Electroencephalographic Correlates of Cerebral Engagement in Auditory and Visual Language Processing Tasks in Persons with Down Syndrome

by

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ABSTRACT

There has been extensive research performed regarding language processing in persons with Down syndrome. The results of initial dichotic listening studies and movement control studies lead Elliott Weeks and Elliott (1987) to propose a model of functional dissociation between brain centers sub-serving language perception and those sub-serving language production in persons with DS. Based on this model many new avenues of research emerged. The predictions of the model that have been tested thus far have focused on behavioural actions of persons with DS as compared to non-DS populations. The results of these subsequent experiments have provided support to the dissociation model (Elliott, Weeks & Elliott 1987). The present experiments were intended to further investigate language laterality in persons with DS. EEG was used as a means of investigating the purported atypical cerebral lateralization for language perception in persons with DS. The results of the present experiments lend some support to the dissociation model of DS and suggest that the model may be broadened to encompass language processing in general and not auditory language processing specifically.

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INTRODUCTION

Trisomy 21 (Down Syndrome) is the leading cause of mental retardation in the world today (Chiarenza & Stagi, 2000). Two thirds of Down Syndrome (DS) conceptions result in spontaneous abortion leading to a DS occurrence of approximately one in eight hundred live births (Rubin & Farber, 1994). Based on the high occurrence of DS it is important to investigate this special population in an attempt to improve knowledge of neural organization, and its consequences on behaviour in general, as well as to improve the living standards for persons with DS.

DS is caused by the presence of an extra, whole or partial, twenty-first chromosome and can be caused by three mechanisms: nondisjunction, translocation, and mosaicism. Nondisjuction during the first meiotic division of gametogenesis is by far the leading cause of DS, accounting for 92%-95% of the cases (Chiarenza & Stagi, 2000; Rubin and Farber, 1994). Translocation of an extra long arm of chromosome 21 to another acrocentric chromosome gives rise to 5% of the cases of DS (Rubin and Farber, 1994). The third common cause of DS, accounting for an estimated 2% of the cases, is mosaicism. This is caused by nondisjunction during mitosis of a somatic cell in the early stages of embryogenesis (Rubin and Farber, 1994).

The incidence of DS is strongly correlated with maternal age. With maternal age of less than 30 years, the incidence of DS is less than 1/1000; with a maternal age of 45 or older the incidence of DS reaches 1/30. As the average maternal age is rising, it is becoming even more important to gain an understanding of the consequences of the extra chromosome in DS.

Persons with DS show a constant and progressive decline in IQ with age (Hartley, 1986). One of the major defects associated with DS appears to be an inability to develop advanced cognitive strategies and processes (Rubin and Farber, 1994). One of the most interesting neurological features of DS is the similarity it has with Alzheimer's disease. The morphologic lesions characteristic of Alzheimer's disease progress at a rapid rate in persons with DS and in the DS population these lesions are universally demonstrated by the age of 35 (Rubin and Farber, 1994).

Persons born with DS can be readily identified by their characteristic morphological features and chromosomal karyotype (Trisomy 21). As a result, the DS population has a specific disease-related genetic make-up. The characteristic genetic make-up, present in DS, influences cerebral development resulting in intellectual and information-processing deficits that are distinctive of the DS population. The specific role of the genetic makeup in terms of the development of these deficits is not well understood.

There has been extensive research concerning the lateralization of language within the human brain. Results indicate that the general population is predominantly left hemisphere (LH) lateralized for language processing. Much of this research has been obtained from studying brain damaged and lesioned patients. Broca (1865)[i] found that LH damage is much more likely, than right hemisphere (RH) damage, to impair language production. In addition, Wernicke (1874)[i] found persons with LH brain damage were significantly more impaired at language perception than were persons with RH damage.

It has been found, through dichotic listening experiments, that individuals with DS display a left ear – right hemisphere advantage for the perception of speech sounds (Pipe, 1983; Žekulín-Hartley, 1981; Žekulín-Hartley, 1982). Motor asymmetry, transfer of training and dual task experiments have produced findings suggesting that movement production, including speech production, are controlled by the left hemisphere in both DS and non-DS populations (Elliott, 1985; Elliott, Edwards, Weeks, Lindley & Carnahan, 1987; Heath & Elliott, 1999).

Recent research has suggested that the DS population shows an abnormal cerebral lateralization in the area of speech perception (Elliott, Weeks & Elliott, 1987; Pipe, 1983; Žekulín-Hartley, 1981; Žekulín-Hartley, 1982). These findings have resulted in the development of a model depicting the dissociation between speech perception, located in the right hemisphere (RH), and speech production, located in the left hemisphere (LH), in the DS population (Elliott, Weeks et al., 1987). The inter-hemispheric transmission resulting from this dissociation degrades the exchange of information between the language subsystems. This results in persons with DS experiencing difficulty while performing tasks that require both the perception of speech and the organization and control of limb and oral movements.

Previous studies investigating the dissociation of language perception and production have all suffered from the same limitation. The studies have attempted to infer central nervous system organization through peripheral means. It would be advantageous for studies, investigating the dissociation of language perception and production in the Down syndrome population, to make use of techniques which allow for a more direct analysis of cortical activity. These studies could involve the use of electroencephalography (EEG) or magnetoencephalography (MEG) techniques.

On a theoretical level these findings would have tremendous implications toward our understanding of the impact of Trisomy 21 on the development of cerebral specialization and organization. Practically, these findings would allow for a better understanding of the general and specific intellectual and information-processing deficits experienced by the DS population. The following literature review describes the different types of studies that have been performed in an attempt to better understand the abnormal cerebral lateralization thought to exist within the DS population. A model depicting a biological dissociation between speech perception and production in persons with DS is explained and tested. The following experiments seek to test and generalize the dissociation model from auditory language (speech) specifically to language perception in general for persons with DS. In the following experiments, EEG will be used as a means of a more direct examination of cortical activity in the DS population during language processing in both the auditory and visual modalities.

1.0 LITERATURE REVIEW

1.1 Neuropsychological Investigations of Cerebral Specialization in persons with DS

1.1.1 Dichotic Listening Studies

Dichotic listening tasks involve the simultaneous presentation of different stimuli to the two ears. Auditory stimuli reach the brain via both contra-lateral and ipsi-lateral connections (Kimura, 1961a). Kimura (1961a) suggested, that while the sounds from both ears are projected to each hemisphere, the contra-lateral connections are stronger and take precedence over the ipsi-lateral connections when two different auditory stimuli are arriving simultaneously at the same cortical auditory processing centers. Typically, the general population displays a right ear advantage in reporting dichotically presented stimuli (Kimura, 1961a). Based on the theory of dominant contra-lateral connections, this would suggest that the left hemisphere dominates perception during concurrent presentation of auditory linguistic stimuli to the two hemispheres.

In a landmark paper Žekulín-Hartley (1981), compared persons with DS to two control groups: a group of persons with a mental retardation other than DS and a control group of mental age (MA) matched persons free of mental retardation. The aim of the study was to investigate the processing of auditory linguistic stimuli and establish whether there were differences in processing patterns between persons with DS and persons with an undifferentiated mental retardation. Žekulín-Hartley was also interested in whether persons with mental retardation in general differ from persons free of mental retardation in the processing of auditory linguistic stimuli.

Žekulín-Hartley (1981) hypothesized, based on her previous work, that the children with DS would show a left ear – right hemisphere advantage in the dichotic listening task and the other groups would show the typical right ear – left hemisphere advantage. The auditory material in this experiment consisted of computer-spoken digits. A trial was composed of digits presented in three pairs (one of each pair presented to each ear) occurring within a two second interval. The children were told to listen to the digits and repeat whatever digits they heard (free recall method). A significant difference in ear dominance was found between the children with DS and the other two groups. The children with DS were seen to demonstrate a clear left ear – right hemisphere advantage as compared to the non-DS retarded group and the MA matched control group (both of whom displayed a right ear – left hemisphere advantage). Based on the finding that the persons with undifferentiated mental retardation demonstrated the typical right ear – left hemisphere advantage, Žekulín-Hartley (1981) suggested that the presence of a mental retardation itself is not enough to affect the establishment of a definite ear advantage for linguistic auditory material.

Another study by Hartley (1981) was aimed at determining whether or not the atypical left-ear (right hemisphere) advantage for auditory stimuli is present in young children (three to five years of age). In this experiment, the persons with DS were part of an early intervention group. The early intervention allowed them to perform the dichotic listening task, despite their relatively young MA and chronological age (CA). The results of this study were such that the children with DS displayed the atypical left-ear (right hemisphere) advantage, while the "normal" children showed the typical right-ear (left hemisphere) advantage. These results demonstrated that the ear advantage that occurs in the dichotic listening task, is present in children as young as three years of age. Hartley (1981) inferred from these results that, provided the task, which is used in the experiment, is appropriate for all participants, dominance will occur at the same chronological age in all experimental groups.

A major criticism of Žekulín-Hartley's (1981) original work was that by using a free recall method, in which participants are asked to attend equally to both ears, the difference in ear dominance could be a result of a difference in lateral selective attention or response biases. In an attempt to investigate the role of selective attention in the appearance of an abnormal ear advantage in the DS population, Žekulín-Hartley (1982) conducted a study in which the participants were instructed as to which ear to attend during a given trial of a dichotic listening experiment. This experiment involved the same set-up as her previous study with pairs of matched digits being presented simultaneously to both ears. The added instructions of which ear to attend to, helped control for selective attention. She found that when participants were attending to their dominant ear (left ear in DS population and right ear in non-DS population) an ear advantage was found in the perception of the test stimuli. This means that, when the participants were to attend to their dominant ear, both groups were more accurate in reporting the stimuli that where presented to their dominant ear than they were at reporting the stimuli that were presented to their non-dominant ear. It appears that the groups were able to disregard information coming in to their non-dominant ear. However, when the participant was instructed to attend to their non-dominant ear (right ear in DS population and left ear in non-DS population) no ear dominance was found in any of the groups. In the conditions in which the participants were asked to attend to their non-dominant ear, Žekulín-Hartley found that they were equally accurate in reporting the stimuli from both their dominant and non-dominant ear. These findings suggest that selective attention does play a role in dichotic listening. However it is not possible to totally disregard information from the dominant ear, even when attention is selectively directed toward the non-dominant ear. Based on the results of her studies Žekulín-Hartley (1981, 1982) concluded that her results suggested a general right hemisphere (RH) dominance for language processing in persons with DS.

Pipe (1983) investigated the effect of training auditory discrimination in the participants prior to the test trials. The pre-training trials involved the monaural presentation of word stimuli similar to those used in the dichotic listening portion of the experiment. Pipe (1983) suggested that auditory discrimination training would act to control motivation, attention span and biases. In this experiment dichotic-listening ear asymmetries were compared for repeated administrations of a dichotic test before and following auditory discrimination training of children with DS, children with undifferentiated mental retardation (developmentally retarded) and normal children. In this experiment, words, rather than digits, were used as the test stimuli. In the dichotic portion of the test the words were paired based on rhymed meaningful words (cat-bat, coat-goat, dig-pig, etc.). Dichotic listening ear advantages were calculated as the proportion of right-ear and left-ear reported stimuli in relation to the total number of reported stimuli.

Correspondingly, a positive index indicated a right ear advantage while a negative index indicated a left ear advantage. The results of this study showed the DS group to display a left ear – right hemisphere advantage, while both the undifferentiated mental retardation group and the MA matched group demonstrated the typical right ear – left hemisphere advantage. The magnitude of the ear advantage, regardless of the direction, was found to be similar across the three groups. These ear advantages were also seen to improve in magnitude in all three groups with training. The results of this study were in support of the studies done by Žekulín-Hartley (1981, 1982) in finding that children with DS, but not other forms of mental retardation, show a RH dominance for language processing.

The dichotic listening studies suggest that there is atypical cerebral lateralization involved in DS. The unusual finding of a left ear- right hemisphere superiority in discriminating dichotic stimuli in the DS population, as compared to the general population findings of a right ear – left hemisphere advantage suggests that there exists, in the DS population, an atypical lateralization involving the language processing systems of the brain.

Based on the results of the dichotic listening experiments, Hartley (1982) proposed a model of reversed cerebral lateralization for language in the DS population. However, research soon moved on to investigating other aspects of language in the DS population. These new lines of research were interested in the production of movement, including speech production. The language production studies in effect challenged the model of the simple reversal of cerebral lateralization of language in the DS population (as proposed by Hartley, 1982).

1.1.2 Movement Production Studies

Movement production studies are based on the relative propensity of the two hemispheres to display a dominance or advantage in performing specific perceptual-motor processing tasks. It is generally accepted, for the majority of right-handers, that the left hemisphere is the dominant hemisphere involved in sequential processing (Taylor & Heilman, 1980). The right hemisphere is believed to be associated with tasks involving spatial content (Witelson, 1974). Movement production studies make use of the differences in hemispheric functioning in an attempt to investigate hemispheric specialization within the brain.

Motor asymmetry

The basic premise of motor asymmetry studies involves the assumption that dominance, of one side of the body, in the performance of a specific motor task is related to the different abilities of the two hemispheres in processing certain types of information. The left-hand dominance seen in tasks, such as the ability to reproduce spatial location, is thought to reflect a right-hemisphere superiority in the processing of spatial information. The right-hand dominance seen in tasks, such as rapid finger tapping, is assumed to reflect a left-hemisphere superiority in the processing of sequential information. Based on this premise, the differences and similarities between the DS and non-DS populations in asymmetry tasks provide a basis to further investigate the abnormal lateralization thought to be present in DS.

In an early study, Elliott (1985) investigated finger tapping in adolescents and adults with DS and compared their results to both mental age (MA) matched persons with undifferentiated mental retardation and non-DS individuals matched for chronological age (CA). Participants were instructed to finger tap as fast as possible for 15 seconds. Elliott found that the CA matched group outperformed the other two groups (more rapid and consistent finger tapping). The CA group was also the only group to display a clear right-hand superiority in this rapid finger tapping task. The MA group showed a combination of right hand and left hand superiority and the DS group demonstrated a relative lack of hand dominance in this task.

In a recent experiment, Heath and Elliott (1999) investigated asymmetries of the mouth involved in the production of speech. They compared the right side of the mouth to the left side of the mouth on a number of factors including: initial lip aperture, maximum lip aperture, and maximum velocity. In this study they found no significant differences in mouth asymmetry between DS and non-DS groups. Both groups showed a definite right mouth advantage in speech production. It has been suggested that this occurs due to the direct association between the muscles on the right side of the mouth and the contra-lateral hemisphere (LH) involved in language production in both the DS and the non-DS populations (Heath & Elliott, 1999).

The results of motor asymmetry studies suggest that superior hand dominance is found when performing a task with the hand that is contra-lateral to the hemisphere involved in processing the stimuli. These studies also show that when the manual asymmetry task does not involve language perception the DS population shows a pattern of lateralization similar to the general population. Although the results of the rapid finger tapping study (Elliott, 1985) did not show the same results in the DS and non-DS groups, the results of these two groups were not opposite as would have been predicted by the reversed laterality model as proposed by Hartley (1982). In addition, the mouth asymmetry study (Heath and Elliott, 1999) suggest that movement organization, including speech production, is controlled by the LH in both DS and non-DS groups.

Transfer of Training

The basic premise of transfer of training tasks involves the idea that when both hemispheres are involved in learning a manual task, that task will show greater transfer of training from one hand to the other because both hands will have direct access to the learned task. However, when only one hemisphere is involved in learning a manual task (the hemisphere contra-lateral to the hand which is trained), there will be less transfer of this training to the ipsi-lateral hand because it will have no direct access to the learned information. The left hemisphere is believed to be involved in sequential processing. As a result, learning a sequencing task with the right hand involves only the LH whereas learning a sequencing task with the left hand involves both the RH and the LH. Therefore it should be seen in such a task that there is a greater transfer of training from the left hand to the right hand (Taylor & Heilman, 1980).

Elliott (1985) used a transfer of training paradigm looking at rapid finger tapping. A baseline measure was made prior to four training trials using either the right or left hand. Following the training trials the participants were measured on rapid finger tapping of the opposite hand. It was found that both groups (DS and non-DS) improved more with their right hand than their left hand, regardless of which hand received the training. Also the transfer of training pattern was the same for both groups. These results have been further supported by a subsequent study by Edwards and Elliott (1989). This asymmetric transfer of training is indicative of LH control of movement sequencing in both the DS and non-DS groups.

Dual Task Performance

Dual Task studies are based on the premise that when an individual is asked to perform two tasks, both of which are processed in the same hemisphere, the two tasks will interfere with each other. For example, both rapid finger tapping and speech are believed to be organized in the LH. Therefore, if while performing a rapid finger-tapping task the participant is asked to speak, the performance of the finger-tapping task will deteriorate. Kinsbourne and Hicks (1978) suggested that the interference occurring during the dual task paradigm results from the structural interference between brain centers subserving the competing tasks.

Elliott, Edwards et al. (1987) performed an experiment investigating the dual task interference involved in rapid finger-tapping and speech production. Persons with DS were found to exhibit the same pattern of interference as the non-DS group. Both groups showed speech production produced more interference in the rapid finger-tapping task when tapping with the right hand than when tapping with the left hand. The asymmetry seen under dual task conditions is thought to reflect intra – hemisphere interference between the subsystems controlling the right hand and those controlling speech production. These findings support the observation that movement production, including speech production, is controlled by the left hemisphere in both DS and non-DS populations.

The movement production studies have all aimed, through different experimental methodologies, to investigate functional cerebral specialization for movement production. Motor asymmetry studies have shown that the DS population displays similar patterns of manual asymmetries as the general population. The transfer of training studies have shown that in both the DS and non-DS populations there is greater transfer of training from the left to the right hand in tasks which involve motor output (LH control). The movement production studies support the theory that in both DS and non-DS population, movement production, including speech production, is controlled by the left hemisphere.

1.2 A Model of Functional Cerebral Organization in Persons with DS

1.2.1 The Model of Biological Dissociation

The findings of dichotic listening studies suggest that language perception is lateralized to the RH in the DS population and the LH in the general population. Motor asymmetry, transfer of training and dual task experiments have provided evidence that movement production, including speech production, are lateralized to the LH in both the DS and general populations. These apparently conflicting results have lead Elliott, Weeks et al. (1987) to develop a model of functional cerebral lateralization for Down syndrome. The basic tenet of this model is that there exists a dissociation between language perception and language production in persons with DS. The model states that a dissociation exists between functional right hemisphere systems subserving speech perception and the left hemisphere systems associated with movement production, including speech. Figure 1 shows the DS model proposed by Elliott, Weeks et al. (1987).

