, Korkman, Granström and Berg (2004) reported that the children produced a LEA due to structural abnormalities in the left hemisphere caused by the seizures. Each participant underwent an MRI to determine brain abnormalities within the hemispheres. Those with a large left hemisphere abnormality produced the LEA, while those with a small left hemisphere abnormality had a normal REA. Seven of the thirty-five children tested had an extreme LEA.

Korkman et al. (2004) confirmed that a unilateral brain pathology can significantly affect and/or change the ear advantage during DL tests with linguistic stimuli.

1.2.2.4 Comparison with Wada

Dichotic listening is a useful, non-invasive method for testing language lateralization. The method that is regarded as the gold standard means to determine language lateralization involves speech arrest following sodium amytal injection (Wada & Rasmussen, 1960). The method was initially developed in monkeys and then later performed on 20 human patients. The subjects/patients were injected in either the right or left carotid arteries on separate days. Following the injections, the patients exhibited contralateral hemiplegia as indicated by the contralateral arm and legs becoming flaccid. The experiment affected speech immediately and dramatically when the injection was applied to the language-dominant hemisphere. The patients ceased their speech within seconds of the injection. When injected into the non-dominant hemisphere, a gradual decline in the ability to speak was observed. Speech arrest lasted for around 20 seconds and normal speech resumed within 30 to 60 seconds post injection.

Following speech arrest with the Wada procedure, the human subjects underwent subsequent craniotomies to further investigate the lateralization of speech dominance using injections of the sodium amytal. In the left-handed patients, the carotid amytal test indicated a right cerebral hemisphere dominance in 6 of the 12 patients and a left cerebral hemisphere dominance in the remaining 6 patients. In the right-handed patients, the carotid amytal test revealed a left cerebral hemisphere dominance in all 6 of the patients. This study has, thus, led to the concept of a left hemisphere dominance in language processing, with the exception of some left-handed individuals.

1.3 ATTENTIONAL THEORY OF THE REA

1.3.1 Basic Assumptions

Evidence for the structural theory of DL was strongly supported by studies in patients with known lesions of the auditory pathway, but researchers noted that results from DL tests may be influenced by factors related to the listener's attention. Marcel Kinsbourne (1998) proposed the attentional theory of DL, noting that perception during listening tasks is subject to selective attention and may depend less on the specific sensory input. The attentional theory suggests that listeners can shift their attention shifts to one ear during DL testing and thereby alter their ear advantage.

1.3.2 Evidence

1.3.2.1 Behavioral Studies

Foundas et al. (2006) used a CV DL test to study left and right-handed adults. The test was comprised of three conditions: non-directed, left-directed, and right-directed. The non-directed trial revealed a strong REA in both right and left-handed individuals with a stronger asymmetry in the right-handed participants. In the directed trials, participants increased their scores towards the directed ear. The attentional theory accounts for these results.

Voyer and Ingram (2005) used the Fused Dichotic Words Test (FDWT) to study attention aspects in DL tests. Participants were randomly assigned to either a free recall or cued condition. The free recall condition produced a strong REA, whereas the REA was reduced during the cued condition. The results suggest the cue, and therefore attention, influences DL and that laterality is affected by attention. This means that there may be a preference to attending to the right ear as opposed to an anatomical predisposition.

Wood, Hiscock and Widrig (2000) studied lag effects with an attentional component. More generally, they found that the number of reports from the lagging ear increased if syllable presentation on one ear was delayed and the syllable presentation to the opposite ear remained constant. Their study determined the difference between preattentional, or automatic, and attentional, or controlled, processes during dichotic listening studies. When asked to attend to a certain source of stimuli, the subject tends to be unable to recall the meaning of the content received by the unattended source. However, they're usually aware that the unattended source is receiving input. This suggests that acoustic information is processed through a preattentive process or automatically, whereas instructions to attend to a specific stimulus requires processing at a higher level in order to gain semantic meaning.

1.4 TEMPORAL PROCESSING THEORY OF THE REA

1.4.1 Basic Assumptions

In addition to structural differences, functional differences between the hemispheres result in a REA. The functional differences are seen in temporal processing, meaning the left temporal lobe has a superior ability to process the stimuli used in dichotic listening tests, which result in a REA.

1.4.2 Evidence

It has been determined that there is a left hemisphere bias for responding to rapid frequency transitions, shown by less activation within the right auditory cortex during rapid acoustic changes (Belin, Zilbovicius, Crozier, Thivard & Fontaine, 1998). Schwartz and Tallal (1980) investigated similar effects of rapidly changing acoustic stimuli. The formant transition was synthetically extended, which, as they hypothesized, would significantly affect the REA recorded prior to the extension. A 40 ms formant transition produced the typical REA. The REA was significantly reduced when the duration of the transition was extended from 40 to 80 ms. With an 80 ms transition, the subjects produced fewer correct right-ear responses, thereby reducing the value of the REA. Schwartz and Tallal (1980) suggested that the REA does not reflect "superiority of the left hemisphere," but that the left hemisphere is better equipped to process rapidly changing acoustic events, which occurs in fluent speech.

1.4.2.1 Imaging Studies

Positron emission tomography scans reveal that parts of the auditory cortex in both hemispheres, specifically Heschl's gyrus (HG), respond to temporal changes, whereas the superior temporal gyrus (STG) responds to spectral changes (Zatorre & Belin, 2001). More specifically, temporal changes affect the HG bilaterally, but create a greater response in the left hemisphere. Spectral changes create a response in the anterior STG in both hemispheres, but a greater response is seen in the right hemisphere. Zatorre and Belin (2001) hypothesized that the greater number of myelinated fibers and greater thickness of the myelin sheaths in the left hemisphere HG create faster conduction, which leads to the ability to respond to rapid acoustic changes. This interpretation was supported by post-mortem tissue analysis of the left hemisphere HG.

1.4.2.2 Speech Characteristic Influences

Tallal, Miller and Fitch (1993) examined language-impaired children to determine the basis of their impairments. Specific language impairment (LI) occurs in children who develop normally in all other areas, but do not develop language at the expected time or rate. A dichotic listening test using CV syllables with a formant transition rate of 40 ms was conducted. Ten out of the twelve participants failed to reach the criterion on the association subtest, meaning they were unable to learn how to use the response panel to complete the test. All of the children described an inability to hear a difference between the two syllables presented. The transition durations were extended. The LIs continued to show difficulty with vowel-vowel stimuli, but showed improvement when the transition rate in CV syllables was extended to 80 ms or more. Thus, the study confirmed that language-impaired children have an inability to integrate the rapidly changing acoustic information within the speech, regardless of the phonetic classification of the sounds.