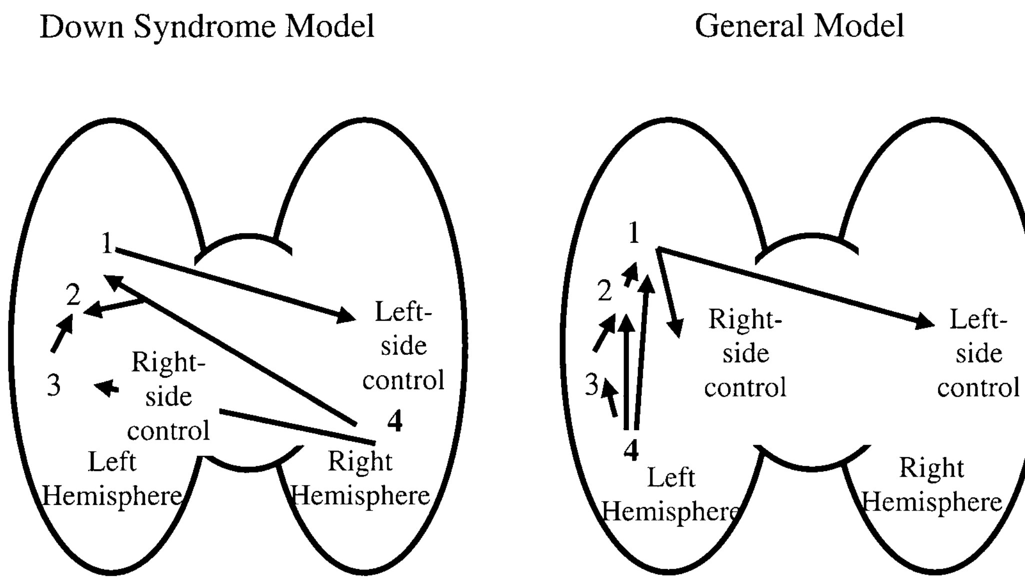

Figure 1 – Dissociation model of DS - model of functional cerebral lateralization in persons with DS and the general population. 1. Movement execution; 2. Praxis control; 3. Speech production; 4. Speech perception (adapted from Chua, Weeks, & Elliott, 1996).

Elliott, Weeks et al. (1987) proposed that this dissociation between the brain areas involved in language perception and those brain regions associated with movement production, including speech, results in a breakdown in communication between the two functional language subsystems. This breakdown in communication is proposed to be associated with many of the general (Gibson, 1975) and specific (Ashman, 1982) language-based problems experienced by persons with DS.

1.2.2 Testing Predictions of the Model

The model as proposed by Elliott, Weeks et al. (1987), is a neuropsychological model of cerebral organization in persons with DS that seeks to explain the pattern of specific functions and dysfunctions that are typical of this population. Many predictions arose from the dissociation model. The development of the model provided predictions that promoted numerous investigations of perceptual-motor behaviour and atypical cerebral lateralization of persons with DS.

One of the major predictions of the dissociation model is that the general population would perform better than persons with DS in a task that involved both language perception and movement production. Elliott, Weeks and Grey (1990) investigated language perception processes involved with visual and auditory presentation of the stimuli. They performed an experiment investigating both verbal and visual cueing in a situation in which the participants had to produce a sequence of events. The instructions for this sequence were presented either verbally or visually (via a demonstration). Compared to persons with an undifferentiated mental retardation matched for MA, the DS group performed worse on the verbal cuing condition. Interestingly, the DS group performed better than the other group in the visually presented sequence replication condition. The results of this experiment were taken as support for the dissociation model of DS.

In a subsequent study Elliott and Weeks (1993) again investigated the effect of visual/verbal cuing for a multi-sequence movement. However, in this experiment they looked at the relation between the performance in the verbal/visual instruction conditions to the laterality scores obtained through a dichotic listening test. An interesting finding in this study was the correlation between ear dominance and performance in the visual/verbal cuing trials. It was found that individuals with DS who exhibited the largest left ear (RH) advantage in the dichotic listening task had relatively more difficulty performing the movement sequences based on the verbal cuing conditions than they did in the visual cuing conditions (demonstration). These findings suggested that persons with DS exhibiting the greatest functional separation of speech perception and movement organization will also exhibit the greatest verbal – motor difficulties.

Most of the research that went into the development of the dissociation model, was centered on the results of dichotic listening experiments. The dichotic listening experiments however were only associated with auditory language perception. The dissociation model (Elliott, Weeks et al., 1987) proposed a functional separation between the brain centers concerned with language perception and language production. This dissociation was generalized to language perception and not specific to auditory language perception. In an attempt to be more generalizable to language perception (as opposed to auditory language perception), tactile and visual analogues to the dichotic listening task were desired.

Witelson (1974) developed a tactile task equivalent to the dichotic listening task. In her experiment, participants were required to feel pairs of objects (either letters or nonsense shapes) and then asked to identify the stimulus objects. Witelson (1974) found a significant left hand (RH) advantage at identifying the nonsense shapes. This finding was explained based on the belief that spatial processing is controlled by the RH. As a result, the left hand has direct access to the spatial processing area, thus giving the left hand an advantage over the right hand in identifying spatially coded stimuli. She also found a trend toward a right hand (LH) advantage for identifying the letters. This finding was explained based on the nature of the stimuli. The letter stimuli were both linguistic and spatial stimuli. Because of this, it was necessary for the participants to analyze the stimuli based on both spatially coded material (RH) and linguistically coded material (LH). As a result the linguistic stimuli would require processing by both hemispheres resulting in the non-significant hand advantage.

In an experiment similar to Witelson's (1974) study, Elliott, Pollock, Chua, and Weeks (1995) performed a study in which they investigated hand dominance involved in tactile perception. In this experiment, participants were asked to manipulate nonsense shapes, which were presented in pairs, for 10 seconds. The participants were then asked to identify the objects that they had felt. The findings of this experiment showed that both the right and left-handed control groups along with the right-handed DS group did not display a hand advantage in this experiment. The left-handed DS group however showed a significant left hand (RH) advantage in this task.

Elliott et al. (1995) were interested in the spatial processing abilities of the DS and non-DS groups. In a follow up study, Weeks, Chua, Elliott, Lyons and Pollock (1995), performed a similar study in which they investigated language perception in DS and control groups. In this experiment participants were required to manipulate letters with their hands. The participants were prevented from seeing their hands or the letters by having them reach into a box containing the letters. Participants were then asked to identify the letters in the box. Results showed that both left and right handed non-DS showed no significant differences in hand dominance whereas the participants with DS showed a significant left hand (RH) advantage at identifying the letters. These findings were thought to reflect processing of spatial stimuli by the right hemisphere. As a result, in DS both language and spatial processing can occur in the same hemisphere (RH) resulting in a left hand dominance for this task. However, in the non-DS population language perception is in the LH and spatial processing is in the RH. This separation would suggest hand dominance in this task would be less obvious in the non-DS population. The results of the experiment were in support of the dissociation model.

Mishkin & Forgays (1952) performed an experiment that tested the visual presentation of language with an approach similar to the dichotic listening task. In this experiment eight-letter English words were presented to either the left or right visual field, as well as the upper and lower visual fields. Participants were then asked to report the words that they saw. Results showed that recognition of words presented in the right hemi-field (LH processing) was significantly more accurate than words presented to the left hemi-field (RH processing). These results can be explained on the basis that words presented to the right hemi-field, had direct access to the language perception areas in the LH. However, the words presented to the left hemi-field were first perceived in the RH and then had to be sent to the LH in order to undergo language processing.

As a method of testing the visually presented material in an experiment analogous to the dichotic listening task, Elliott et al. (1995) performed an experiment in which visual processing was investigated in a manner similar to the technique used by Mishkin and Forgays (1952). Participants fixated on a central target located on a computer screen. A varying number of dots were then presented to either the right or left visual hemi-field for a duration of 75msec. The participant was then asked to respond with the number of dots that they saw. The duration of 75 msec was of a sufficiently short duration to ensure no eye movements were possible. As a result stimulus presentation was isolated to a single hemisphere. This hemisphere had first access to the information; however inter-hemispheric transfer could still occur, thus although both hemispheres had access to the stimulus, it was more strongly represented in the hemisphere contra lateral to the presentation field. It was found that both groups (DS and non-DS) displayed the same left visual field (RH) advantage in this experiment. This suggests that persons with and without DS demonstrate the same right-hemisphere superiority for analyzing spatial relations in the visual modality.

Weeks et al. (1995) performed a subsequent study in which they were interested in language perception and processing in the visual modality. In this experiment, language stimuli, in the form of sets of three letters presented in a vertical column, were presented randomly to the right and left visual hemi-field. The participants were asked to report the letters that they perceived (or thought they perceived). The results of this experiment failed to show a significant field advantage in either the DS or control group. However, a strong trend towards a left visual field (RH) advantage was found in right handed persons with DS. Although this experiment failed to show the predicted left visual field (RH) advantage in the DS group, the results were in the predicted direction based on the dissociation model of cerebral specialization of DS.

The previously mentioned studies suggest that the atypical cerebral organization of function found in persons with DS is not confined to auditory speech perception. The studies involving haptically, and visually presented language suggest that this dissociation in language perception and production may also include modalities other than the auditory modality although more research is required in this area.

The previously discussed research has attempted to infer lateralization of language processing through behavioural studies. To a large extent, our present understanding of language lateralization has been based on behavioural studies such as those mentioned above. However, there are also techniques, such as EEG and MEG, which allow for a more direct interpretation of brain-behaviour relations. The research methodologies involved in EEG and MEG have significantly added to our understanding of language processing lateralization within the brain.

1.3 Electrophysiological Investigations of Language

Electroencephalography (EEG) is a non-invasive method of recording the electrical activity of the brain. The electrical activity recorded by an EEG represents the sum of excitatory postsynaptic potentials and inhibitory postsynaptic potentials occurring in the upper layers of the cerebral cortex (Epstein and Andriola, 1983). In order to record the electrical activity of the brain, electrodes are placed on the surface of the scalp. The EEG recording is a state dependant function that changes with age, arousal level, and cerebral dysfunction (Bizas et al., 1999; Birch, 1997; Klimesch, 1999; Locatelli, 1996). The EEG spontaneous frequency range is typically between 0.5 Hz and 70Hz. This frequency range can be broken up into bands (alpha, beta, delta, theta, and gamma) and these bands correspond with different levels of functioning or activity within the brain.

Alpha activity occurs with a frequency of 7.5-12.5Hz. It is seen in the greatest amplitude in the occipital and parietal regions of the brain. Alpha activity is at a maximum during rest with eyes-closed in a quiet room. There are several conditions that may lead to the blocking, or attenuation, of the alpha rhythm. These attenuating conditions include: opening the eyes, intense sensory stimulation, alert attention or mental activity (Birch, 1997; Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Röhm, Klimesch, Haider & Doppelmayr, 2001). Beta activity occurs in the range of 12.5-30HZ and occurs primarily during sleep. The beta rhythm is predominantly seen in the frontal areas of the skull. Delta (0.5-3.5 Hz) and theta (3.5-7.5) rhythms are characterized as slower wave patterns and typically occur during sleep. These lower frequency waves, however, have also been associated with cortical involvement in tasks and working memory (Bizaset al., 1999, Klimesch, 1999).

The gamma band is characterized by activity occurring in the range of $\geq$ 20 Hz. Increases in gamma activity are believed to be indicative of higher cognitive process (Krause, Korpilahti, Pörn, Jäntti & Lang 1998; Pulvermüller, Lutzenberger, Preißl, & Birbaumer, 1995). The increases in gamma activity appear to be maximal around 40 Hz (Pulvermüller, Birbaumer, Lutzenberger, and Mohr, 1997).

There are a number of techniques used in EEG analysis: spectral analysis of spontaneous EEG patterns and evoked potential analysis are among the most common techniques. Spectral analyses of spontaneous EEG patterns involve investigating the changes in the power spectrum as a result of stimulus presentation or task requirements. Continuous EEG data is analyzed through power spectra analysis in order to obtain information on the frequency components of the spontaneously occurring cortical activity (Lopes da Silva, 1999a). Evoked potentials (EP) are defined as a detectable electrical change occurring in the brain, in response to a deliberate stimulation of a peripheral sense organ, a sensory nerve, or any related structure of the sensory system (Chang, 1959[ii]). Lopes da Silva (1999b) stated that evoked potentials are usually defined in the time domain as the brain electrical activity that is triggered by the occurrence of particular events or stimuli. Evoked potentials (EP) differ from more general changes in spontaneously occurring EEG patterns in that EPs bear a temporal relationship to the onset of the stimulus, and a specific characteristic wave pattern.

EEG has been used to investigate language processing in the brain. Wood and Goff (1971) were among the first to investigate auditory evoked potentials occurring during speech perception. In this experiment they had participants perform two auditory discrimination tasks (linguistic and non-linguistic). The two tasks used the same consonant-vowel syllables, but with different identification requirements. In the linguistic task, the required analysis involved acoustic parameters providing linguistic information. For this task participants were asked to indicate which of two possible stimuli had been presented on the previous trial (ie. /ba/ or /da/). The non-linguistic task involved the same syllables, but the required analysis involved acoustic parameters, which provided no linguistic information. For this task, participants were again required to identify which of two possible stimuli had occurred. However, in this task the two possible stimuli provided the same linguistic information and differed only in the fundamental frequency (ie. /ba/-low or /ba/-high). The basic premise of this experiment was that if the only difference between the two tasks was the linguistic content of the stimuli, then the areas of the brain associated with linguistic processing would be active only during the linguistic task and not during the non-linguistic task. Wood and Goff (1971) found that the evoked potentials from the right hemisphere were the same for both the linguistic and non-linguistic task; however the evoked potentials in the left hemisphere were significantly different between the two tasks. Because the two tasks used the same acoustic stimuli, Wood and Goff (1971) attributed the left hemisphere asymmetry observed in the linguistic task to the language processing requirements of the condition.

In the 1960's and 1970's most researchers investigating language were interested in evoked potentials occurring in response to language stimuli. In the 1980's there was a transition towards researchers using spectral analysis of the EEG data as a means of investigating the language areas of the brain. Makino, Matsumoto and Shichijo (1985) performed a study in which they used alpha attenuation as a measure of cerebral engagement in the task. In this experiment there were three verbal task conditions, all of which were performed with eyes-closed. The first condition involved participants selecting and counting the number of specific "target" words, presented in a story (word selection). The second condition required participants to compose a sentence using two given words (composition). The final condition involved mental addition (calculation). Alpha levels were then recorded and analyzed for alpha attenuation occurring in response to the different tasks. Alpha attenuation was compared across hemisphere, allowing for an evaluation of the differences between right and left hemispheres. Results indicated that 67% of participants showed greater alpha attenuation in the left hemisphere during the word selection task, 75% showed it during the composition task and 83% of participants showed it during the calculation task. There are a number of methodological concerns with the Makino et al. (1985) experiment. Firstly, there were no statistics run on the data collected from this experiment. Secondly, the required response was a verbal response. This verbal response can be assumed to be controlled by the LH (movement production), which may then account for the LH "dominance" observed in this experiment. However, despite these limitations, there has been extensive research regarding the alpha rhythm and it is now generally accepted that there is alpha attenuation in response to mental effort and cognitive activity (Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Röhm et al., 2001).

Initially, when mental activity was being investigated, most EEG analysis focused on alpha rhythms; however, the trend in EEG analysis has recently shifted away from solely using alpha band toward analysis in the higher frequency bands. Krause et al. (1998) performed an experiment in which they investigated the effects of auditory word perception on the level of 40 Hz EEG activity. They were interested in discovering whether there would be a difference in the level of change in the 40Hz EEG data between the presentation of words and "pseudowords". Krause et al. (1998) found an increase in 40Hz activity following the presentation of the word stimuli only (not the pseudoword stimuli). From the results of this experiment Krause et al. (1998) concluded that cortical processing of auditory words and pseudowords differ, even when the stimuli are not attended.

The previously discussed studies (Krause et al., 1998; Makino et al., 1985; Wood & Goff, 1971) were interested in auditory language processing. Recently, however interest in cerebral engagement in language has expanded to include visually presented language. Bizas et al. (1999) performed an experiment in which cerebral engagement in a reading task was analyzed using EEG. This experiment involved 4 target detection tasks (varying in language requirements). The first task required participants to detect a string of four lines in a predetermined pattern. This task, having the least language requirements was designed to utilize only visuospatial analysis. The second task required participants to detect a pre-specified (unpronounceable) string of consonants. This task, involving slightly more language processing, was designed so as to require both visuospatial and orthographic analysis. The third task condition required participants to detect "pseudowords", pronounceable units irrelevant of spelling. This third task was thought to involve visuospatial, orthographic and phonological analysis. The final task required the participants to read rows of words and detect those words referring to a human value. The final task was the most dependent upon language processing and thus involved lexical-semantic analysis along with the other language components from the other tasks.

Results showed that there was an increase in spectral power as the complexity of the task was increased. The results also showed that the changes in spectral power, as a result of stimulus presentation, were restricted to signals recorded over the left hemisphere. Bizas et al. (1999) found significant power enhancement effects in the delta, theta and beta2 bands in the LH in response to tasks requiring language processing. The results of this experiment suggest that the left prefrontal cortex is involved in a number of reading related processes.

Although limited, there is research investigating EEG in persons with DS. Many of these studies have acted to compare baseline EEGs between control participants and persons with DS. There is a consensus in the published data that there are some stereotypical differences between persons with DS and control participants in relation to their baseline EEG data. The most salient characteristic appears to be the levels of relative power in the alpha and theta bands of this special population. Persons with DS have been found to have greater relative power in the theta band and less relative power in the alpha band, when compared to control participants (Katada et al., 2000; Locatelli et al., 1996; Schmidt, Tirsch, Rappelsberger, Weinmann, & Poppl, 1992)

EEG has provided us with a great deal of support as to the areas of the brain associated with language processing. In comparison with the behavioural studies, EEG has allowed for a more direct investigation of brain lateralization. However, EEG is not alone as a more direct analysis method. Magnetoencephalography (MEG) is another method that has been quite extensively used as of late in the investigation of language processing occurring within the brain. Simos, Breier, Zouridakis and Papanicolaou (1998a) performed an experiment, using MEG, in which they investigated auditory language processing. In this experiment the participants were asked to listen to pairs of stimuli (words or tones). The stimuli were presented in 25–pair blocks. The participants were asked to attend to the stimuli and count the number of mismatched pairs. Following the block, the participants were asked to report the number of mismatches they counted. Simos et al., (1998a) found a significant difference in hemispheric activation between the word and tone tasks. A laterality index (LI) was used as a measure of between hemisphere differences. During the word-matching task the LI was seen to favour the LH, while during the tone-matching task the LI showed greater RH activation.

Simos et al. (1998a) investigated only auditory language processing. In a subsequent experiment Simos, Breier, Zouridakis and Papanicolaou (1998b) examined the difference in cerebral engagement, based on MEG analysis, during auditory and visual processing of language. In this experiment participants were asked to perform both an auditory and visual language processing task. The findings of this study displayed a definite asymmetrical engagement between the language and non-language tasks. This asymmetry resulted from an increased engagement in the LH during the language tasks. The observed increase in engagement of the LH was seen during both the auditory and visual language tasks.

Recently, Papanicolaou et al. (1999) performed an experiment in which participants were asked to identify when a word, presented in either an auditory or visual modality, had been presented earlier in the same trial (i.e. was repeated). There was found a strong LH engagement in the language, as compared to the nonlinguistic, task. Papanicolaou et al. (1999) concluded that the hemispheric asymmetries seen in activation during their task were a result of hemispheric specialization for language. They further suggested that the asymmetries are in the predicted direction of language laterality for the general population and the language specific areas overlap independent of stimulus modality. Papanicolaou et al. (1999) suggest that their results are in agreement with those areas known to subserve receptive language.

Despite this valuable method of investigating language associated areas in the brain, there is relatively limited research involving DS and either EEG or MEG. Recently Weeks, Chua, Weinberg, Elliott and Cheyne (2002) presented a single subject study in which MEG was used as an empirical test of the dissociation model. Cortical activity was monitored during a task in which the participant was presented visually with a series of both real words and nonsense words. The words were arranged in order that when the nonsense words were removed, the real words formed a basic story. Because of the single subject design of the experiment, Weeks et al. (2002) were guarded in drawing any strong conclusions; nonetheless results of the experiment were indicative of RH visual language processing of the participant with DS.

EEG and MEG provide an exciting additional means of investigating the language processes in the brain. The results of the EEG and MEG studies have been in support of the behavioural studies. EEG and MEG have allowed for a more direct investigation and analysis of the human brain while undergoing language processes. The results of these imaging techniques have suggested that the language processing areas of the human brain are not dependent upon modality of the language stimuli.

1.4 Overview

The biological dissociation model of DS as proposed by Elliott, Weeks et al. (1987) was based, in large part, upon dichotic listening studies and other early behavioural research. The model makes a number of predictions that can be tested in investigations of perceptual-motor behaviour and brain-behaviour relations. Earlier behavioural and neuropsychological studies have set the framework for more recent investigations examining brain-behaviour relations. The objective of the present experiments was to employ EEG in investigating cerebral engagement in both auditory and visual language processing in persons with Down syndrome.

Experiment One was intended to investigate auditory language processing in both controls and persons with DS. These two groups were presented with auditory language in the form of a story and auditory tones were used as a control to the language-processing task. Experiment Two involved an investigation into visual language processing. The experimental design of this experiment involved the participants reading a story as a means of monitoring visual language processing. The control portion of Experiment Two involved a discrimination task of nonsense shapes.

The primary research question of interest was whether the cortical activation pattern occurring in persons with DS during a language perception task would show a right hemisphere dominance as suggested by the dissociation model (Elliott, Weeks et al., 1987). The first experiment investigated language perception in the auditory modality. The second experiment examined the cortical activation pattern during a visual language perception task.

2.0 PARTICIPANT INFORMATION

2.1 Purpose

The following test batteries were intended to provide the necessary background participant information required for proper analysis and allow for potential comparisons between Experiments One and Two.

2.2 Participants

There were 15 participants composing two groups. The first group consisted of 7 young adults with Down syndrome (DS) recruited from the Down Syndrome Research Foundation and Resource Centre (DSRF). The second group acted as a control group and was composed of 8 young adults selected to approximate the gender, chronological age (CA) and handedness of the group of participants with DS. All control participants were free of any mental, language or learning disability. Informed consent was attained from all participants. Informed consent from participants with DS was attained in the presence of their caregiver.

2.3 Test Batteries

2.3.1 Handedness

Handedness of the participants with DS was determined using a performance test in which the participants were asked to print their name, throw a ball and demonstrate eating soup. Participants who used their right (left) hand for all three tasks was considered right-handed (left-handed), whereas participants who used a different hand for one of the task was considered as having mix-handedness. Handedness of the control participants was based on a self-proclamation of handedness.

2.3.2 Psychometry Testing

In order to assess primary language and mental abilities, mental age of the participants with Down syndrome was assessed using the Slosson Intelligence Test (Slosson Educational Publications, Inc.). This test involves the participants answering a number of questions from all subject areas. Mental age refers to the average age of normal children who perform at the level of the individual being tested. Mental age of the control participants was assumed to match their chronological age.

2.3.3 Dichotic Listening

Dichotic listening tasks involve the simultaneous presentation of a different stimulus to each ear. Auditory stimuli reach the brain through both contra-lateral and ipsi-lateral connections. Kimura (1961a) suggested however, that the contra-lateral connections in the auditory system are stronger and processed more readily than are the ipsi-lateral connections when two stimuli reach the same auditory processing centre simultaneously. Therefore, if the stimulus presented to the right ear is processed and perceived preferably compared to that presented to the left ear (which is typically found), this would suggest that the auditory language processing system is located in the left hemisphere. Each participant underwent a dichotic listening task in order to determine the direction and degree of their laterality for language processing and perception.

Apparatus

The auditory stimuli consisted of pairs of spoken English digits, presented as to arrive simultaneously in pairs to the two ears. The stimuli used were prepared by DK Consultants (1985) and presented on a Sony cassette player using stereo headphones.

Procedures

Testing took place in a quiet, comfortable testing room. The volume of the auditory stimuli was adjusted to approximately a 70Db sound pressure level at the participants' ears. The testing procedure was arranged into four sections. The first section (8 trials) consisted of the stimuli being presented in pairs of three digits to each ear over a two second interval. The second section (6 trials) involved the pairs of three digits being presented to each ear over a 5 second interval. The third section (6 trials) of the testing involved the presentation of four stimuli to one ear and 2 stimuli to the other ear. The stimuli were counterbalanced across ears in order to ensure overall equal stimuli presentation to the two ears. In this section only two number pairs were synchronized across ears, while the other 2 stimuli were presented alone to one ear. The stimuli in this third section were presented over a duration of 5 seconds. The presentation of the stimuli in the fourth and final section (6 trials) was similar in procedure to the first section. All sections of this assessment had an inter-trial interval of 10 seconds. The participants were asked to report as many digits as they could remember during the presentation of the binaural dichotic auditory stimuli. The earphone arrangement was counterbalanced across participants in order to control for slight discrepancies in volume or clarity of stimuli.

Although it has been suggested that a free recall dichotic listening procedure can mask true laterality asymmetries due to attentional and response bias (Kimura, 1961b; Pipe, 1985; Žekulín-Hartley, 1981), it was felt that due to the mental capacity of some of the participants, a free recall procedure would be the most suitable.

Analysis

Ear advantage in reporting the correct stimuli was assessed based on a laterality index (LI). In this analysis, the LI (Equation 1) is a measure of the proportion of right-ear reported stimuli in relation to the total number of reported stimuli (Studdert-Kennedy & Shankweiler, 1970).

$$LI = \frac{\text{Right ear score - Left ear score}}{\text{Right ear score + Left ear score}} \times 100$$

Equation 1 – Laterality Index – Equation used to analyze the dichotic listening results. A positive LI indicates a right ear advantage in the dichotic listening task.

Thus a positive LI indicates a right ear advantage (REA), while a negative LI indicates a left ear advantage (LEA) for the perception of auditory language stimuli.

2.4 Results and Discussion

Table 1 shows the results of the participants' information and test batteries. The participant column gives both the group and participant number. SC refers to the control group and SD refers to the participants with DS. The column entitled sex defines the participants as either female (F) or male (M). The chronological age of each participant (in years) is recorded in the CA column. Column MA gives the calculated mental age of the participants with DS. MA of the control participants was assumed to be equal to their CA. Laterality index values for the dichotic listening assessment are provided in the dichotic – LI column. Finally handedness of the participants is presented as right (R), left (L), or mixed (M) in the column entitled handedness.

Table 1 – Participant Information

Participant	Sex	CA	MA	Dichotic - LI	Handedness
SC01	F	23		18.1	R
SC02	F	19		11.9	R
SC03	F	25		4.8	R
SC04	F	25		43.4	R
SC05	M	25		0	R
SC07	F	23		1.5	R
SC08	F	23		8.6	R
SC09	F	26		9.2	R
SD01	F	28	8-6	-93.6	R
SD02	F	13	8-4	-73.9	R
SD03	F	15	7-2	34.4	R
SD04	F	16	9-0	-39.3	L
SD05	M	23	6-5	21.5	M
SD06	F	22	8-4	7	R
SD07	F	22	7-9	-31.6	R

Note. This table displays the participant information for all the participants from both Experiment One and Two. The columns refer to group and participant number, sex, chronological age, mental age, laterality index of dichotic listening and handedness. Mental age values are reported as years-months.

The results of the dichotic listening data can be seen in Figure 2. All control participants had dichotic LIs greater than or equal to zero. This suggests that all of the control participants in the present experiments were LH lateralized for language processing (or showed no lateralization effects). The participants with DS were not as cohesive in their dichotic LI values. Four of the participants with DS had results suggesting RH language processing and three had results indicative of LH language processing.

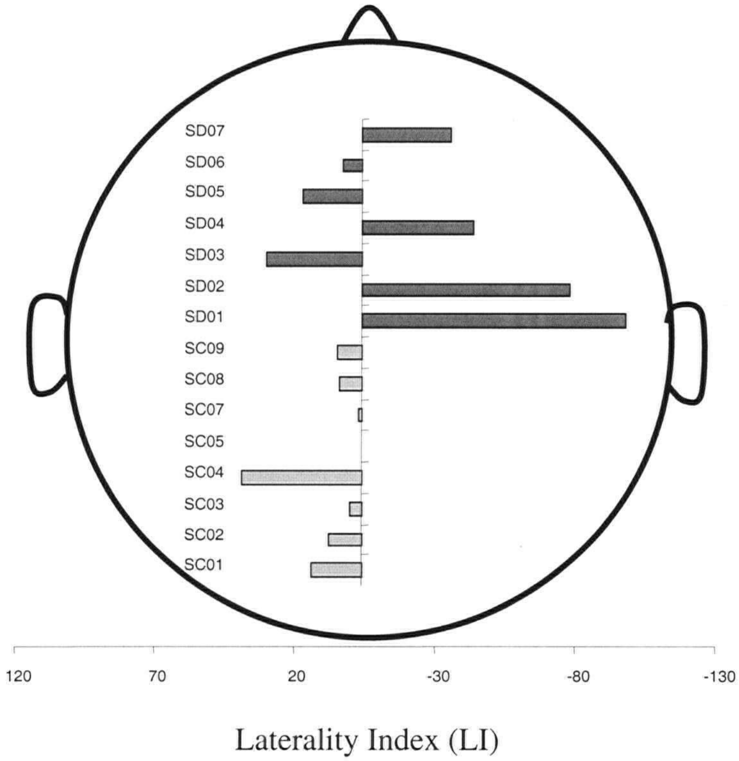

Figure 2 – Individual Laterality Indices (LI) of dichotic listening paradigm – Control participants are displayed towards the bottom of the Figure and participants with DS are displayed towards the top of the Figure. All control participants had LIs of ≥ 0 (indicating a right ear/left hemisphere advantage). Four of the 7 participants with DS displayed LIs of < 0 (indicating a left ear/right hemisphere advantage), while 3 of the 7 participants displayed LIs of > 0 (right ear/left hemisphere advantage).

The data from the dichotic listening task were separated into groups (control, DS) and each group was subjected to a t-test against a hypothesized mean of zero. The results indicated a significant REA in the control group (M = 12.187, SD = 13.88) $t(7) = 2.484$, $p = .0420$. This pattern (mean LI=12.19) is in agreement with previous research suggesting a right ear/left hemisphere advantage in the perception of linguistic stimuli in a control population (Elliott & Weeks, 1993; Hartley, 1982; Žekulín-Hartley, 1981; Žekulín-Hartley, 1982). Results indicating non-significance for lateralization of dichotic listening for the participants with DS was likely due in large part to the large subject variability of LIs present for the DS participants (Figure 3). Although not significant, Figure 3 shows that there was a trend toward left ear/right hemisphere advantage in the DS population (mean LI = -25.07), which is in agreement with previous research. (Elliott & Weeks, 1993; Hartley, 1982; Žekulín-Hartley, 1981; Žekulín-Hartley, 1982)

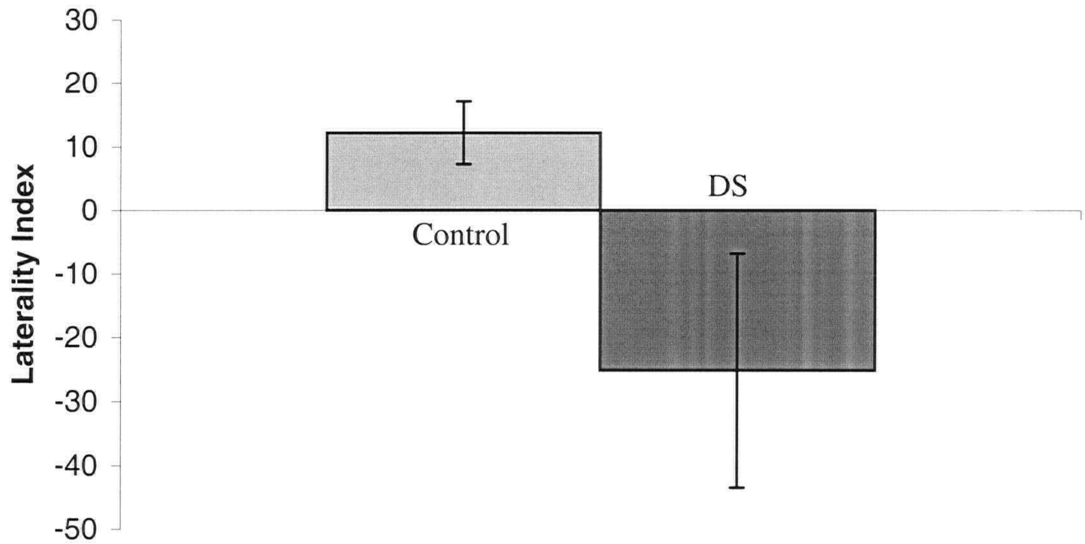

Figure 3 – Group Laterality Indices (LI) of dichotic listening paradigm – Mean values of dichotic listening results are shown for each group (control and DS) error bars show the standard error for the groups[1].

Comparison between Figure 2 and Figure 3 results in the observation that there was an overall left ear/right hemisphere advantage in the participants with DS and that 4 of the 7 participants displayed large negative LI values. This suggests, that although the results for the participants with DS were not significant, the findings for both the control and DS participants are in general in agreement with previous research that suggests the DS population displays an atypical left ear/right hemisphere advantage in the dichotic listening paradigm (Elliott & Weeks, 1993; Hartley, 1982; Žekulín-Hartley, 1981; Žekulín-Hartley, 1982).

[1] All figures represent the mean values with error bars refering to the standard error value

3.0 EXPERIMENT ONE

3.1 Purpose

The purpose of Experiment One was to investigate the pattern of cortical engagement during an auditory language perception task in persons with Down syndrome. Cortical activity, during task performance, was monitored through the use of a continuous EEG recording.

3.2 Participants

There were 15 participants in the present experiment. The same participants who took part in the test batteries made up the participant pool in the present experiment. The control group was composed of 7 females and 1 male ranging in age from 19-26 years (mean 23.6). The group of participants with DS was composed of 6 females and 1 male. The group with DS had a chronological age range of 13-28 years (mean 19.9) and a mental age range of 6years 5 months (6-5) to 9 years 0 months (9-0) (mean 7-11).

3.3 Apparatus

<u>Stimuli</u>

The experimental stimuli consisted of a female speaker reading a story at a relaxed and comfortable pace[2]. The stories were selected based on being simple children's stories that would be at a level appropriate for the mental age of all participants. The control stimuli were tones composed of frequencies in the range of 500-1500 Hz. The tones were 0.5 sec in durations and had an inter-tone interval of 0.5 seconds. The auditory control stimuli were pre-recorded onto a zip disk with the use of a Digital studio workstation (Roland Corporation, model VS-840EX). For presentation during the experiment, all the auditory stimuli (stories and tones) were burned onto a CD. The auditory stimuli were adjusted to approximately a 75-dB sound pressure level at the participant's ear.

<u>EEG Recording</u>

Electroencephalographic (EEG) scalp activity was recorded via an electrode cap (Easy Cap – Falk Minow Services) using silver / silver chloride sintered ring electrodes

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[2] Acknowledgements to Deborra Hope (Anchor, BCTV News, Global BC) for her assistance in recording the stories.

organized in the international 10-20 system (Figure 4). A ground electrode was attached to the mid-frontal region and linked mastoids were used for the reference electrodes.

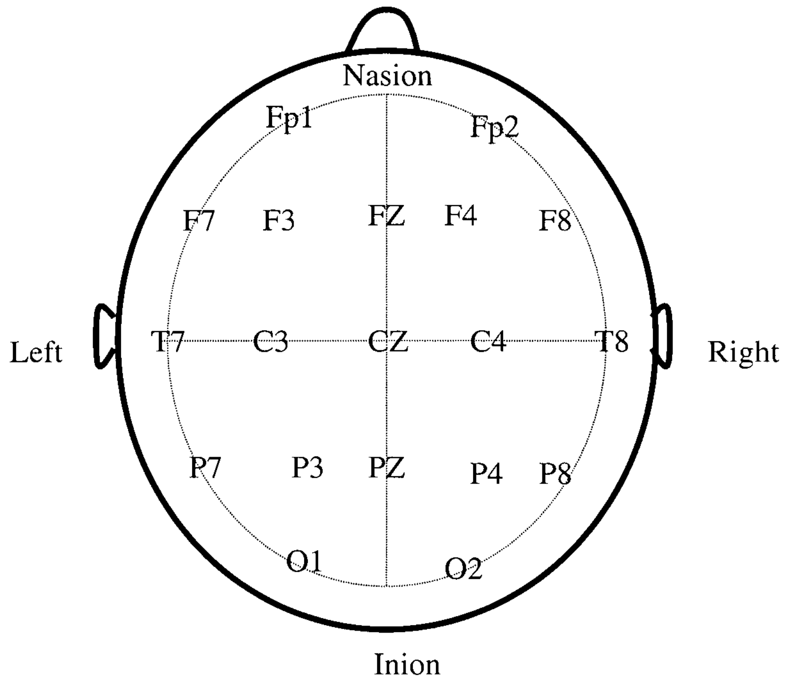

Figure 4 - The 10-20 system of electrode placement. Based on percentage distances from four standard landmarks: inion, nasion, left and right pre-auricular points.