In another study, Studdert-Kennedy and Shankweiler (1970) offered an alternative explanation that the REA arises due to the dominant hemisphere's ability to isolate the phonological features or phoneme segments during language processing, as opposed to the assertion that the dominant hemisphere is specialized to attend to rapidly changing acoustic stimuli. Studdert-Kennedy and Shankweiler (1970) tested synthetic versus natural speech in DL tests. However, they used consonant-vowel-consonant syllables and tested with initial-consonant-varying (IC) syllables and final-consonant-varying (FC) syllables. They also constructed an IC vowel test, which differed only in contrasting vowels used. The initial-consonant test revealed a significant REA, while the final-consonant test created a less significant REA. The REA was greatest in IC syllables and weakest with vowels. The listeners' results were least reliable with vowels. Studdert-Kennedy and Shankweiler (1970) concluded that the auditory system must analyze the speech signals and the laterality effect seen is due to the loss of auditory information, which occurs when the ipsilateral pathways transfer the information to the dominant hemisphere during processing.

These studies demonstrated that the right ear advantage may depend upon characteristics of speech that may create a bias toward the left hemisphere and that the presence of stop consonants may be most significant in producing this effect. It was hypothesized that stop consonants enhance the REA (Haggard, 1971) because the frequencies change quickly, which allow the listeners to encode the sound as a consonant. This supports the hypothesis that rapid acoustic changes influence the REA because stop consonants produce the most rapid acoustic changes in CV syllables. Features without rapid changes, such as liquids, vowels and fricatives did not produce a reliable REA (Haggard, 1971; Darwin, 1971).

A study performed by Berlin, Lowe-Bell, Cullen and Thompson (1973) investigated lag effects and the differences between voiceless syllables and voiced syllables. Stimulation of the right ear results in a shorter response time as opposed to the few millisecond delay in the response of left ear. The lag effect occurs when one of the syllables "lags" behind the lead syllable by a certain length of time. A lag of 30 milliseconds eliminated competition for both ears. When the syllable presented to the right ear followed the presentation of the syllable to the left ear by 30 milliseconds, a reliable and even stronger REA was observed. In the reverse situation, no ear advantage or even a LEA was observed. Furthermore, it was discovered that when the second syllable onset began 90-500 milliseconds after the onset of the first syllable, perception of both syllables improved. Therefore, it can be seen that introducing a lag effect can dramatically alter the REA, meaning the temporal processing of stimuli changes when presentation times are changed. In regards to voiceless versus voiced syllables, Berlin et al found related time effects as the lag effects. When a voiced syllable and voiceless syllable are presented simultaneously, the voiceless sound is more intelligible. It is assumed that the long burst duration of the voiceless sound overcame the voiced sound. However when the voiced sound was moved in time so that the onsets matched, the intelligibility was equal, leading to the assumption of a speech processor within the left-hemisphere which suppresses ipsilateral information during contralateral stimulation.

1.5 RECENT WORK IN DICHOTIC LISTENING STUDIES

As of 2014, DL tests have been used for 53 years to test lateralization and demonstrate the REA. Imaging studies, such as PET (Hugdahl et al., 1999) and fMRI (e.g. Van den Noort, Specht, Rimol, Ersland, & Hugdahl, 2008), and electrophysiology measures, such as EEG (Jung et al., 2003), and MEG (Brancucci et al., 2004), have supported the structural and anatomical theory, discussed above, which produces the REA.

1.5.1 Gender Differences

Daniel Voyer (2011) published a meta-analysis examining gender differences in the laterality shown in dichotic listening studies. The study revealed a small, but significant, difference between men and women, revealing men to be more lateralized than women. Voyer discussed both top-down and bottom-up factors involved in these results. Bottom-up factors include the structural and anatomical differences between males and females, suggesting a biological basis.

Top-down factors include attentional biases. Previous studies (Ingram and Voyer, 2005) have suggested that men have an easier time attending to the cued ear and that women may spread attention between both ears.

1.5.2 Studies with Impaired Adults

Bouma and Gootjes (2011) used Kimura's dichotic digits paradigm with elderly and Alzheimer's patients. The study showed the REA effect in the non-forced trial in the normal, elderly adults. Attentional instructions elicited a higher number of correct responses in the left ear for the forced left trial and a higher number of correct responses in the right ear for the forced right trial (also seen in the current study). Correct responses decreased with increasing age, more so in the left ear than the right ear. Alzheimer's patients showed a REA in all three trials, whereas control subjects showed a LEA in the left-forced trial. This suggests that Alzheimer's patients have trouble attending and rely more heavily on the bottom-up processes (discussed in 1.5.1) of the dichotic listening tests (Bouma & Gootjes, 2011).

1.5.3 Studies with Children

Moncrieff (2011) found children, aged 5-11 years, produced a less reliable REA using the Dichotic Words Test (DWT), a relatively new dichotic listening test, which uses two single syllable words with equal phonemic content, and the Randomized Dichotic Digits Test (RDDT). The majority of children showed a REA, but the prevalence of the LEA was higher than previously reported among children, especially for testing with words. For RDDT, the results were similar to results among adults of 80-85% REA and 15-20% LEA or NEA (Hiscock, Inch

& Ewing, 2005). For DWT, around 25% of the children produced a LEA. Results indicated an effect of age with younger children producing larger ear advantages across both stimulus types that decreased in magnitude with development. Moncrieff (2011) also reported a greater prevalence of the NEA among the oldest age group (11-12 years), possibly because the task failed to bias one ear over the other. In combination with gender, REA prevalence increased in females with age, but deceased in males with age, suggesting a gender difference in maturation.