Inter-electrode impedance was maintained at a level of less than 5KΩ. The electrophysiological activity was amplified with a gain of 1000 and band-pass filtered with settings of 1-50Hz using a Synamps amplifier (Neuroscan El Paso, USA). The EEG data was sampled at a frequency of 250Hz. EOG data was recorded in order to measure eye activity during the experiment. The EOG signal was amplified with a gain of 250 and band pass filtered with setting of 1-50Hz.

3.4 Procedures

Participants were seated in a comfortable "dentist" chair and fitted with the appropriate size electrode cap. A story trial consisted of a one-minute silent period, followed by a two-minute story and then another one-minute silent period. The control condition consisted of a one-minute silent period followed by a two-minute presentation of tones and concluded with another one-minute silent period (Figure 5). There were 3 different story trials and 3 control (tone) trials. The order of the trials was randomized across the participants while maintaining a reciprocating story/tone or tone/story format.

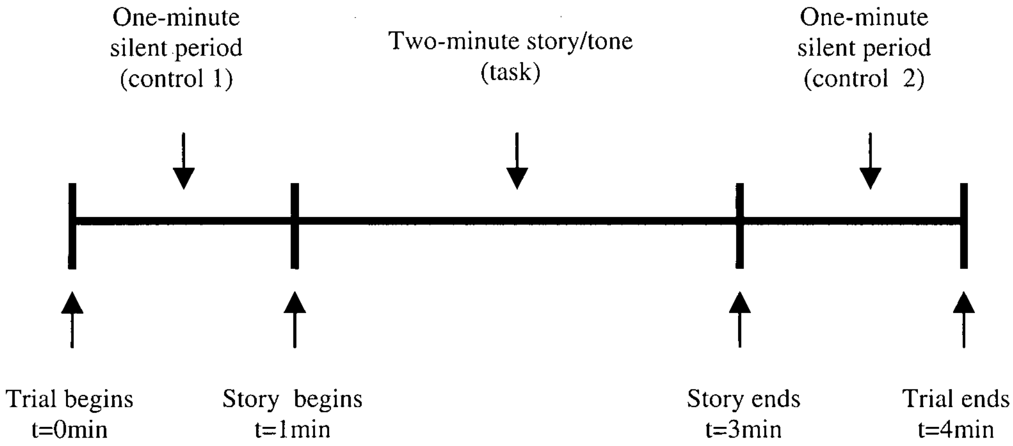

Figure 5– Template for trials for Experiment One – All trials (both story and tone trials) abided by the same time period allocations.

The set-up of the trials was explained to the participants prior to beginning the experiment. Participants were asked to remain relaxed with eyes-closed throughout the course of a trial. Following each of the trials, participants were asked simple questions regarding the content of the stories or number of high-pitched tones presentation to ensure they were attending to the task. The EEG data from one trial were collected in one continuous file for later off-line analysis.

3.5 Analysis

The data from one of the participants with DS (SD02) were excluded due to the participant's inability to remain awake throughout the course of a trial. The data collected during the tone trials from a second participant with DS (SD05) were excluded as a result of excessive eye movement artifact during the collection of data. These excessive eye movements resulted in insufficient amounts of data to satisfy the 30, 1-second epoch requirements of the data analysis. The data from one of the control participants (SC03) were excluded due to technical difficulties during the data collection phase of the experiment. As a result, analysis of the data from the present experiment was composed of 13 participants (7 controls, 6 DS) for the story trials, and 12 participants (7 controls, 5 DS) for the tone trials. The story and tone data were analyzed based on presentation order. As a result, in the analysis, story one refers to the first story that was presented to that particular participant, and not a specific story. Also due to a number of the participants with DS being unable to stay focused through six trials, only the first two story and tone trials were analyzed.

3.5.1 Estimated Relative Power

The EEG record from each trial was divided into three segments: 1st control period, task period, and 2nd control period. EEG epochs were selected using a two-step process. The EEG and EOG records were visually inspected for the occurrence of eye movements, and epochs that were contaminated by eye movements were rejected. Following visual inspection, the EEG record was submitted to further artifact rejection using an algorithm that rejected any epoch in which the voltage exceeded ±100 μv in any of the channels. In this experiment, 30 artifact-free epochs, each of 1 second duration, were derived from the 1st control and task periods of the EEG record and were submitted for spectral analysis. As a result, 60 seconds of EEG data were analyzed for each trial (30 seconds of control, and 30 seconds of task data).

EEG data were analyzed using in-house algorithms written in LabView (National Instruments Corp., Austin, Texas). The selected EEG epochs were band-pass filtered (1-50 Hz, dual-pass, 2nd order Butterworth filter), windowed (Hanning window), then submitted to FFT analysis to obtain the power spectrum profile (V^2rms) for each EEG lead, over each 1-second epoch. The individual power spectra for each EEG lead were then averaged separately to obtain the average power spectrum profile for each EEG lead. Thus, an average spectrum was obtained for each EEG lead for both the control segment and the task segment. For each average spectrum, relative power estimates for the alpha (8-13 Hz), beta (14-30 Hz), and 40 Hz (36-44 Hz) bands were calculated as the ratio of the power within the specific frequency band over the power within the entire 1 – 50 Hz frequency range. For each trial analyzed, these procedures yielded a relative power value for each EEG lead, frequency band, and control and task conditions. Relative power was the variable for analysis in this experiment because unlike band power, relative power is not strongly influenced by a decrease in total power (Gasser, Bächer, & Möcks, 1982).

3.5.2 Log Transformation and ANOVAs

In order to normalize the data, the relative power values were log transformed [log(x/(1-x))] prior to further analysis (where x= relative power value) (Gasser et al., 1982). In all of these calculations log refers to the natural log. The transformed relative power values were then separated into left hemisphere (LH) and right hemisphere (RH) leads. The log-transformed relative power was then averaged across all left hemisphere leads to give one value for the log-transformed relative power of the LH. The same calculations were performed on the right hemisphere data in order to calculate one value for the log-transformed relative power of the RH. Based on these calculations it can be seen that:

as $x \to 1$ (a relative power of 100%) $\log(x/(1-x)) \to +$'ve ∞

as $x \to 0$ (a relative power of 0.00%) $\log(x/(1-x)) \to -$'ve ∞

when $x = 0.5$ (a relative power of 50%) $\log(x/(1-x)) \to 0$

Therefore a positive value corresponds to a relative power > 0.5 (50% relative power) and a negative value corresponds to a relative power of < 0.5. The more negative the value the less relative power that is in the particular band. As a result attenuation of a particular band would be seen as the task condition having a more negative log-transformed relative power value than the control condition.

The log-transformed relative power values were then subjected to a 2 Group (control and DS) x 2 Presentation (either story 1 and 2 or tone 1 and 2) x 3 Band (alpha, beta, and 40Hz) x 2 Condition (control and task) x 2 Hemisphere (LH and RH) mixed analysis of variance with repeated measures (RM) on the final four factors. Separate ANOVAs were performed for story and tone data sets.

3.5.3 Attenuation

Levels of attenuation were calculated based on the original relative power values (non-transformed). Attenuation values were calculated separately for the left and right hemispheres (Equation 2).

$$\text{attenuation} = (RP_T - RP_C)/RP_c \times 100\%$$

Equation 2 – Attenuation – This equation was used to calculate attenuation of each of the frequency bands involved in the analysis. RPc refers to the original relative power during the control, RP_T refers to the relative power during the task.

A positive attenuation value results when there is greater RP during the task than during the control. As a result a positive attenuation value refers to an enhancement of the associated frequency band in the specific hemisphere. A negative attenuation value refers to attenuation in that particular frequency band in the specified hemisphere.

Following calculation of an attenuation value, the attenuation values from the left and right hemisphere were combined in order to assess laterality of attenuation (Equation 3).

$$\text{Laterality of attenuation} = \text{attenuation (LH)} - \text{attenuation (RH)}$$

Equation 3 – Laterality of Attenuation – This equation was used to assess the laterality of the attenuation for each of the frequency bands involved in the analysis. Attenuation (LH) refers to the attenuation value for the LH and attenuation (RH) refers to the attenuation value for the RH.

Interpretation of the laterality of attenuation is dependent upon the original attenuation values. If the original attenuation values are negative a positive laterality of attenuation refers to greater RH attenuation and a negative value refers to a greater LH attenuation. If the original attenuation values are positive, a positive laterality of attenuation refers to greater LH enhancement.

3.6 Hypothesis

Based on the dissociation model of cerebral lateralization in persons with DS (Elliott, Weeks et al., 1987), it was expected that the results of the DS group would differ from the control group in the areas associated with auditory language perception and comprehension. The DS group was anticipated to show more cerebral activity associated with cognitive processes in the right hemisphere during the language perception and comprehension task as compared to the control participants. The DS group was hypothesized to display greater alpha attenuation in the RH as compared to the control group. Correspondingly, during the language perception task, the DS group was expected to display a significant alpha attenuation in the RH and the control group to display a significant level of alpha attenuation in the LH.

3.7 Results and Discussion

The analysis of Experiment One was conducted in a step-wise manner in order to answer a number of important questions and test the hypothesized results of the experiment. Prior to testing the hypothesis however, there were a number of preliminary analyses that were performed in order to assess whether the data collected during the present experiment demonstrated the typical patterns of cortical engagement found in previous EEG research. Following this initial assessment the data were subjected to analysis based on answering specific questions or hypotheses of the experiments.

3.7.1 Question 1: Do the data display typical characteristics of EEG data?

The data were analyzed to ensure that the data collected during this experiment were in accordance with data collected in past experiments. This was assessed based on an examination for patterns in the EEG data that are typical of base-line and task data from prior research. The typical patterns which were specifically examined included: 1) a comparison of relative power values attained in this experiment to those found in previous experiments, 2) alpha band activity being greatest in the occipital and parietal regions, 3) a predominance of alpha band activity with eyes-closed, and 4) some expected differences between the control group and the participants with DS.

Relative powers of band frequencies

There has been extensive research done using EEG. As a result it has been possible to develop "norms" tables for relative powers of the different band frequencies in the general population (Senf, 1988). It is generally accepted that in the eyes-closed and relaxed state that the alpha rhythm predominates the brain activity and is most prominent in the occipital and parietal regions of the brain (Birch, 1997; Shaw, 1996). It is also generally accepted that there will be less relative power in the beta band when compared to the alpha band.

The alpha band data collected during the control portion (relaxed body state with eyes-closed) of the present experiment were compared to the normative measures of alpha relative power (Senf, 1988). The normative measures used are based on an eyes-closed, relaxed awake EEG recording of a 35-year old participant. The results of the present experiment, showed that both the control and DS groups displayed alpha band relative power value profiles that were similar to those of the 35-year-old normative values. Figure 6 shows that the control population in the present experiment displayed alpha relative power values greater than the normative values and the population with DS in the present experiment displayed alpha relative power values lower than the normative values. It can be seen that in both of the populations in the present experiment the alpha relative power was greatest in the occipital and parietal regions.

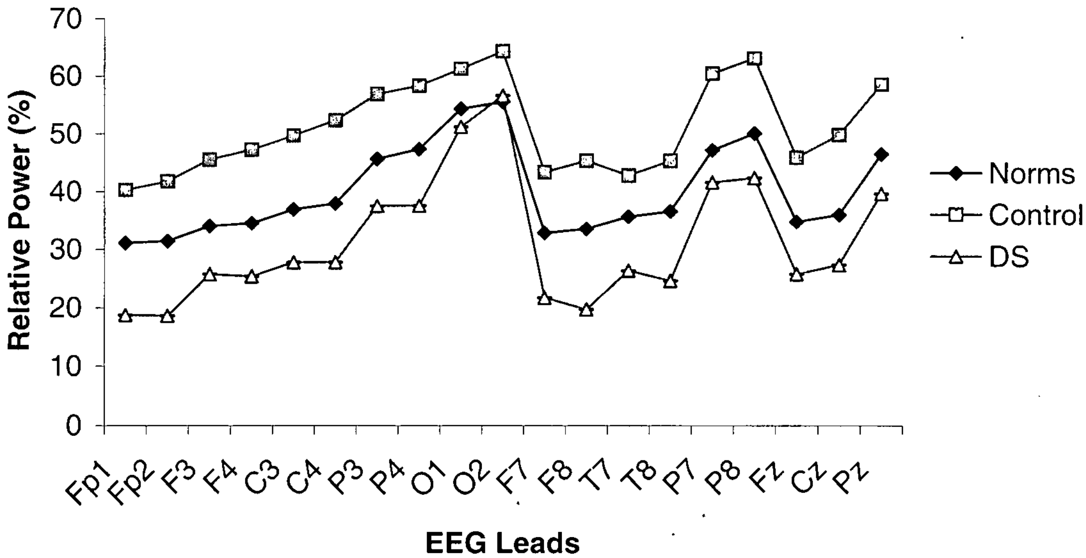

Figure 6 - Relative power of the Alpha band during an eyes-closed and relaxed condition at the different electroencephalographic leads. The results of the control and DS populations are shown along with the norm values relating to a 35-year-old participant.

Figure 6 shows that the expected pattern of relative power distribution is seen in both the control and DS participants.

The beta band data collected during the control portion (relaxed body state with eyes-closed) of the present experiment were compared to the norm values of beta relative power (Senf, 1988). The results of the present experiment when compared to the "norms" table of a 35-year-old participant showed that both the control and DS groups displayed relative power values similar to the expected, normative, values. Figure 7 shows that both the control and DS populations in the present experiment displayed beta relative power values slightly lower than the norm values. It can be seen that in both of the populations in the present experiment, during the control condition, the beta relative power was greatest in the temporal region.

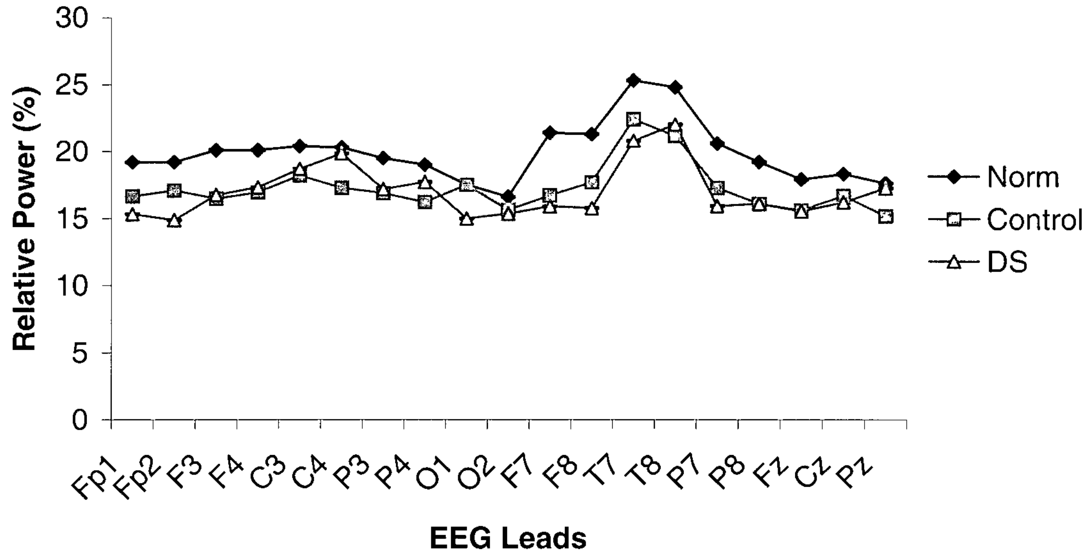

Figure 7 - Relative power of the Beta band during an eyes-closed and relaxed condition at the different electroencephalographic leads. The results of the control and DS populations are shown along with the norm values relating to a 35-year-old participant.

Figure 7 shows that the distribution pattern of relative beta band power is similar in the two groups involved in the present experiment and the norm values.

<u>A predominance of alpha activity</u>

The literature suggests that there should be a predominance of alpha band activity in an individual in a relaxed state with eyes-closed (Birch, 1997; Klimesch, 1999). The present data were subjected to analysis to evaluate whether this typical EEG pattern was displayed in the present experiment.

The ANOVA for stories revealed a significant band main effect $F(2,22)=365.8$, $p<.0001$. Newman-Keuls (NK) post hoc analysis of this main effect revealed that there was significantly greater relative power in the alpha band than in either of the beta or 40Hz bands. The post hoc analysis also revealed significantly greater relative power in the beta band than the 40Hz band (Figure 8). Because these effects are seen as a band main effect they are averaged across both the control and task portion of both stories. This suggests that during an eyes-closed condition there is significantly greater alpha band relative power than either beta or 40Hz.

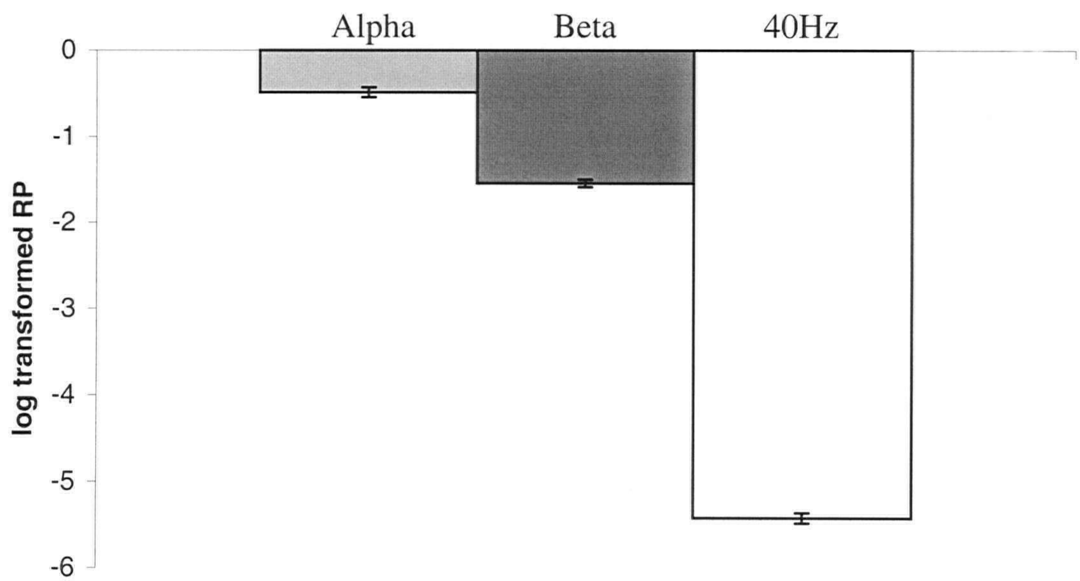

Figure 8 – The relative power (log transformed)[3], occurring during the story trials of the analyzed bands (Alpha, Beta, 40Hz). Error bars show the standard error for the values.

The ANOVA for the tones also revealed a significant band main effect $F(2,20)=396.12$, $p<.0001$. Post hoc analysis of this main effect revealed that there was significantly greater relative power in the alpha band than in either of the beta or the 40Hz Bands. There was also a significant difference between the relative powers of the beta and 40Hz bands, whereby there was significantly greater relative power in the beta

[3] Data were analyzed as log transformed values. Values reported represent the mean of the log transformed relative power values. As a result, more negative values refer to less relative power and less negative (or more positive) values refer to greater relative power.

band (Figure 9). This result shows that there was significantly greater relative power in the alpha band than in either the beta or 40Hz bands across the entire trial, including control and task, during the presentation of the tone trials.

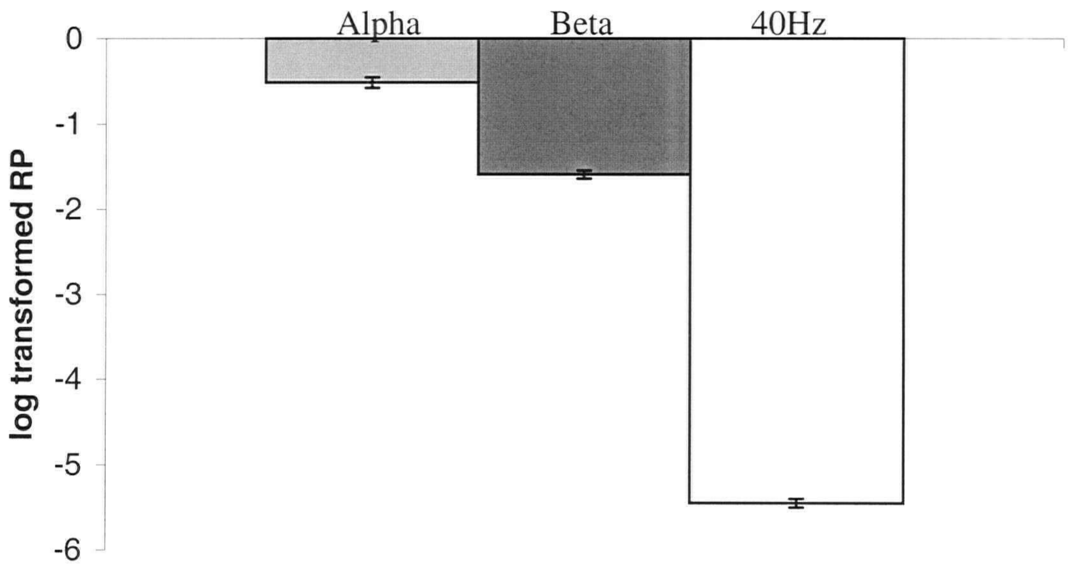

Figure 9 - The relative power (log transformed), occurring during the tone trials, of the analyzed bands (Alpha, Beta, 40Hz).

The presence of significantly greater alpha band relative power was seen during both the stories and tones trials. Because these values were averaged across groups, conditions and presentations, it suggests that the participants displayed an overall dominance of alpha band activity, as compared to either beta or 40Hz activity during an eyes-closed condition. These findings are in support of previous research, which suggests that alpha band is the predominant EEG band when the eyes are closed (Birch, 1997; Shaw, 1996).

<u>Group Differences</u>

Previous research suggests that there are some common differences in the EEG patterns as displayed by a control population and a population with Down syndrome. These studies have shown that there exists, in persons with DS, a decrease in alpha band power and an increase in slow wave band powers as compared to control populations (Locatelli et al., 1996; Schmidt et al., 1992).

The concordance of the data from the present experiment with previous experimental data regarding group differences was investigated by examining the band x group interaction. Although this result was not significant for the story $F(2,22)=2.301$, $p=.1237$ or the tone $F(2,20)=2.075$, $p=.1518$ trials, a trend for the alpha band is evident during both the story (Figure 10) and the tone (Figure 11) trials. The trend for the alpha band is in the direction of control participants displaying greater relative power in the alpha band than the participants with DS.

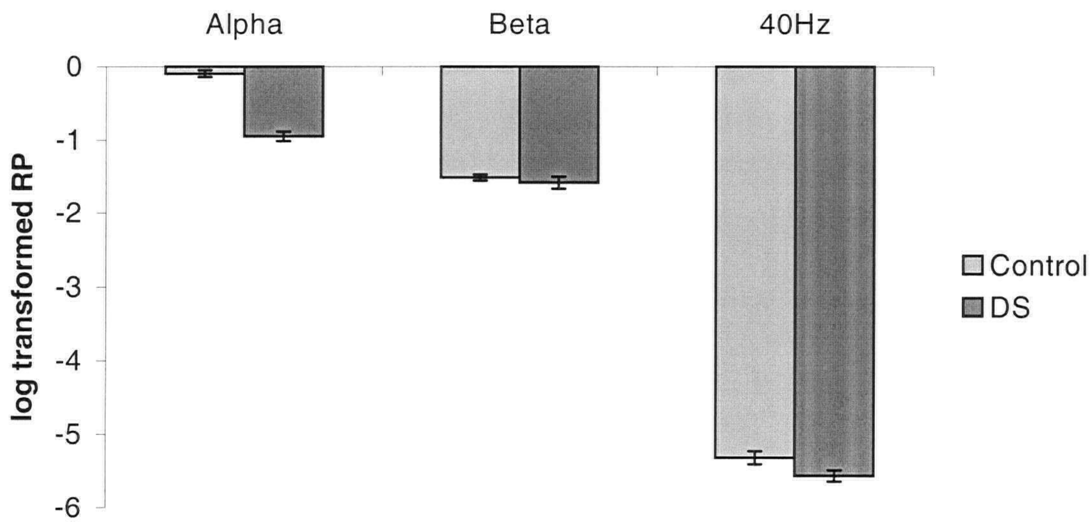

Figure 10 –The relative power (log transformed) of the band by group interaction during the story trials. Although not significant the results show a trend of decreased relative power in the alpha band of the participants with DS as compared to the control participants.

It can be seen that for both the story (Figure 10) and tone (Figure 11) trials, the participants with DS displayed less relative power across all three experimental bands (alpha, beta and 40Hz). The fact that the group differences for the bands were all in the same direction (greater RP for the control participants), would help to account for not finding a significant band by group interaction.

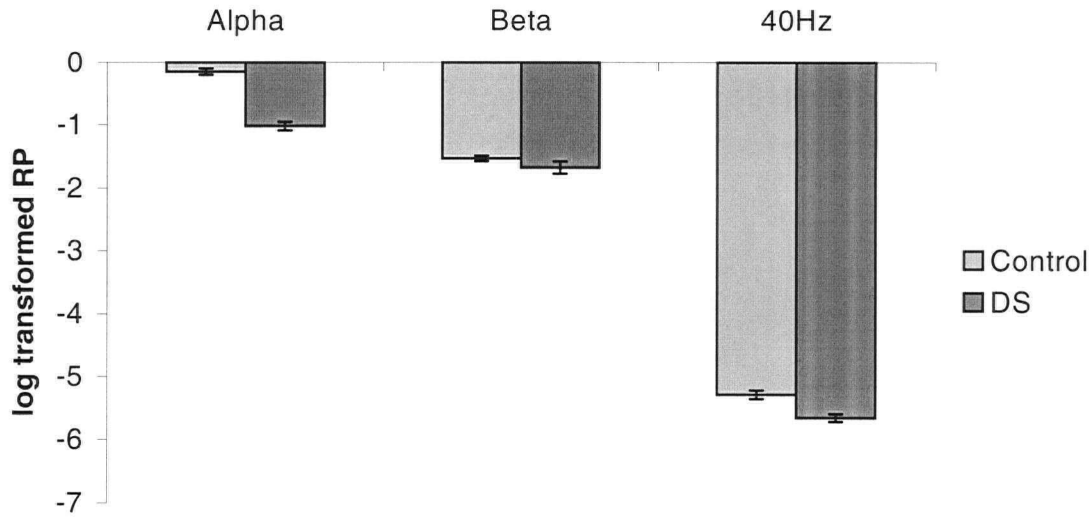

Figure 11 – The relative power (log transformed) of the band by group interaction during the tone trials. Although not significant the results show a trend of decreased relative power in the alpha band of the participants with DS as compared to the control participants.

There was a significant group main effect for presentations of both the stories $F(1,11)=6.309$, $p=.0289$ and tones $F(1,10)=9.655$, $p=.0111$. The patterns of these significant findings were the same for both the story and tone trials in that the control participants displayed greater relative power in the alpha band than did the participants with DS. Figure 12 displays the tone data, which shows that there was significantly greater relative power in the control group as compared to the group with DS.

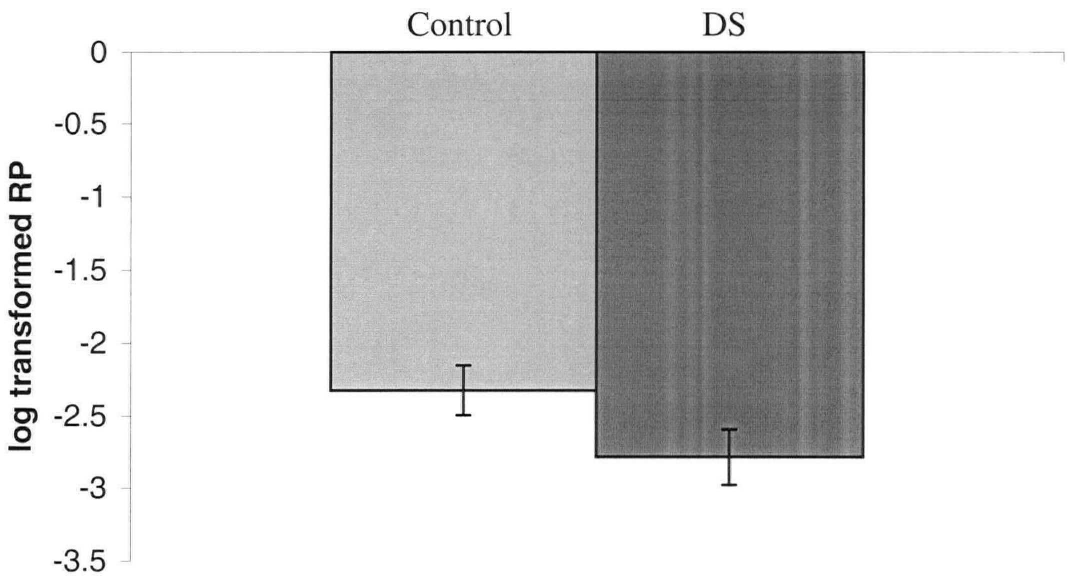

Figure 12 – Relative power values (log transformed) averaged across the alpha, beta and 40Hz bands for the control participants and participants with DS during the presentation of the tones.

This group main effect (Figure 12) can be seen as a decreased relative power for the participants with DS across the three bands of interest (alpha, beta 40Hz), when compared to the control participants during the stories (Figure 10) and tones (Figure 11) trials. This decrease in relative power suggests that the participants with DS have less relative power than the control participants in EEG frequency bands that have been investigated in the present experiment. Although there is a general trend towards decreased relative power in the participants with DS it can be seen that the discrepancy between groups is greatest in the alpha band (Figures 10&11). It is also possible that this group main effect could act to mask a significant decrease in alpha band relative power in the DS group. In order to assess this, the data for each frequency band were further analyzed separately.

Separate Band Analysis

In order to further examine potential restrictions of the primary analysis, additional analyses were performed in order to isolate effects within specific frequency bands. This analysis was based on a 2 group (control, DS) x 2 presentation (either story 1, story 2 or tone 1, tone 2) x 2 condition (control, task) x 2 hemisphere (LH, RH) ANOVA with RM on the final 3 factors. A separate ANOVA was run for each band (alpha, beta, 40Hz) and for both the story and tone trials.

Group differences – Alpha: There was a significant group main effect in the alpha band for the presentation of both stories $F(1,11)=15.050$, $p=.0326$, and tones $F(1,10)=13.127$, $p=.0106$. This finding (Figure 13) is in agreement with previous research that has shown that the population with DS displays significantly less relative power in the alpha band as compared to the control population.

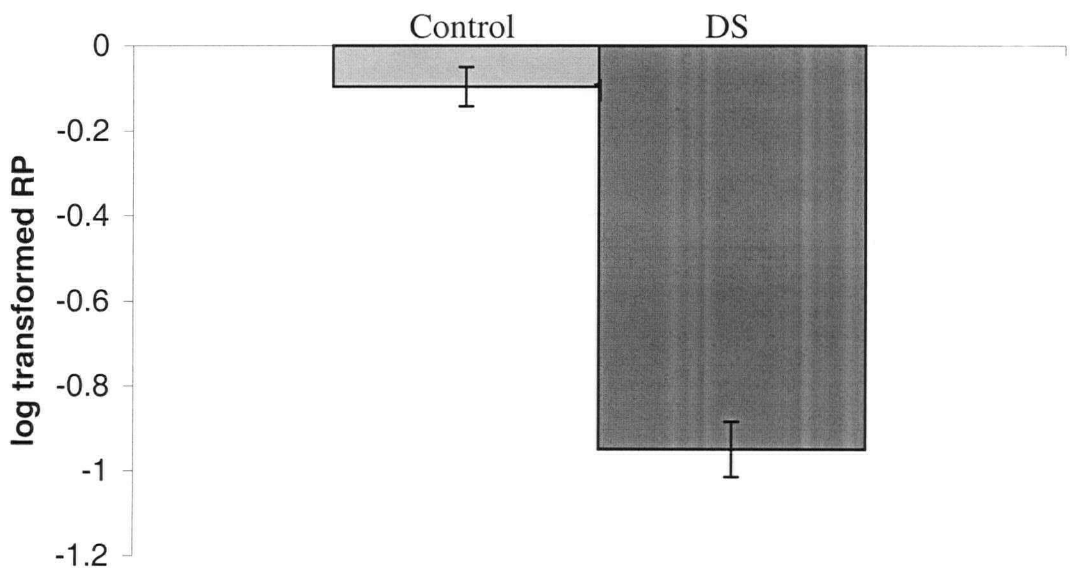

Figure 13 - The alpha band relative power (log transformed) of the group main effect during the story trials. The participants with DS displayed significantly less relative power in the alpha band than the control participants.

There were no significant group main effects for either the beta or 40Hz bands. This suggests that the control group and participants with DS did not show different relative power distributions in either the beta or 40Hz bands.

Interim Summary

The results of the initial set of analyses are in support of previous research. The analyses have revealed that the expected relative power values for both alpha and beta were found in the data from the present experiment. Alpha band was found to be the predominant frequency band during the eyes-closed relaxed condition, and the control participants were found to have greater alpha band relative power than did the participants with DS.

3.7.2 Question 2: Do task conditions have an effect on relative power?

Previous research has suggested that there exist some stereotypical shifts in power and frequency of cortical activity in response to cognitive effort. There is extensive research that suggests that cognitive effort and activity results in a decrease in alpha band relative power and an increase in beta band relative power (Birch, 1997; Bizas et al., 1999; Shaw, 1996).

In agreement with previous research, the ANOVA for stories revealed a significant band x condition effect $F(2,22)=4.079$, $p=0.0311$. Post hoc analysis of this data, using Newman-Keuls (NK) test, revealed that there was significant alpha attenuation in response to the task. Although not significant it can be seen that there was also a trend of beta enhancement in response to the task (Figure 14).

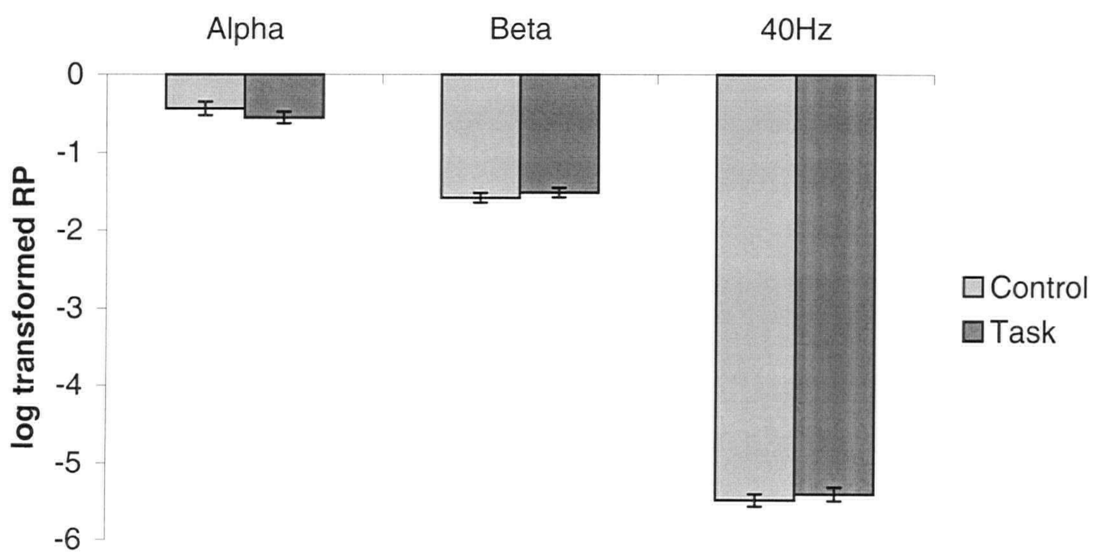

Figure 14 –The relative power (log transformed) of the band by condition interaction during the story trials. There was significant alpha attenuation in response to the task. Although not significant the results show a trend of both beta and 40Hz enhancement in response to the task.

The results of the tone conditions were such that there were no significant findings for a band by condition interaction.

Separate band Analysis

In order to analyze further this band by condition effect occurring during the story trials, separate analyses were performed for each frequency band.