1.6 RIMOL, EICHELE & HUGDAHL

The temporal processing theory asserts that the speech characteristics may affect and lead to the REA. In combination with the structural theory, the specific speech characteristics of the speech stimuli in dichotic listening tests are processed preferentially in the left temporal lobe. Voice-onset-time (VOT) may be one of those characteristics, which are preferentially processed in the left temporal lobe. The present study replicates and is meant to investigate possible differences in results shown by the study performed by Rimol, Eichele and Hugdahl (2006). They performed a dichotic listening test using consonant-vowel (CV) syllables on 89 subjects. The investigators analyzed the effect of VOT on the outcomes in terms of ear scores, laterality indices and errors. They reported that syllables with a long VOT were reported more frequently than those with a short VOT and that long VOT syllables produced a bias in the ear toward which they were presented, even enough to overcome the REA. In this way, short-long syllable combinations with the long VOT syllable presented to the right ear produced the strongest REA and long-short syllable combinations with the long VOT syllable presented to the left ear produced a LEA.

We hypothesized that if the temporal characteristics of the syllable pairs are the primary influences for ear advantage, then the English version of the DCV test should produce the same pattern of results as reported by Rimol et al. (2006). If, however, features of the listener's native language also influence laterality during a DL test, then results from the English version of the test may differ from those obtained during the Norwegian version.

2.0 METHODS

2.1 SUBJECTS

Sixty-two right-handed, healthy volunteers (32 females and 30 males) between the ages of 17 and 32 years, served as subjects in the present study. None of the subjects reported a history of neurological or psychiatric illness. All were native English speakers. Each subject was screened using audiometry (250, 500, 1000, 2000, and 4000 Hz), and only subjects with a threshold of 20 dB or better were included in the study. Subjects had to show an overall REA on the first trial to be included in the statistical analyses.

2.2 STIMULI

The dichotic stimuli included six stop consonants paired with the vowel /a/ to form six consonant-vowel (CV) syllables: /ba/, /da/, /ga/, /pa/, /ta/, /ka/. The syllables were originally read through a microphone by a male voice with constant intonation and intensity, and they recordings were digitized for computer editing on a computer equipped with a standard sound board. Each pair of syllables was aligned using the Cool Edit software, to make sure that they were presented simultaneously to each ear. Temporal alignment between channels was set at the energy release in the consonant segment of the CV (Rimol, Eichele & Hugadahl, 2006).

Thirty combinations of the CV syllables were created, not including homonym combinations. Each combination was presented nine times during the sequence of the experiment. Three syllables contained voice consonants and, thus, short VOT (/ba/ /da/ /ga/) and three syllables contained voiceless consonants and, thus, long VOT (/pa/ /ta/ /ka/). This generates six combinations of syllables with long VOT and six with short VOT. There were nine combinations with a short VOT syllable in one ear and a long VOT syllable in the other ear. The combinations are listed in Table 1.

Table 1. Combining syllables

Table 1

Combining syllables with short and long VOT yielded four categories of syllable pairs.

LL	LS	SL	SS
pa_ta	pa_ba	ba_pa	ba_da
pa_ka	pa_da	ba_ta	ba_ga
ta_pa	pa_ga	ba_ka	da_ba
ta_ka	ta_ba	da_pa	da_ga
ka_pa	ta_da	da_ka	ga_ba
ka_ta	ta_ga	da_ta	ga_da
	ka_pa	ga_pa	
	ka_ta	ga_ka	
	ka_ga	ga_ta	

The categories are labeled according to which VOT category is presented to the left and right ear, respectively. L = long; S = short

The voiceless syllables had VOTs between 75 and 108 ms and the voiced syllables between 15 and 28 ms, as seen in Table 2. This is in contrast to the original study, which was performed in the Norwegian language. In the original study, the voiceless syllables had VOTs between 72 and

82 ms and the voiced syllables had VOT's between 11 and 20 ms. It should be noted that the order of magnitude of the VOTs for each of the individual syllables are the different between the languages: English - ka > ta > pa > ga > ba > da, Norwegian – ta > ka > pa > ga > da > ba. This could possibly lead to differences between the results of the present and original study.

Table 2. VOT Data

English	Mean Intensity (dB)	VOT (ms)	Mean F0 (Hz)	F0 minimum (Hz)	F0 Max (Hz)	Duration (ms)
da	63.03	15	117.31	114.11	127.59	365.3
ba	63.77	18	114.65	75.40	127.07	463.6
ga	59.36	28	132.66	129.38	137.42	467.9
pa	60.07	75	125.00	121.49	134.56	455.2
ta	55.04	82	121.33	116.00	135.43	449.12
ka	58.06	108	122.65	115.64	136.93	517.9

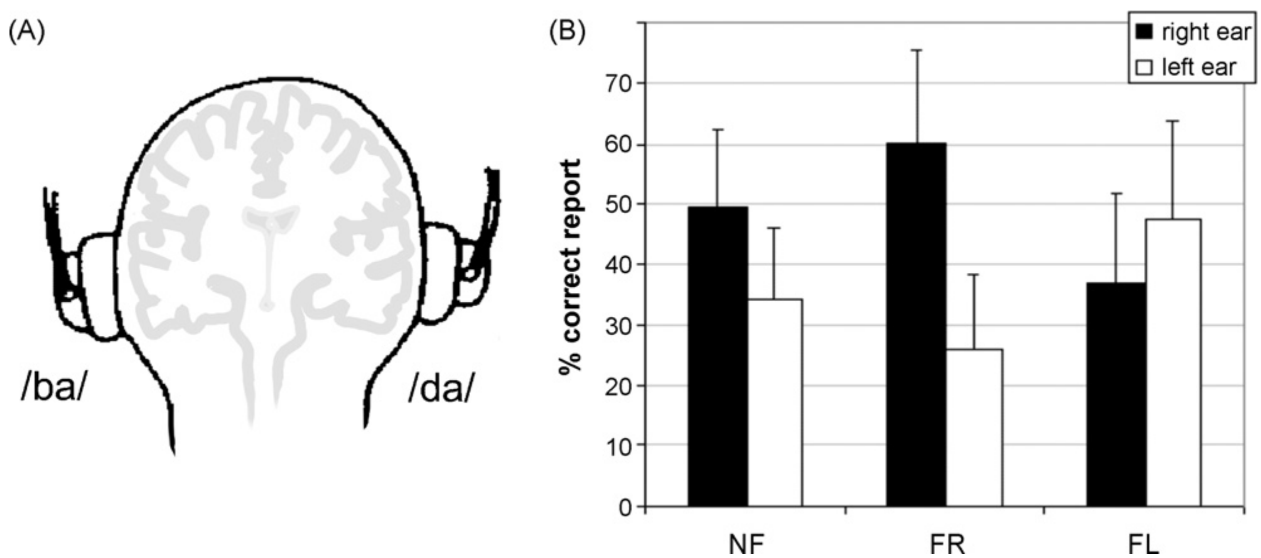
Norwegian	Mean Intensity (dB)	VOT (ms)	Mean F0 (Hz)	F0 minimum (Hz)	F0 Max (Hz)	Duration (ms)
da	72.36	16	138.76	125.43	160.04	496
ba	73.53	11	139.24	123.07	164.70	491
ga	72.26	20	133.18	125.02	154.02	532
pa	71.56	72	146.01	122.08	149.21	534
ta	70.39	82	126.13	115.33	137.58	566
ka	71.11	73	134.0	122.27	149.12	557

2.3 DICHOTIC LISTENING TESTING PROCEDURE

Each subject was fitted with over-the-ear headphones and seated in a chair within a soundproof booth. The subject underwent a hearing screening then the dichotic listening test during on 30-minute session. All syllable pairs were presented and repeated nine times through the headphones. Each subject was instructed to repeat aloud the syllable heard “best or most clearly” following the presentation of the syllable pair.

To control for unwanted biases from attention to either the right or left side, the session was split into three separate conditions. The first condition was always no instruction or non forced (NF). The following two conditions were randomized, in which the subject was instructed to attend either to the right ear, forced right (FR), or the left ear, forced left (FL). Figure 2 depicts the percentage correct in both ears for each of the three trials for the original study.

Figure 2. Dichotic Listening



Courtesy of Kenneth Hugdahl, PhD, University of Bergen, Norway

2.4 DATA ANALYSIS

A univariate analysis of variance (ANOVA) was performed on each participant's total score across all three listening conditions with the factors of ear (right and left) and VOT (LL, LS, SL, SS). A Tukey's post hoc test was performed on the four types of VOT to determine significant differences across the four stimulus conditions.. A laterality index was calculated for each subject under each VOT condition with the formula [(RE correct reports – LE correct reports)/total of correct reports]. Error scores were calculated for each subject under each VOT with the formula [(Total # of stimuli – Total correct)/Total # of stimuli)] to estimate the degree of difficulty in processing the VOT combinations. Laterality indices and error scores were also examined using a univariate ANOVA across VOT conditions (LL, LS, SL, SS).

3.0 RESULTS

All participants had a REA advantage in the NF trial, while the FR and FL trials varied. However on average, the FR trial showed a REA and the FL showed a LEA. The variability in the forced attention trials is normal. On average, participants showed the highest scores in the LS condition in the left ear and the SL condition in the right ear. This can be seen in Figures 3 and 4. The statistical findings are discussed below.

There were significant main-effects of VOT: F (3,186) = 28.772, $p < 0.001$, and ear: F (1, 61) = 83.974, $p < 0.001$. The differences between the VOT conditions, when compared separately for the left ear and right ear scores separately, were both significant with p < 0.001. The value of the left ear for VOT: F (3, 247) = 119.089, and the right ear for VOT: F (3, 247) = 93.504. The order of magnitude for the left ear was LS>LL>SS>SL and for the right ear was SL>LL>SS>LS, as seen in Figures 3 and 4.

Figure 3. Mean Scores for VOT in Left Ear with standard error

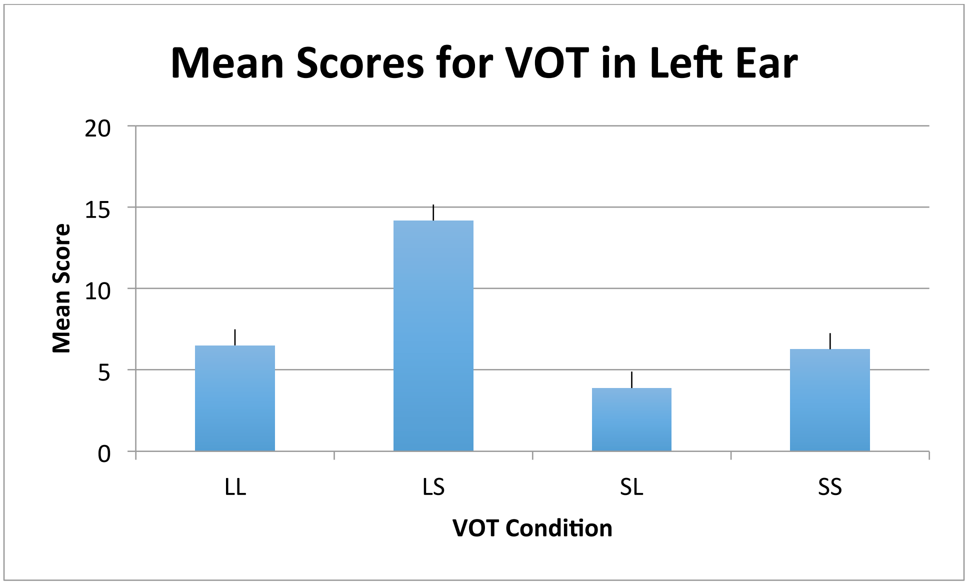
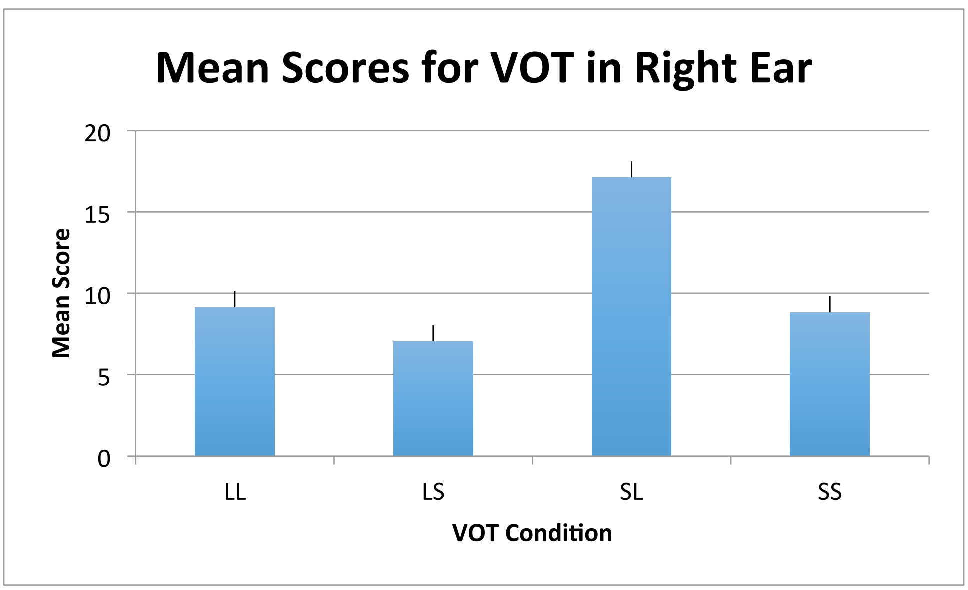