Alpha: There was a significant condition main effect for the presentation of story trials $F(1,11)=8.137$, $p=.0157$. This finding shows that there was less relative power in the alpha band during the task as compared to the control condition (Figure 15). The pattern of alpha band attenuation in response to the task was found to occur for both the controls and participants with DS. These results support previous research that has shown alpha attenuation in response to cognitive activity.

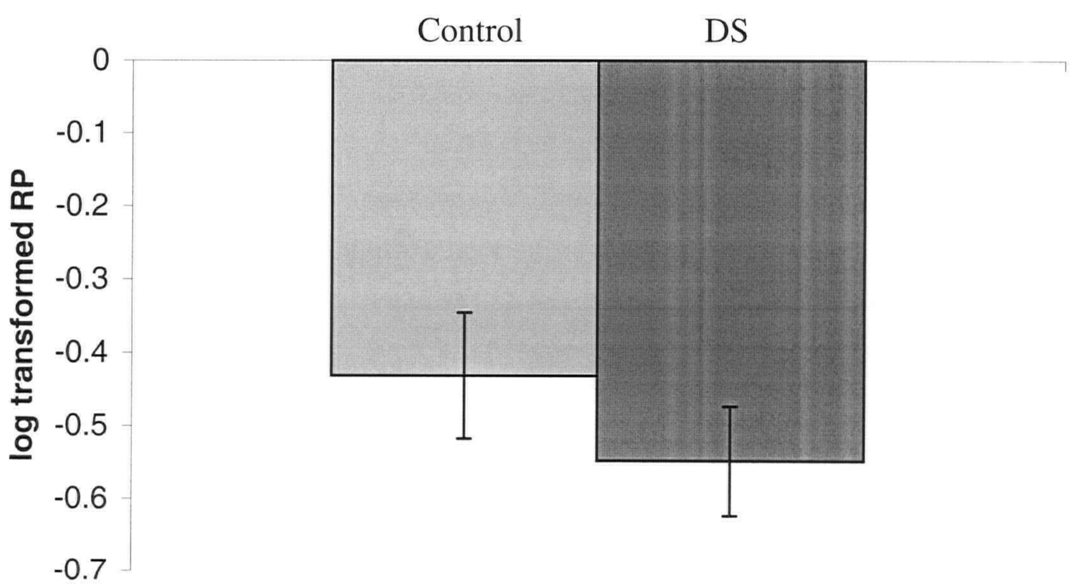

Figure 15 - The alpha band relative power (log transformed) of the condition main effect during the story trials. There was significant alpha attenuation in response to the task.

The relative power was not significantly influenced during the presentation of the tone trials $F(1,10)=.103$, $p=.7548$.

Beta: There was a significant condition main effect for the presentation of story trials $F(1,11)=7.844$, $p=.0173$. This finding shows that there was greater relative power in the beta band during the task as compared to the control condition (Figure 16). Both the controls and participants with DS were found to display a pattern of beta enhancement in response to the auditory language processing task. This finding is in agreement with previous research that has found beta enhancement occurring in response to cognitive effort.

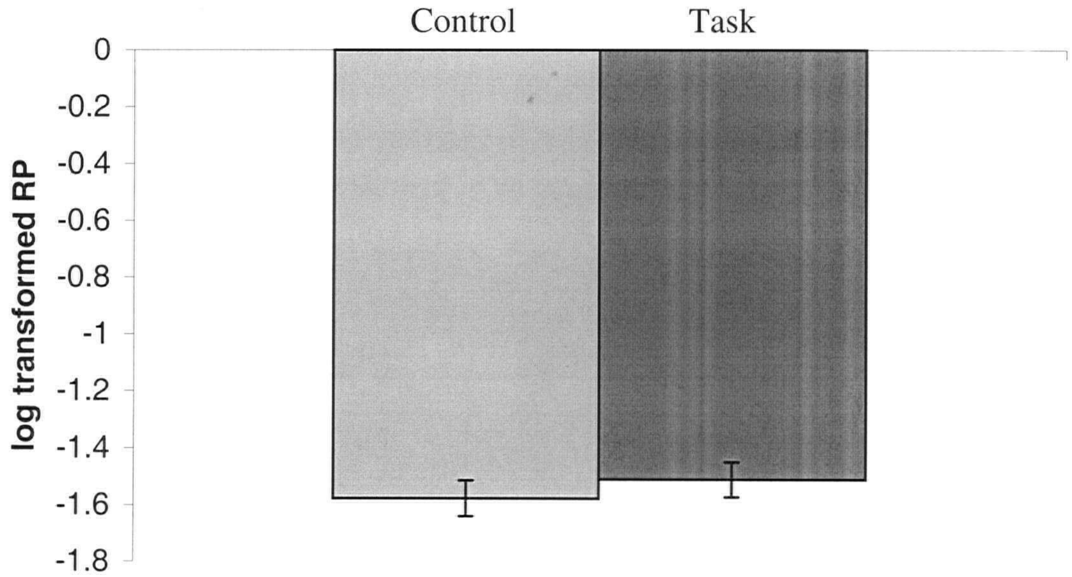

Figure 16 – The beta band relative power (log transformed) of the condition main effect during the story trials. There was significant beta enhancement in response to the task.

The condition main effect was not found to be significant during the presentation of the tone trials $F(1,10)=2.101$, $p=.1778$.

Interim Summary

The finding that there was significant alpha attenuation and beta enhancement during the story but not during the tone trials suggests that the participants were actively involved and engaged during the presentation of the stories but may not have been during the presentation of the tone trials. This may be a result of the tone trials having not been challenging and therefore engaging enough to elicit a cognitive engagement effect during the present experiment.

3.7.3 Question 3: Were there task-related hemispheric differences that differed between the control and experimental groups?

Based on previous research, it was hypothesized that there would be specific group differences in laterality of activation occurring during the language task. In order to investigate this effect with the current data, the ANOVAs for both the stories and the tones were analyzed for a band x condition x hemisphere x group interaction. The interaction however was not significant for either the presentation of the stories of the tones. The data were also analyzed on an individual band basis to investigate a possible condition x hemisphere x group interaction. There were no significant findings for this interaction in the alpha, beta or 40Hz band analysis. These non-significant findings suggest that the control group and the experimental group did not show significantly different patterns of hemispheric activation in response to the task. In addition to the mixed reports of many researchers regarding the difficulty of localizing cortical activity using EEG (Cook et al., 1998) there are a number of possible explanations as to the lack of significant asymmetries in the present analysis: 1) the small sample size may not have made possible detection of actual differences in laterality between the two groups (power for the story trials = .138, for the tone trials = .154), 2) the current procedures may not have been sensitive or difficult enough to detect or produce hemispheric activation differences.

3.7.4 Question 4: Were there other significant findings?

The 2 group x 2 presentation x 3 band x 2 condition x 2 hemisphere mixed model ANOVA for tones revealed a significant tone by condition by hemisphere interaction. Post hoc analysis of this interaction revealed that during the presentation of the second tone trial there was an attenuation of relative power in the LH in response to the task. The present experiment is interested in differences in cortical activation between two groups (control and DS). Although significant, this finding was not informative as the values are collapsed across both groups and bands and as a result it was not possible to find the effect that group or band had on this interaction.

The analysis of the tone trials also revealed two other significant findings: tone by band and tone by band by hemisphere. Because both of these effects involved an interaction with band, it was possible to further investigate them using the separate band analysis.

Separate band Analysis - Stories

Alpha and Beta: Results of the separate band analysis for the story trials revealed a significant story (presentation order) main effect for both the alpha $F(1,11)=6.810$, $p=.0243$ and beta $F(1,11)=8.307$, $p=.0149$ bands. Results were such that there existed significantly greater alpha band relative power during the presentation of the first story than during the presentation of the second story. The beta band results showed significantly greater beta band relative power occurring during the presentation of the second story. These findings although significant were not informative as the relative power had been collapsed across a number of factors (hemisphere, control/task condition, group) and as a result it was not possible to see where this discrepancy was taking place. As there was no significant finding of story interacting with another factor, we cannot determine definitively the nature of these significant findings.

Alpha: Analysis of the alpha band alone during the presentation of stories revealed a significant hemisphere x group interaction $F(1,11)=5.202$, $p=.0435$. Post hoc analysis of this effect found that there was a significant difference between the two hemispheres for the control group but not for the participants with DS. This difference was in the direction that there was significantly greater alpha band relative power in the RH than the LH for the control participants. Although significant, these findings were not very informative as they were collapsed across the control and task conditions, thus masking any of the task effects that may be contributing to the values.

Beta: Analysis of the beta band for the story trials revealed a significant condition by hemisphere interaction $F(1,11)=5.611$, $p=.0372$. Post hoc analysis (NK) revealed that there was significant beta enhancement in the LH but not in the RH. It was also found that there existed significantly greater relative power in the LH than the RH during the task, but no significant difference between the LH and the RH during the control portion of the story trials (Figure 17).

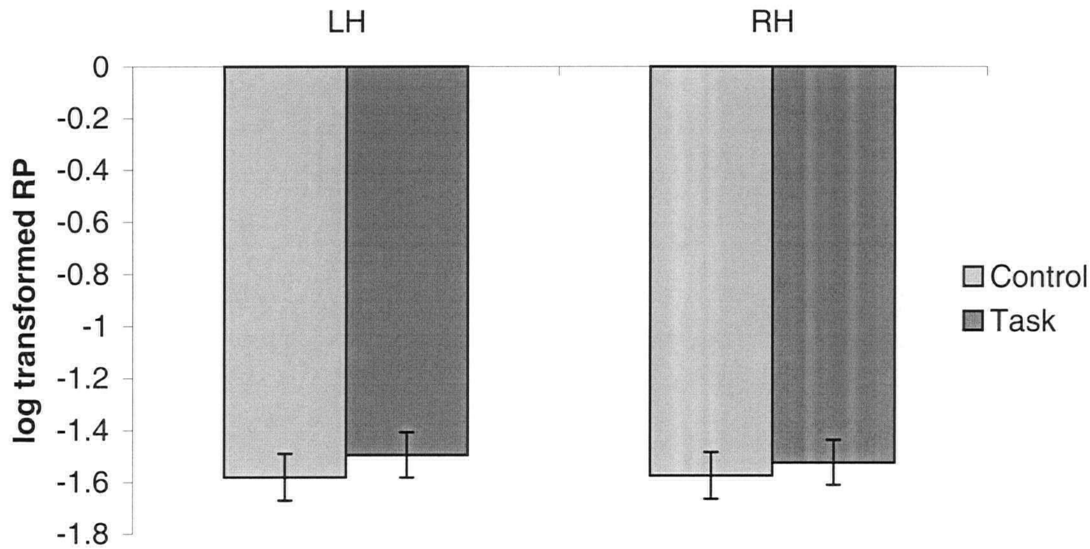

Figure 17 – The relative power (log transformed) of the condition by hemisphere interaction for the beta band during the presentation of stories. Note: LH = left hemisphere, RH = right hemisphere.

These results suggest that there was greater beta enhancement in the LH than the RH during the presentation of the stories. Although significant, it is important to note that these results are averaged across groups and therefore, it can not be known what the influence of each group was on the overall hemisphere by condition findings.

Separate Band Analysis - Tones

Alpha: Analysis of the alpha band alone during the presentation of the tone trials resulted in a significant tone x condition x hemisphere x group interaction $F(1,10)=5.037$, $p=.0486$. Post hoc analysis of this interaction revealed a number of significant findings (Figure 18). The control group displayed significant alpha attenuation in only the RH during the second tone presentation. Alpha attenuation in the RH in response to task for the control population suggests that control participants were processing the tone stimuli in the RH. Because most of these findings for the control group were not significant, it is possible that the tone trials were not difficult or engaging enough as to cause significant alpha attenuation in the control population.

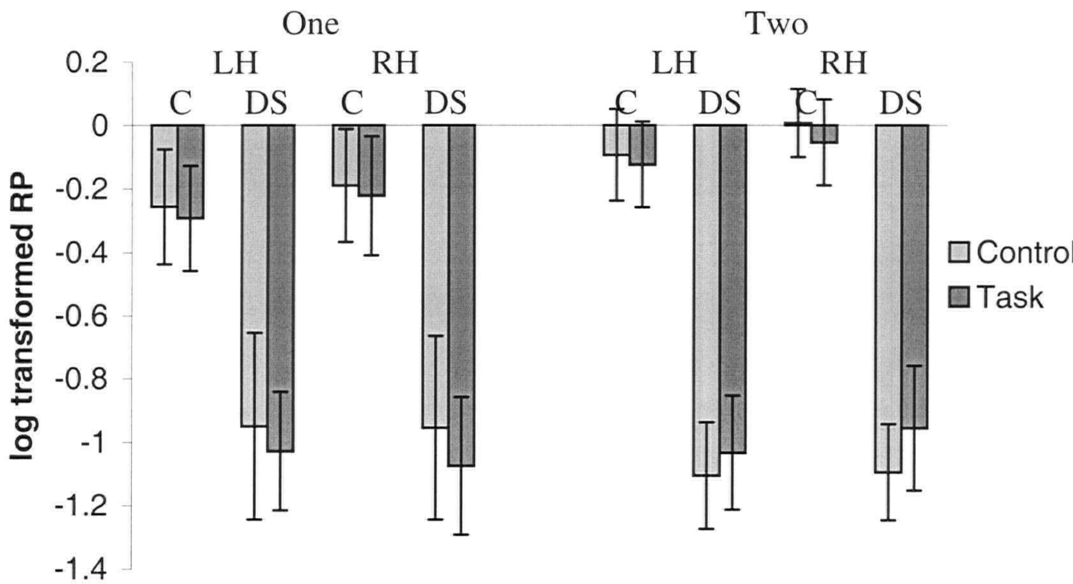

Figure 18 – The relative power (log transformed) of the tone (presentation order) by condition by hemisphere by group interaction for alpha band during the presentation of the tone trials. Note: One = first tone presentation, Two = second tone presentation; LH = left hemisphere, RH = right hemisphere; C = control participants, DS = participants with DS; Control = control/silent condition, Task = tone presentation condition.

The participants with DS displayed significant findings across both hemispheres and during the presentation of both tones. During the presentation of the first tone trial, the participants with DS displayed significant alpha attenuation in both the right and the left hemispheres. These results are in agreement with previous research that suggests alpha attenuation in response to cognitive engagement. During the second tone presentation however, the participants with DS displayed significant findings in the opposite direction. During the presentation of the second tone trials the participants with DS exhibited a significant alpha enhancement in response to the task. These findings are in disagreement with previous research and the first tone trial, which suggests that there is alpha attenuation in response to cognitive effort. These seemingly contradictory results may be a result of the lower levels of baseline alpha relative power for the participants with DS during the control portion of the second tone trial. It can be seen (Figure 18) that there existed a large decrease in baseline alpha band relative power from tone one to tone two in both the RH and the LH. This difference in alpha band relative power for the participants with DS during the second tone presentation could be a result of different motivational states on the part of the participants during the testing procedure.

Beta: Analysis of the beta band for the tone trials revealed a significant tone by condition by group interaction $F(1,10)=9.290$, $p=.0123$. Post hoc analysis (NK) revealed significant beta attenuation in response to the task during tone two in the group of participants with DS (Figure 19).

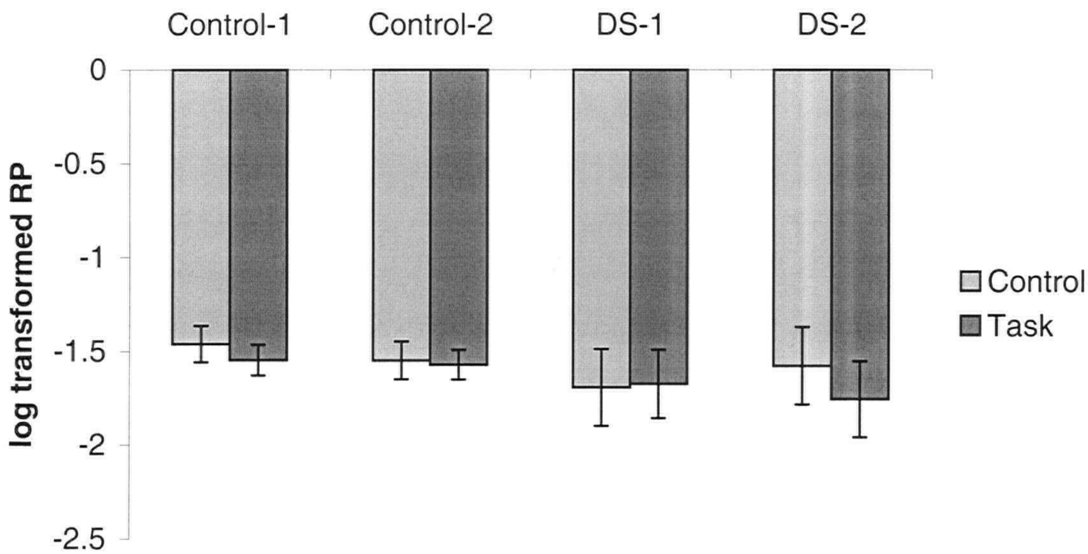

Figure 19 – The relative power (log transformed) of the tone by condition by group interaction for the beta band during the presentation of tones. Note: Control-1 = first tone trial for control participants; DS-2 = second tone trial by DS participants.

These results appear to be contradictory to previous research and the story trials of the present experiment, which show beta enhancement in response to cognitive effort. It is likely the case however, that the task required of the participants during the tone trials was not challenging or engaging enough. As a result the task of listening to a series of tones may have had an effect that is opposite to the desired effect, in essence the tone task may have produced a state of relaxation in the participants. This state of relaxation may account for the beta attenuation seen during the tone trials.

Interim Summary

The results of this final section of analysis showed a number of significant results. However, most of the results were non-informative, as the data were collapsed across factors that were important to the interpretation of the data.

3.8 General Summary

The analysis of Experiment One data revealed a number of interesting results. Previous research has shown alpha attenuation and beta and 40Hz enhancement in response to a task (Krause et al., 1998; Makino et al., 1985; Pulvermüller et al., 1995; Pulvermüller et al., 1997). Research also suggests that persons with DS are RH dominant for language perception (eg. Elliott, Weeks et al., 1987). Taken together, it was hypothesized that the two groups involved in the present experiment would display a different pattern of lateral activation in response to the language task. It was further hypothesized that the participants with DS would show asymmetries in cortical activation indicative of RH activation and the control participants would show asymmetries in cortical activation indicative of LH activation in response to the language task.

Results of the present experiment indicated that there was cortical engagement during the story trials for both the control and DS participants. This was seen as a condition main effect whereby there was both alpha attenuation and beta enhancement in response to the auditory language stimuli. Despite this condition main effect the present experiment was unable to localize the cortical activation pattern to the RH for the participants with DS and the LH of the control participants.