Figure 4. Mean Scores for VOT in Right Ear with standard error



The differences between the left and right ear were compared for each VOT condition. Significant differences were as follows: LL condition, F (1, 123) = 66.96, $p < 0.001$; LS condition, F (1,123) = 68.307, $p < 0.001$; SL condition, F (1, 123) = 339.534, $p < 0.001$; SS condition, F (1, 123) = 38.820, $p < 0.001$. The mean scores for left and right ears for each VOT condition are displayed in Figures 5-8. They depict a greater average score in the right ear for the LL, SL, and SS conditions and a greater average score in the left ear for the LS condition.

Figure 5. Mean Scores for LL Condition in Left and Right Ears with standard error

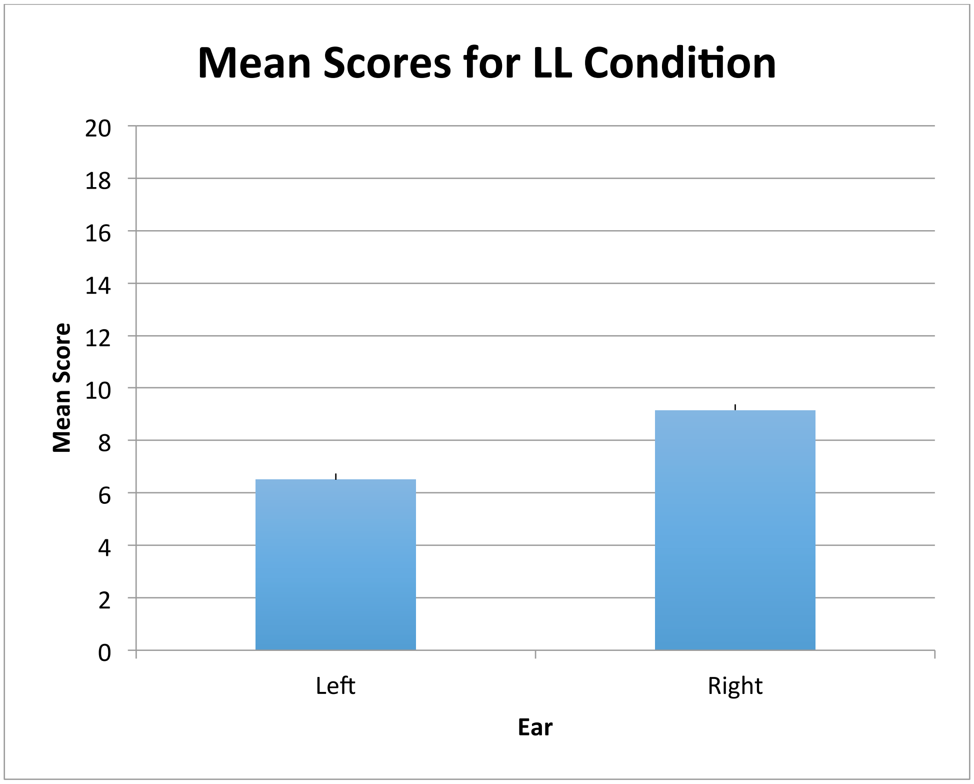


Figure 6. Mean Scores for LS Condition for Left and Right Ears with standard error

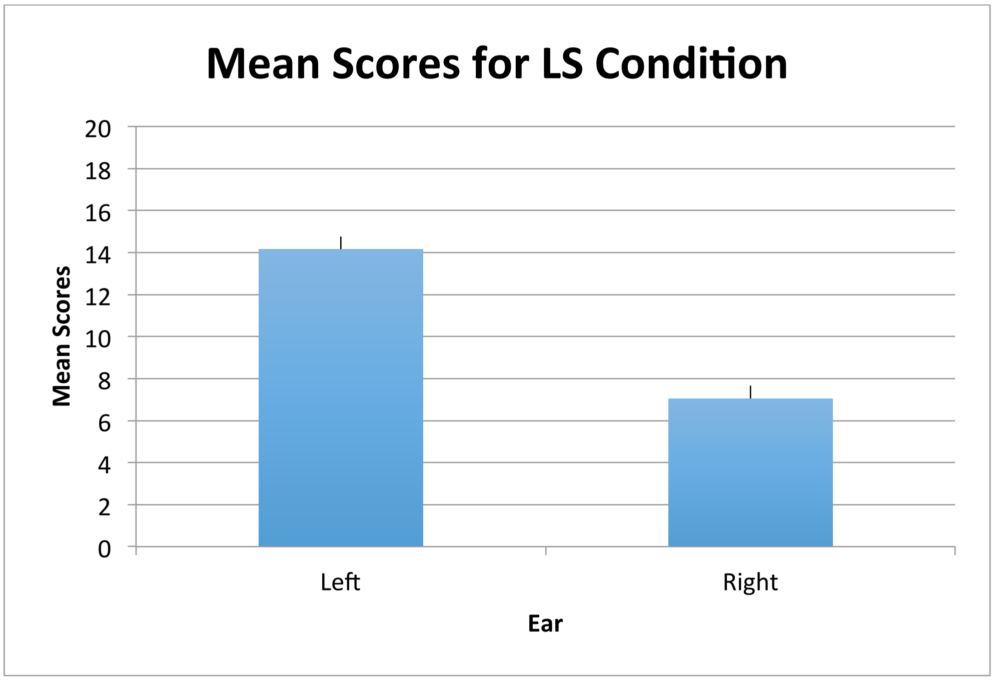


Figure 7. Mean Scores for SL Condition for Left and Right Ears with standard error

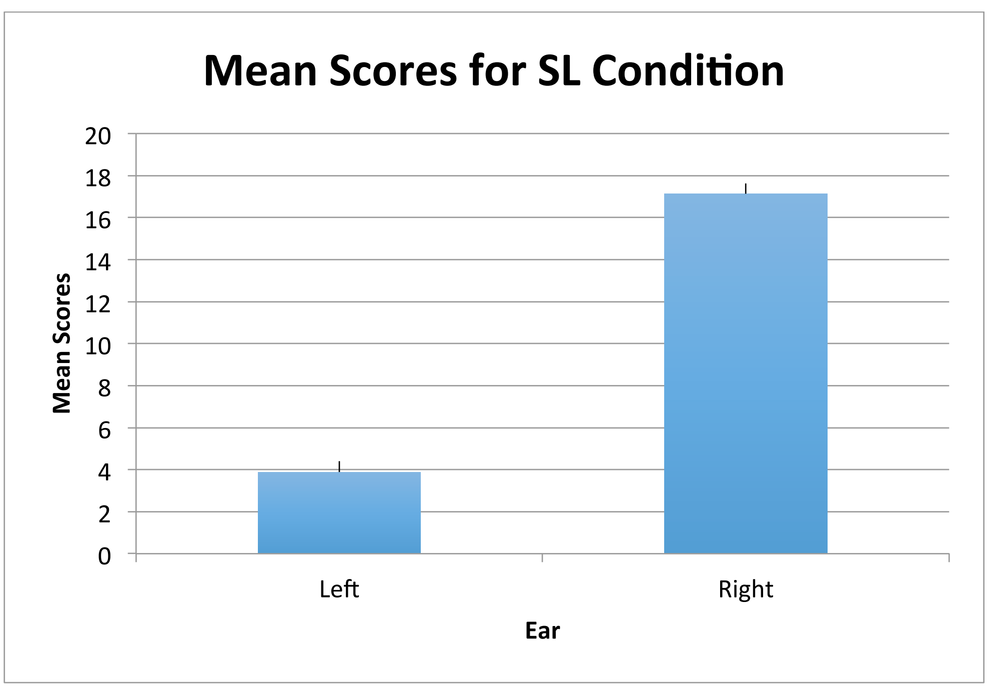
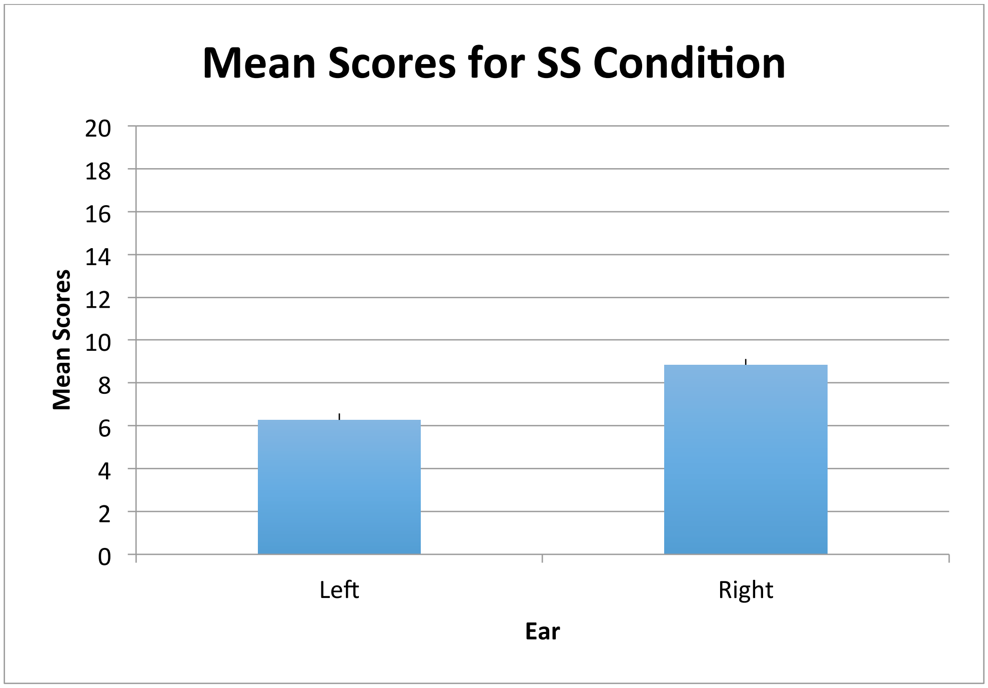
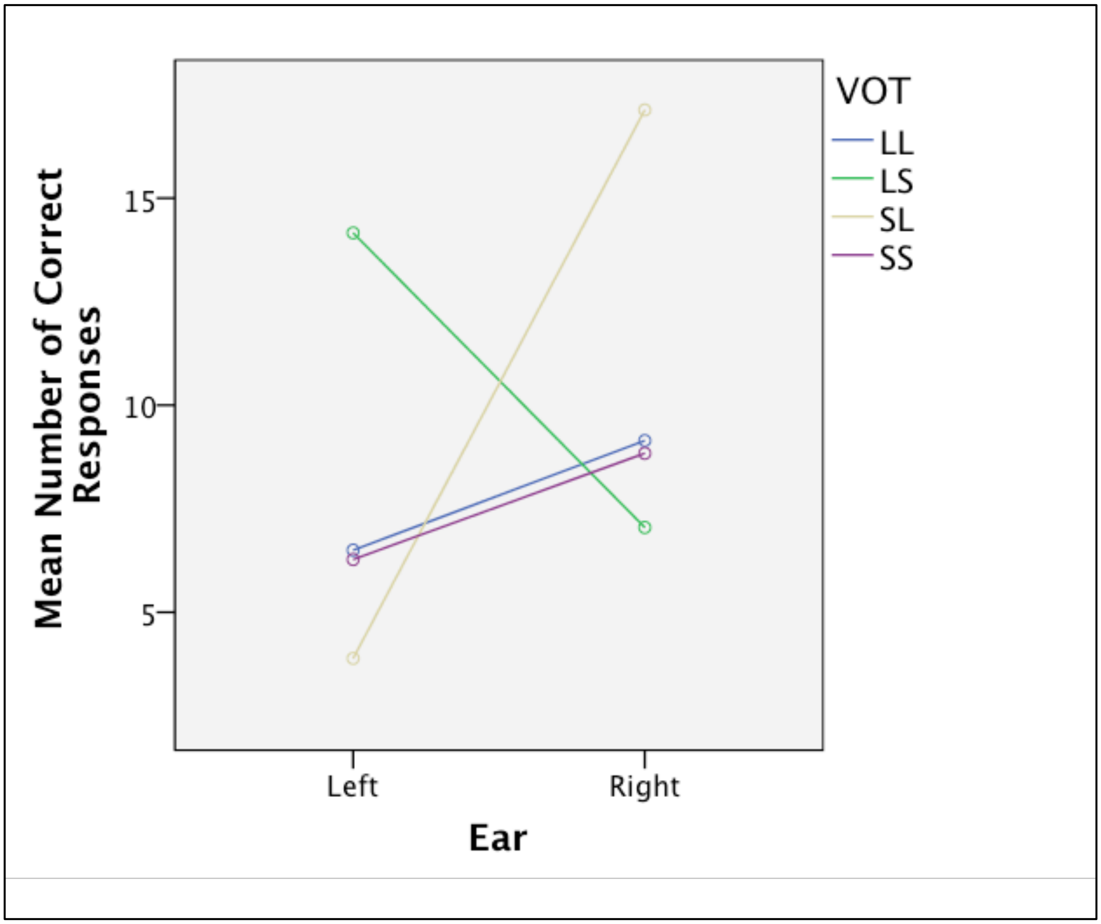