In addition to alpha and 40Hz responses to cortical activation and cognitive effort, there has been extensive research performed recently investigating the effects of cognitive activity on the lower frequency wave bands. Wolgang Klimesch and his colleagues have performed a number of studies that have lead them to suggest that both alpha and theta bands are accurate indicators of cognitive activity, but with opposite activation patterns (Doppelmayr, Klimesch, Schwaiger, Auinger & Winkler, 1998; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Schwaiger at al., 2001; Röhm et al., 2001). They go further to suggest theta enhancement is indicative of the process of encoding new information, while alpha attenuation is indicative of search and retrieval processes in long term memory. As a result, theta band was investigated in Experiment Two as an additional means of assessing lateralization of language processing.

The present experiment was unable to provide support of differential lateralization for auditory language processing in persons with DS and controls for either the alpha, beta or 40Hz bands. However, results of the present experiment did reveal a number of trends in the data whose directions were consistent with predictions of the dissociation model of DS (Elliott, Weeks et al., 1987). There are a number of possible explanations that can be proposed for the lack of statistically significant findings. These include: small sample size resulting in low statistical power, task difficulty, and the selection of the frequency bands. Results of the present experiment suggest that further research, using a larger sample size, tasks modified for difficulty between groups, and a different selection of frequency bands, is warranted in order to determine the significance of the trends in the data found in the present experiment.

4.0 EXPERIMENT TWO

4.1 Purpose

The purpose of Experiment 2 was to examine cortical activity occurring in persons with DS during a reading task (visual perception of language). Cortical activity, during the reading task, was monitored through the use of a continuous EEG recording.

4.2 Participants

There were 12 participants composing two groups of 6 in the present experiment. One of the participants with DS from Experiment One chose not to participate in the present experiment. Two of the control participants who took part in the previous experiment did not participate in the present experiment. With these exceptions, the same participants who took part in the test batteries and Experiment One formed the participant pool for the present experiment.

4.3 Apparatus

4.3.1 Stimulus Presentation

The visual stimuli were pre-recorded on a computer, using Microsoft PowerPoint, and played back to the participants on a computer monitor. The stimuli were presented as white stimuli on a black background. The story (reading) stimuli consisted of the presentation of one word at a time appearing in the center of a computer monitor. The stimuli used for the story trials were simple stories which were at a level that was appropriate for the participants. Different stories were used for the control and DS participants. The control condition involved the presentation of nonsense shapes, ranging from four to eight sides (Figure 20). The control stimuli were white outlines of shapes with a few (6,8 for control group and 2,4 for the DS group) of the shapes filled in gray. The nonsense shapes were selected to be as unfamiliar and meaningless as possible to discourage verbal labeling by the participants. No shape was the spatial reversal of another shape. The same shapes were used as stimuli for both the control and DS groups.

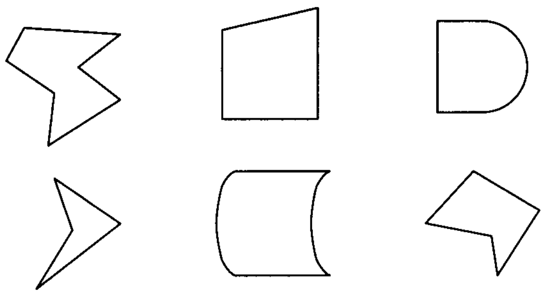

Figure 20 - Sample of the nonsense shapes used as the control task for Experiment Two

4.3.2 EEG Recording

The EEG set-up was the same as the set up from Experiment One. Again, the data were recorded for later off-line analysis. The data from one trial were collected in one continuous (five and a half minute) file.

4.4 Procedures

Participants were seated in a comfortable "dentist" chair and fitted with the appropriate size electrode cap (Easy Cap – Falk Minow Services). The computer monitor, which presented the stimuli, was positioned 282cm in front of the participants. The visual stimuli were on average 15cm wide by 6cm high. The reading trials consisted of one word appearing at a time in the center of the computer monitor thus forming a story. The rate of presentation of the visual stimuli was modified between the two groups in order to ensure adequate time for the participants to comprehend the stimuli (118ms/slide in the control group conditions and 659ms/slide in the DS group conditions). The visually presented stimuli were generally shown with no inter-stimulus interval; however interstimulus intervals (blank screens) were presented at the end of sentences (236ms for both control and DS groups) to clarify the flow of the reading task. The duration of presentation was selected so as to be sufficient for stimulus perception by all participants (see Papanicolaou et al., 1999). A story trial consisted of a one and a half-minute visually-silent period, followed by a two and a half-minute story (reading) and then another one and a half-minute silent period. The control trial consisted of a one and a half-minute silent period followed by a two and a half-minute period of visual presentation of nonsense shapes. Following the nonsense shapes there was again a one and a half-minute silent period (Figure 21). There were 2 different story trials and 2 control (nonsense shapes) trials. The order of the trials was randomized across the participants while maintaining a reciprocating reading/shape or shape/reading presentation pattern.

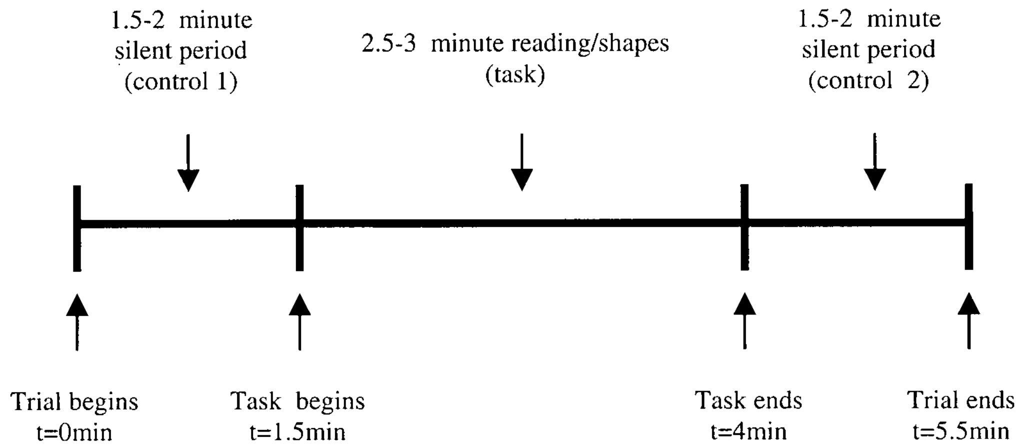

Figure 21 – Template for Trials for Experiment Two

The set-up of the trials was explained to the participants prior to beginning the experiment. Participants were asked to remain relaxed with their eyes fixed on the center of the computer monitor, while trying to limit blinking and eye movements as much as possible, throughout the course of a trial. Following each of the story trials, participants were asked a few questions about the story to ensure they were attending to the story. Following each of the control trials participants were asked to report the number of shapes that were filled in to ensure they were concentrating on the task.

4.5 Analysis

The data from this experiment were reduced and analyzed in much the same manner as the data from Experiment One. However, based on the results of Experiment One and some further research (Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Schwaiger et al., 2001; Locatelli et al., 1996; Röhm et al., 2001), the EEG bands analyzed in the present experiment were alpha (8-13 Hz), beta (14-30 Hz) and theta (4-8 Hz). The same analysis techniques as were used in Experiment One were carried out focusing on the alpha, beta and theta bands.

4.6 Hypothesis

Based on previous research interested in visual language processing in persons with DS (Elliott et al., 1995; Weeks et al., 1995) and the functional dissociation model of DS (Elliott, Weeks et al., 1987), it was anticipated that the cerebral activation pattern of persons with DS would differ from the non-DS group. The DS group was expected to show more cerebral activity associated with cognitive processes in the right hemisphere during the reading task as compared to the control participants. The DS group was hypothesized to display EEG changes associated with cognitive activity, decrease in alpha power and an increase in theta power, to a greater extent in the RH as compared to the control group.

4.7 Results and Discussion

Similar to Experiment One, the analysis of Experiment Two was performed in a step-wise manner in order to answer a number of important questions and test the hypothesized results of the experiment. Prior to testing the hypothesis however, there were a number of preliminary analyses that were conducted in order to provide an initial assessment of the data. The data were analyzed in order to assess whether the data collected during the present experiment demonstrated the typical patterns of cortical engagement reported in the EEG literature. Following this initial assessment the data were subjected to analysis to address specific questions or hypotheses of the experiments. The primary analysis involved a 2 Group (control and DS) x 2 Presentation (either story 1 and 2 or shape 1 and 2) x 3 Band (alpha, beta, and theta) x 2 Condition (control and task) x 2 Hemisphere (LH and RH) mixed model ANOVA with RM on the final four factors.

4.7.1 Question 1: Do the data display typical characteristics of EEG data?

The data were analyzed to ensure that the data collected during this experiment were in accordance with data collected in past reserach. This was assessed based on looking for patterns in the EEG data that are typical of base-line and task data from prior experiments reported in the literature. Alpha power is known to be attenuated in response to an eyes-open condition, as compared to an eyes-closed condition. Because the present experiment employed a procedure in which the participants' eyes remained opened it was not possible to compare the alpha band relative powers attained in the present experiment with normative values. As a result, the typical patterns that were specifically examined for the present experiment involved normative values of the beta and theta bands and expected differences between the control group and the participants with DS.

Relative powers of band frequencies:

As previously mentioned, it has been possible to develop "norms" tables for relative powers of the different band frequencies in the general population. It is generally accepted that in the eyes-closed and relaxed state that the alpha rhythm predominates brain activity and is most prominent in the occipital and parietal regions of the brain. It is also generally accepted that there is significant alpha attenuation in response to an eyes-open-condition as compared to an eyes-closed condition. Because EEG normative tables tend to be calculated for an eyes-closed and relaxed condition it is not possible to compare the normative alpha band powers to alpha band powers attained during an eyes-open condition. As a result, for the present experiment it is only feasible to compare the beta and theta bands with the normative values.

The beta band data collected during the control portion (relaxed body state with eyes-open and fixed) of the present experiment were compared to the normative measures of beta relative power (Senf, 1988). The normative measures used are based on an eyes-closed, relaxed, awake EEG recording of a 35-year old person. The results of the present experiment, when compared to a "norms" table of a 35-year-old participant, show that both the control and DS groups displayed beta relative power values similar to those of the 35-year-old norm values (Figure 22).

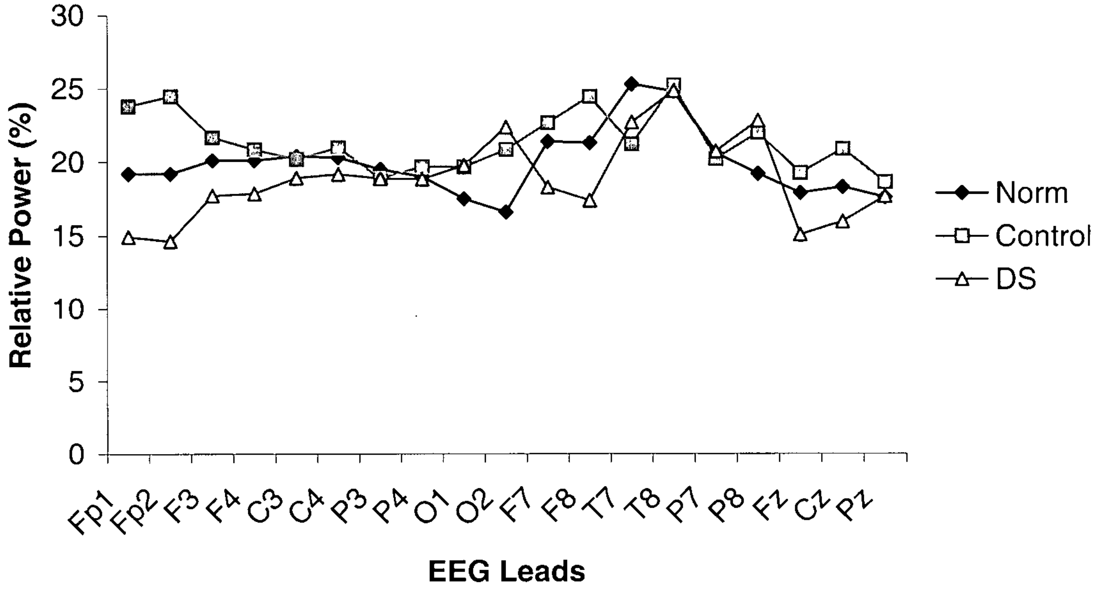

Figure 22 – The relative power of the beta band at the different electroencephalographic leads. The results of the control and DS populations during an eyes-open and relaxed condition are shown along with the norm values relating to a 35-year-old participant during an eyes-closed and relaxed condition.

Figure 22 shows that the expected pattern of beta band relative power distribution is seen in both the control and DS participants. It is also evident that the control participants tend to have a slightly higher beta band relative power in comparison to the participants with DS.

The theta band data collected during the control portion (relaxed body state with eyes-open) of the present experiment were compared to the norm values of theta relative power (Senf, 1988). The results of the present experiment when compared to the "norms" table of a 35-year-old participant, during an eyes-closed and relaxed condition, showed that the control group displayed relative power values similar to the expected values. Figure 23 shows that both of the groups in the present experiment displayed theta band relative power values higher than the normative values.

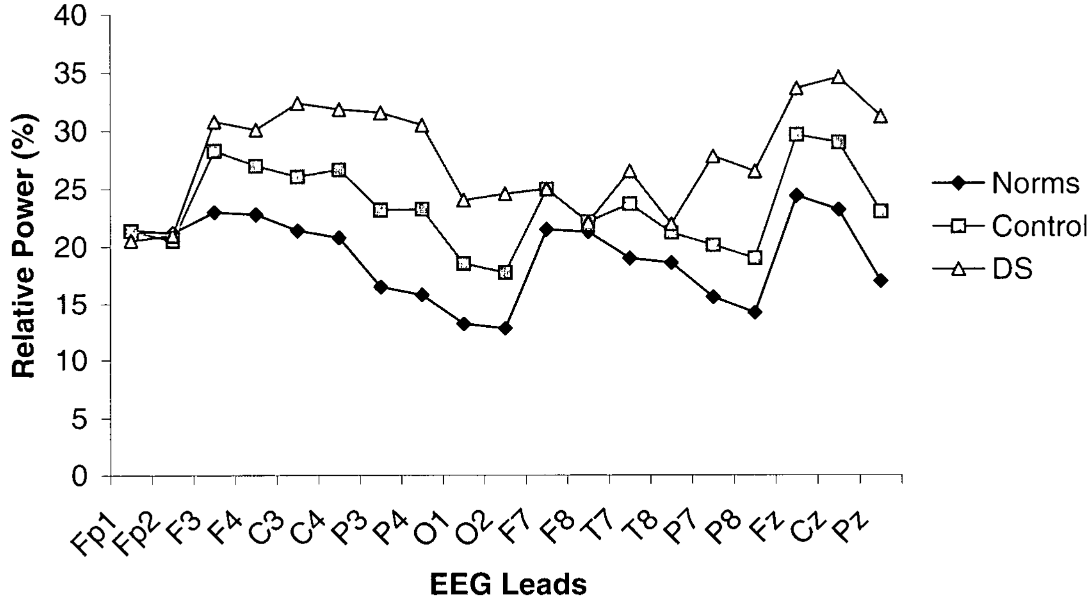

Figure 23 – The relative power of the theta band at the different electroencephalographic leads. The results of the control and DS populations during an eyes-open and relaxed condition are shown along with the norm values relating to a 35-year-old participant during an eyes-closed and relaxed condition.

It is evident from Figure 18 that the control participants displayed theta band relative power values that were closer to the normative values than did the participants with DS, who displayed theta band relative power values that were greater than both the normative and control participant values. Both the control and DS groups displaying theta band relative power values higher than the normative values could be a result of the eyes-open condition, which was employed in the present experiment. It is important to remember that the normative values used in this analysis are based on an eyes-closed condition. Research has suggested that cognitive activity and attention result in alpha attenuation and theta enhancement (Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Klimesch, Doppelmayr, Wimmer, Schwaiger et al., 2001; Locatelli et al., 1996; Röhm et al., 2001). As a result, it seems reasonable to expect that during an eyes-open condition there would be higher values for theta band relative power as was found in the present experiment.

Group Differences

Previous research suggests that there are some common differences in the EEG patterns displayed by a control population and a population with Down syndrome. These studies have shown that there exists, in persons with DS, a decrease in alpha band power and an increase in slow wave band powers (delta and theta) as compared to control populations (Locatelli et al., 1996; Schmid et al., 1992).

The concordance of the data from the present experiment with previous experimental data regarding group differences was investigated by looking at the band x group interaction. Analysis revealed a significant band x group interaction for both the story $F(2,20)=8.347$, $p=.0023$ and the shape $F(2,20)=10.898$, $p=.0006$ trials.

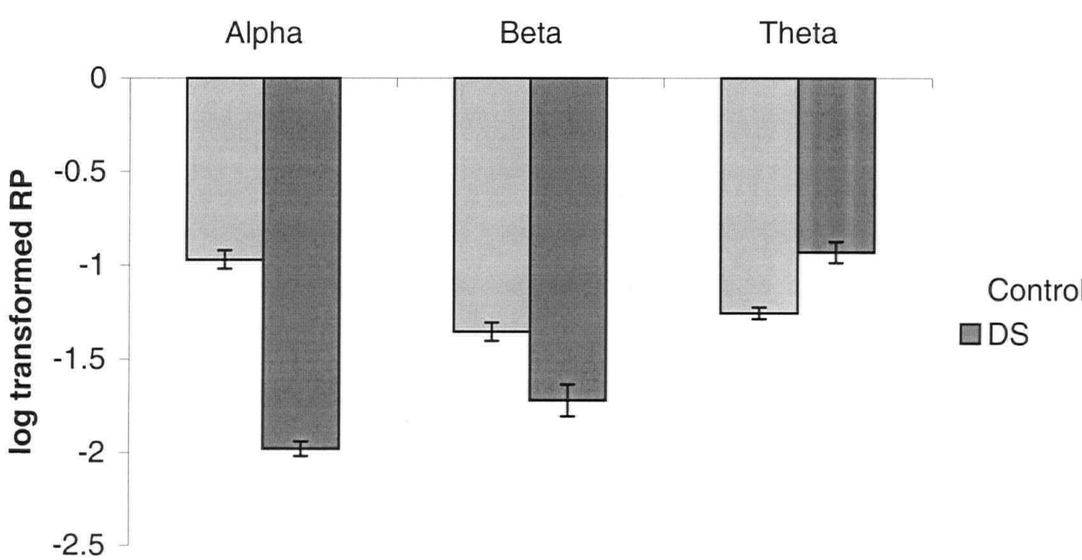

Figure 24 – The band x group interaction during the story trials. The control group displayed significantly greater relative power in the alpha band than did the participants with DS.