Figure 8. Mean Scores for SS Condition for Left and Right Ears with standard error



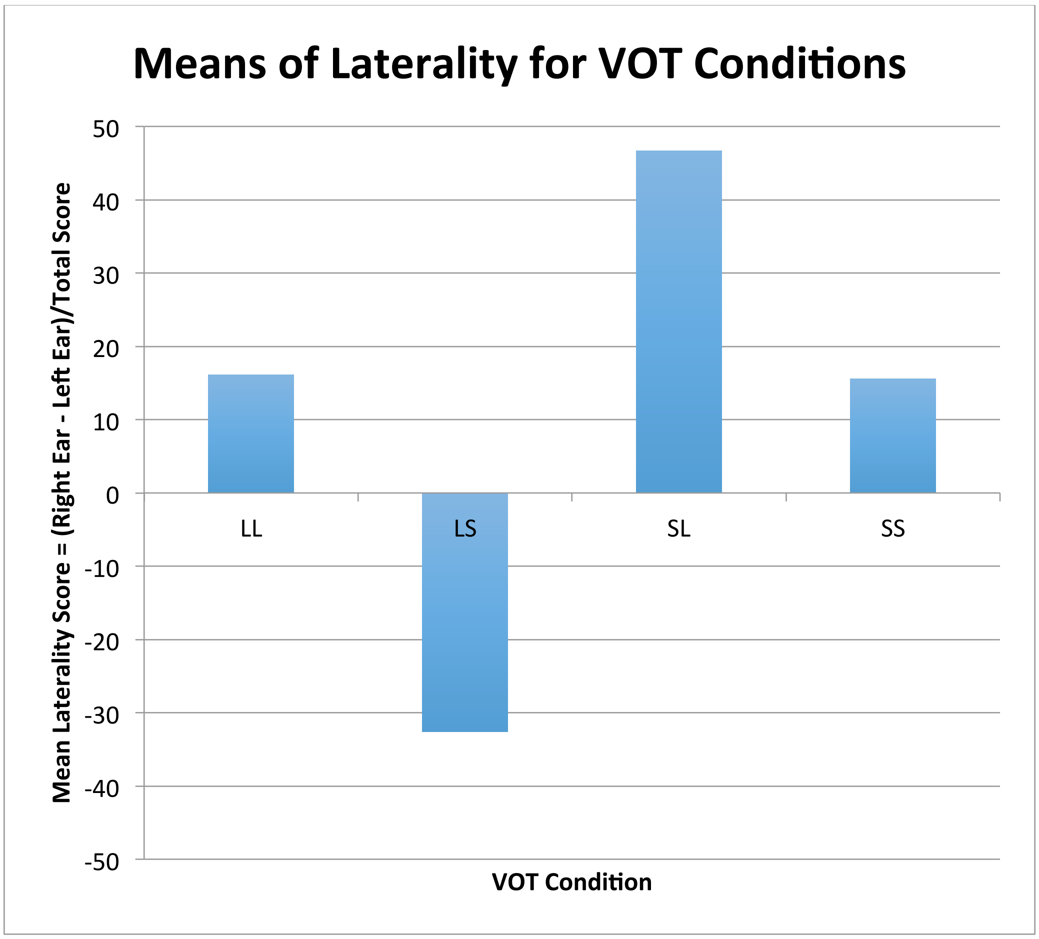
There was an interaction effect between ear and VOT: F (3, 186) = 180.597, $p < 0.001$. As depicted in Figure 9, average scores during the LL and SS conditions were highly similar with more correct responses for the right ear and fewer responses for the left ear. The SL condition produced the most correct responses in the right ear and the fewest correct responses in the left ears. During the LS condition, average results demonstrated a reversal with more correct responses in the left ear than the right ear. The difference between the left and right ears during the LS condition was greater than during the SS and LL conditions, but not as great as during the SL condition.

Figure 9. Interaction Effect



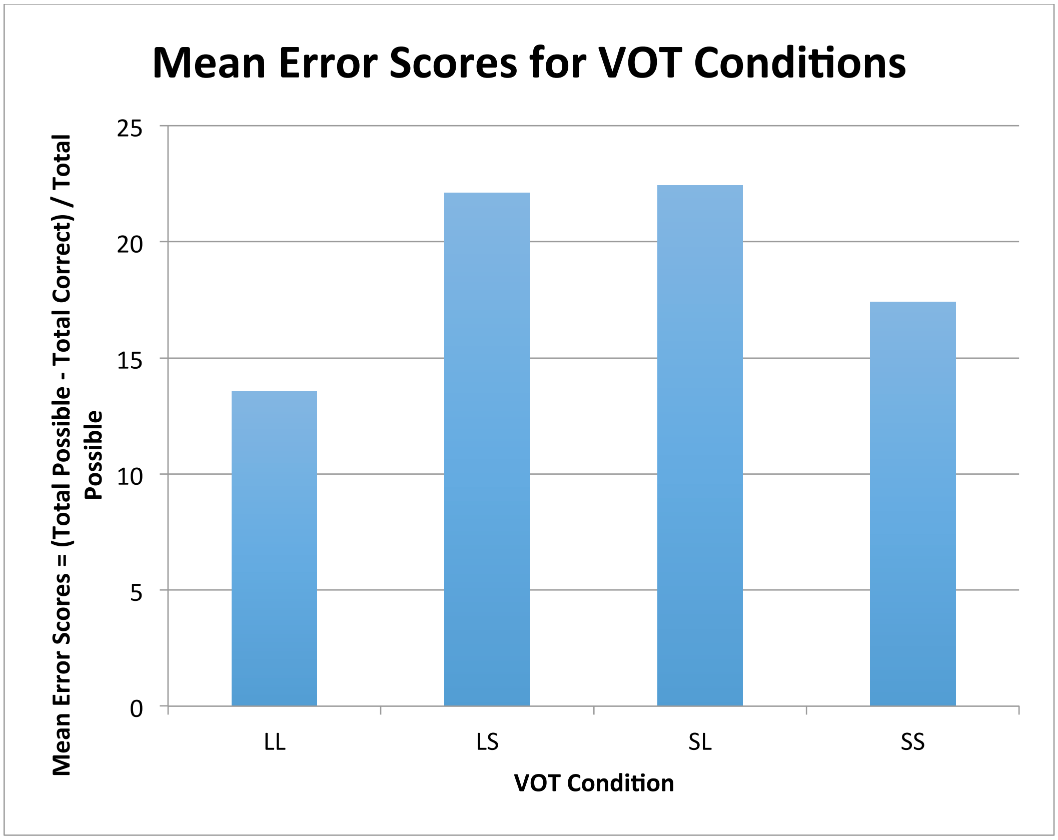
Laterality indices were performed for each VOT condition for every participant, using the formula: (Right ear score – left ear score)/total score. The total score is the summation of right and left ear scores. The ANOVA performed on measures of laterality index indicated a significant main-effect of VOT, F (3, 247) = 73.317, p < 0.001. One-sample t-tests for each VOT condition showed that the laterality index was significantly larger than zero for the SS, LL and SL VOT conditions, $t(61) = 5.225$, p< 0.001; $t(61) = 6.704$, p < 0.001; and $t(61) = 10.420$, p < 0.001; respectively. The LS condition showed a value of $t(61) = -6.686$, $p < 0.001$. These results confirm a significant REA in the SS, LL and SL conditions, and a significant LEA in the LS condition. Figure 10 reflects the mean scores for laterality in each VOT condition. The negative value of laterality in the LS condition indicates the LEA, while the positive values of the other conditions indicates the REA.

Figure 10. Means of Laterality for VOT Conditions



Error scores were also performed for each VOT condition for every participant, using the formula: (Total possible – total correct)/total possible. A one-way ANOVA test on the error scores also showed a significant main-effect of VOT, F (3, 247) = 5.463, p = 0.001. Tukey's post hoc test showed that the error rates for the LL condition were significantly different from the LS condition with a value of p = 0.005 and the SL condition with a value of p = 0.003. The error scores comparing the other conditions did not produce significant results, in contrast to the original study by Rimol, et al. (2006). Figure 11 reflects the mean error scores for each VOT condition, revealing lower error scores for the LL and SS conditions.

Figure 11. Mean Error Scores for VOT Conditions



4.0 DISCUSSION

The goal of this study was to investigate the effects of VOT on ear scores, laterality indices and errors during the English language version of the DCV test and to compare results obtained from native-English speaking participants to the results previously obtained from native-Norwegian speaking participants performing the Norwegian version of the test. We hypothesized that the temporal characteristics between syllables as measured in terms of VOT would influence the results in the same way as in the Norwegian study, lending support to the temporal processing theory of the dichotic listening REA.

The results revealed similar results as the original study performed in Norway with native-Norwegian speakers. The results indicated that the long VOT syllables were perceived and reported more often than the short VOT syllables for both ears. The short-long (SL) condition revealed the strongest REA, followed by the long-long (LL) and the short-short (SS) conditions. The long-short (LS) condition showed a LEA. The LEA is remarkable because each subject was required to show an overall REA in the non-forced (NF) trial of the experiment, indicating that they were typical listeners. Separate analyses of the left and right ears showed the differences in ear advantage for the VOT conditions, as reflected by differences in the mean scores and laterality indices. Error scores showed that more errors were made in the short-long (SL) and long-short (LS) conditions.

The overall REA demonstrated by all of the participants is strong evidence for the structural theory for the REA. Across the four different VOT conditions, there was a predisposition for the anatomical structures in the left temporal lobe to process speech stimuli, reflected by higher average scores for input to the right ear than to the left ear. In addition, the study provides support for the temporal processing theory. It reveals that VOT influences the results of DL tests, similar to other speech characteristics that influence DL tests noted in section 1.4.2.2. The results confirm that the LS condition provides a processing enhancement in the listener's ipsilateral left ear, thereby overcoming the structural bias toward left hemisphere processing of information from the contralateral right ear. These findings have implications on DL tests with single syllable words, which may also be affected by VOT. This is a possible area for future research.

Bottom-up and top-down processes have been previously implicated in the VOT effect seen in the present and original study. Bottom-up factors are stimulus driven and imply that specific features of the stimuli, such as frequency, intensity and timing, produce the results. Top-down factors such as attention can also influence whether a listener produces a REA or a LEA. Hiscock and Kinsbourne (reference) noted that the LEA found in DL trials during which the listener is directed to preferentially attend to the left ear suggests that top-down processes potentially overcome the structural preference for the right ear. However, the effect seen in this study of a LS condition VOT producing an overall LEA suggests that there is temporal competition between the competing stimuli (Arciuli, 2011) which is a feature characteristic and therefore engages a bottom-up process. The enhanced performance seen in the left ear during the LS condition occurred across all three conditions of the DCV test whether the listener was non-forced, directed right or directed left.

Since the main results did not differ between the present and original study, the assumption can be made that differences between the two languages did not appear to affect the overall results of ear advantage. However an alternative explanation, which could cause the differences in ear advantage, is that the other cues, such as syllable durations or vowel transitions, co-vary with VOT and create Future studies investigating the role of VOT in dichotic listening could focus on other types of speech stimuli such as single syllable words and digits and could also focus on the use of DCV in other native languages.

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