Post hoc analysis (NK) of the story trials revealed that the control participants displayed significantly greater alpha band relative power than the participants with DS (Figure 24). Although not significant there was also a trend towards the participants with DS displaying greater relative power in the theta band than the control group.

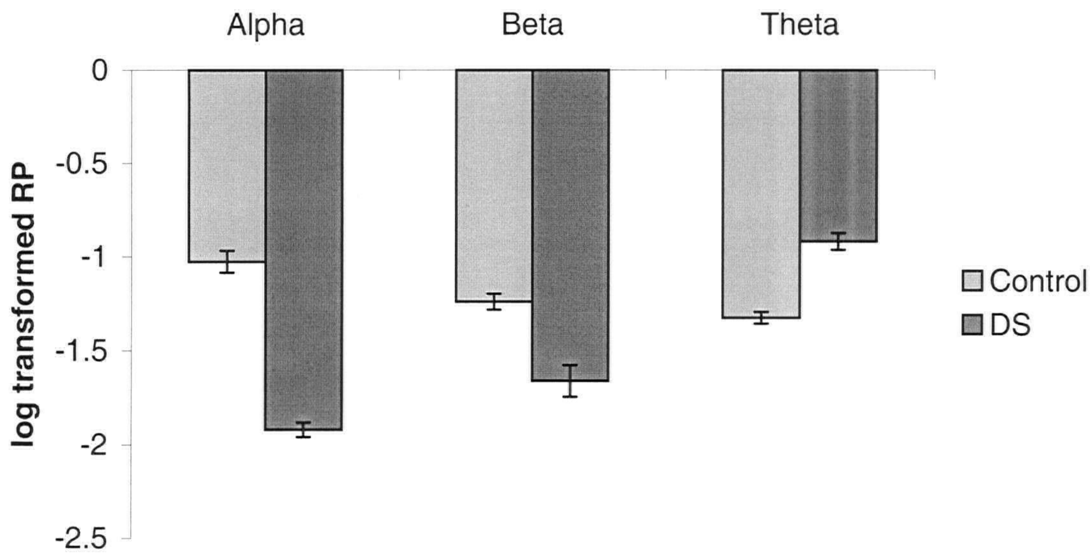

Figure 25 – The band x group interaction for the shape trials. The control participants displayed significantly greater relative power in the alpha band than the participants with DS.

Like the story trials, post hoc analysis (NK) of the shape trials revealed that the control participants had significantly greater relative power in the alpha band than did the participants with DS (Figure 25). Although not significant, a trend can be seen for the participants with DS having greater relative power in the theta band than the control participants.

The results of both the story and shape trials are in agreement with previous research, which has shown that the population with DS displays significantly, reduced power in the alpha band (Locatelli et al., 1996). Although not significant, the trends are also consistent with previous research, which has shown that the DS population is characterized by increased power in the theta band, in relation to a control population.

Separate Band Analysis

In order to examine further the data, additional analyses were performed in order to isolate effects within specific bands. This analysis method was based on a 2 Group (control, DS) x 2 Presentation (either story 1, story 2 or shape 1, shape 2) x 2 Condition (control, task) x 2 Hemisphere (LH, RH) ANOVA with RM on the last 3 factors. A separate ANOVA was run for each band (alpha, beta, theta) and for both the story and shape trials.

Alpha: In agreement with the initial analysis, analysis of the alpha band separately revealed a significant group main effect for both the story $F(1,10)=45.783$, $p<.0001$ and shape $F(1,10)=22.591$, $p=.0008$ trials. The control participants displayed significantly greater alpha band relative power than the participants with DS during both the story and shape trials. Both of these significant findings are in agreement with research (Katada et al., 2000; Locatelli, 1996), which has shown that the DS population is characterized by a decrease in alpha band relative power.

Beta: There has been no previous research to suggest that persons with DS display atypical patterns of beta band activation. Separate beta band analysis for the present experiment revealed no significant group main effect for the beta band. The finding of no significant differences between relative beta power in the control and DS population suggests that the control and DS populations do not differ overall in their base-line levels of beta band relative power.

Theta: The primary analysis revealed a trend towards the participants with DS displaying greater relative power in the theta band in comparison to the control group. Separate band analysis of the theta band revealed effects that were not found in the initial analysis. The separate band analysis revealed a significant group main effect for the theta band during the presentation of the shape trials $F(1,10)=9.304$, $p=.0122$. Although not significant, analysis of the theta band during the presentation of the story trials revealed a trend $F(1,10)=3.457$, $p=.0926$. The lack of significance in this analysis may be caused in part by the low power (.379) associated with the effect. The significant findings for the shape trials and the trend for the story trials are both in the direction of the participants with DS displaying greater relative power in the theta band than did the control participants. These findings are in agreement with previous research (Locatelli, 1996), which suggests an increase in theta band relative power in the DS population.

Interim summary

The results of the initial analysis are in agreement with previous research. This analysis revealed that the relative power values for the beta and theta band are similar to the expected normative values. The distinguishing characteristics of the DS group's EEG patterns (Katada et al., 2000; Locatelli et al., 1996; Schmid et al., 1992), as found in previous research (i.e. increased alpha and decreased theta band relative power in persons with DS), was found to be supported by the data collected from the present experiment.

4.7.2 Question 2: Do task conditions have an effect on relative power?

As mentioned previously, past research has shown that there exist stereotypical shifts in power and frequency of brain activity in response to cognitive effort. There is extensive research that shows that cognitive effort and activity result in a decrease in alpha band relative power and an increase in both slow wave (delta and theta) as well as beta band relative powers (Birch, 1997; Bizas et al., 1999; Klimesch, 1999; Shaw, 1996).

In order to investigate the task effect on the baseline relative power values, the aforementioned primary ANOVAs were analyzed for a band x condition interaction. In addition to the primary analysis, the separate band analysis ANOVAs were analyzed for a condition main effect.

In agreement with previous research, the ANOVA for stories revealed a significant band x condition interaction $F(2,20)=5.066$, $p=0.0166$. Post hoc analysis (NK) of this interaction, revealed significant alpha attenuation in response to the task. Although not significant it can be seen that there was also a trend of beta attenuation and theta enhancement in response to the task (Figure 26).

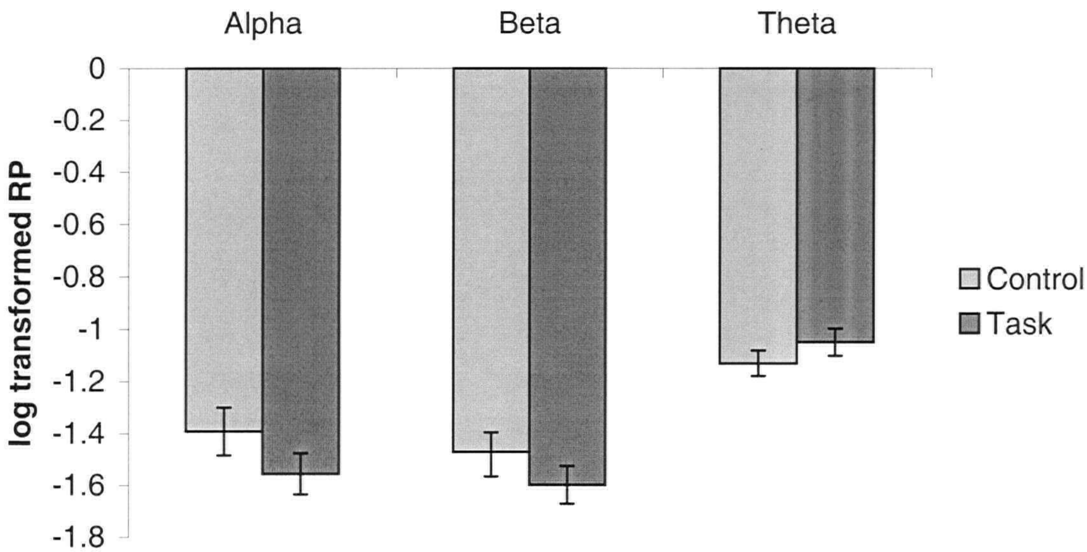

Figure 26 – The band by condition interaction during the story trials. In addition to the significant alpha attenuation, there was a trend towards beta attenuation and theta enhancement in response to the stories.

The results of the shape trials ANOVA revealed no significant interactions. Results of the shape trials, although not significant, showed trends in the same direction for all the analyzed bands as were found for the story trials.

<u>Separate Band Analysis</u>

Alpha: Analysis of the alpha band revealed a significant condition main effect for the presentation of the story trials $F(1,10)=6.969$, $p=.0247$. In support of the primary analysis and previous research (Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Röhm et al., 2001), this main effect revealed significant alpha attenuation in response to the presentation of the story trials. The condition main effect for the presentation of the shapes was not significant; however it did display a trend toward alpha attenuation in response to the shape presentations $F(1,10)=3.806$, $p=.0796$.

<u>Beta:</u> A condition main effect $F(1,10)=12.368$, $p=.0056$ was found for the presentation of the story trials when the beta band was analyzed separately. This main

effect revealed significant beta attenuation in response to the presentation of the stories. The presentation of the shapes produced no significant condition main effect.

Theta: There were no condition main effects found for either the presentation of the story or shape trials. However, for both the story and shape trials, there was a trend towards theta enhancement in response to the task.

Interim Summary

The results of the analysis investigating task effects on the relative power were in partial agreement of previous research. The results of significant alpha attenuation in response to the reading (story) task were expected and in support of previous research which has shown alpha attenuation in response to cognitive activity. The results indicating significant beta attenuation in response to the reading task are contradictory to previous research, which has shown beta enhancement in response to cognitive activity. The lack of significance in the theta band is also in contradiction to previous research, which has shown theta enhancement in response to tasks requiring cognitive and memory processes. Recently Klimesch (1999) has suggested that frequency bands should be calculated separately for each participant. We employed standard frequency ranges across all individuals. As a result of having not calculated individual frequency bands for each participant it may be the case that for some of the participants the beta band used in the analysis was actually measuring some of their upper alpha band, thus showing attenuation in response to the task. It may also be the case that some participants' alpha band is lower than the range used and thus the theta band may have captured some of the lower alpha band, thus masking theta enhancement. The lack of significance in response to the shape task could be a result of the task being too easy and therefore not engaging enough for some or all of the participants as to require significant cognitive or memory processes.

4.7.3 Question 3: Were there task-related hemispheric differences that differed between the control and experimental groups?

Based on previous research, it was hypothesized that there would be specific group differences in laterality of activation occurring during the language task.

In order to investigate this effect with the current data, the primary ANOVAs for both the stories and the shapes were analyzed for a band x condition x hemisphere x group interaction. However, the interaction was not significant for either the presentation of the stories or the shapes.

Separate Band Analysis

The data were also analyzed on an individual band basis to investigate a possible condition x hemisphere x group interaction.

Alpha and Beta: For both the alpha and beta bands there were no significant findings for this interaction during the presentation of either the story or shape trials.

Theta: There was a significant condition x hemisphere x group interaction for the theta band during the presentation of the story trials $F(1,10)=5.344$, $p=.0434$. Post hoc analysis (NK) revealed that the participants with DS displayed significant theta enhancement in the RH and the control participants displayed significant theta enhancement in the LH in response to the reading task (Figure 27).

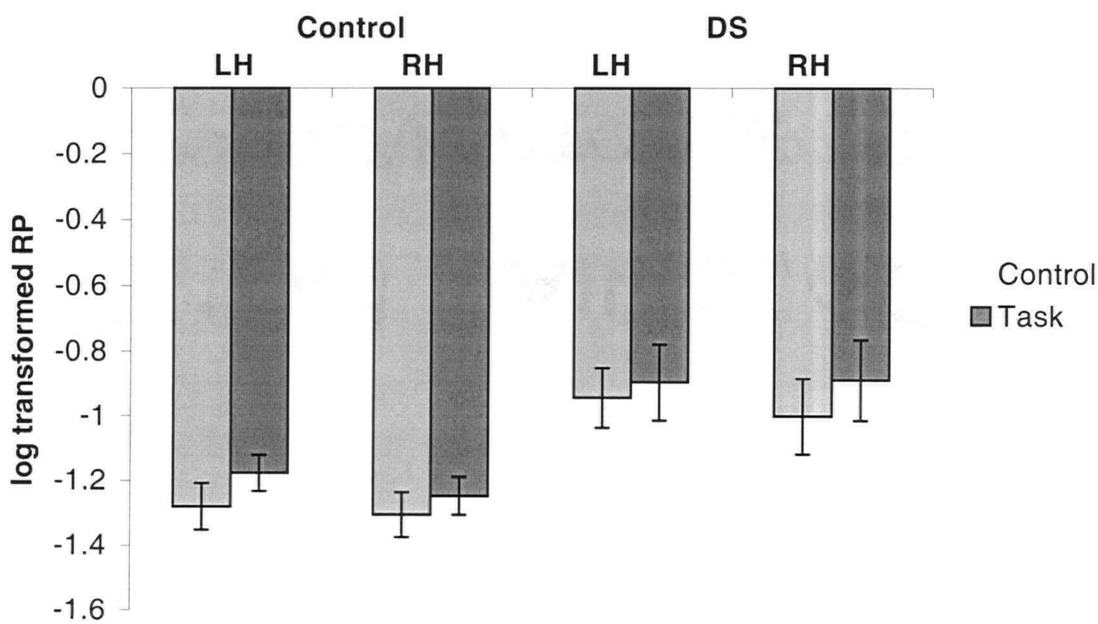

Figure 27 - The group by hemisphere by condition interaction for the theta band during the presentation of the story trials. The control participants displayed significant theta enhancement in response to the task in the LH and the participants with DS displayed significant theta enhancement in response to the task in the RH.

Assuming that theta enhancement reflects cognitive and working memory process, as has been previously reported (Klimesch, 1999), these findings would suggest that the RH of the participants with DS, and the LH of the control participants, was more engaged in response to the reading task. There were no significant findings for the presentation of the shapes.

Interim Summary

The results of the analyses within this section were primarily non-significant statistically. The absence of significant findings suggests that the control group and the experimental group did not show different patterns of hemispheric activation in response to the task. The significant findings for the different patterns of theta activation in response to the story trials was in a direction predicted by the functional dissociation model for persons with DS (Elliott, Weeks et al., 1987). The results of the theta band analysis suggest that the processing of the reading stimuli was performed primarily in the RH of the participants with DS and in the LH of the control participants. Taken together, the present findings suggest that the tasks involved in the present experiment may have been challenging enough as to elicit the theta enhancement effect but not challenging enough as to elicit different lateralization patterns of activation for the alpha or beta band in response to the language stimuli (cf. Bizas et al., 1999).

4.7.4 Question 4: Were there other significant findings?

The previously mentioned ANOVA's were analyzed in order to assess any additional significant results that were not predicted for the present experiment.

Group Differences

There was a significant group main effect for the presentation of both the story $F(1,10)=16.406$, $p=.0023$ and shape $F(1,10)=8.105$, $p=.0173$ trials. Results indicated that the participants with DS displayed significantly less relative power in the three bands investigated (alpha, beta and theta) than did the control participants. Conversely, this result also suggests that the participants with DS have greater relative power, than do the control participants, in frequency bands not investigated in the present experiment.

Band

Results indicated a significant band main effect during the presentation of both the story $F(2,20)=4.372$, $p=.0266$ and shape $F(2,20)=3.896$, $p=.0372$ trials. Post hoc analysis (NK) revealed that during the story trials there was significantly greater theta band power than either alpha or beta, which were not significantly different from each other. The results of the shape trials showed that there was significantly greater relative power in the theta band than in the beta band, but that neither of these bands was significantly different from the alpha band. These results are averaged across both condition and group and indicate that, in general, of the three bands investigated in the present experiment, the theta band was the dominant frequency band throughout the experimental trials.

Condition

A significant condition main effect was found for the presentation of the story trials $F(1,10)=13.119$, $p=.0047$. Post hoc analysis (NK) revealed that there was significantly greater relative power in the bands of interest (alpha, beta and theta) during the control portion of the trials than the task portion of the trials. This suggests that when collapsed across group, hemisphere and band, there was significant relative power attenuation in response to the reading task. Although this was a significant finding it was not informative for the purposes of the present experiment as it was collapsed across three bands, which have been reported to have different responses to the task portion of the trials.

Separate Band Analysis

Alpha: The presentation of the story trials resulted in a significant presentation order main effect $F(1,10)=6.949$, $p=.0249$ when the alpha band was analyzed independently of the other bands. The results indicate that there was significantly greater relative power in the alpha band during the presentation of the second story. For the shape trials, there was also a presentation order main effect for shapes $F(1,10)=18.110$, $p=.0017$. Again, there was significantly greater alpha band relative power during the presentation of the second shape trial. For both the story and shape there was significantly greater alpha band relative power during the second trial, as compared to the first trial. Because these findings are collapsed across both control and task conditions it was not possible to determine which of two possible explanations is most plausible. These results may reflect that the participants were nervous or anxious during the first trials and were able to relax after the opening trials resulting in a decreased alpha band relative power during the control portion of the initial trials. These results may also reflect greater engagement during the first presentation, resulting in decreased alpha band relative power during the task portion of the first presentations.

Beta and Theta: There were no additional significant findings for either the beta or theta bands when these bands were analyzed on an individual basis.

Interim Summary

The results of this final section of analysis showed a number of significant results. However, most of the results were non-informative, as the data have been collapsed across factors that were important to the interpretation of the data.

4.8 General Summary

The analysis of Experiment Two data has revealed a number of interesting results. Based on previous research that has shown alpha attenuation and theta and beta enhancement in response to a task (Bizas et al., 1999; Doppelmayr et al., 1998; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Klimesch, Doppelmayr, Wimmer, Schwaiger et al., 2001; Röhm et al., 2001), along with previous research suggesting that the population with DS is RH dominant for language perception while the general population is LH dominant for language perception (eg. Elliott et al., 1995; Elliott, Weeks et al., 1997; Weeks et al., 1995), it was hypothesized that the two groups involved in the present experiment would display a different pattern of lateral activation in response to the language task. It was further hypothesized that the participants with DS would show asymmetries in cortical engagement in the direction of the RH and the control participants would show asymmetries in cortical engagement in the direction of the LH in response to a language task.

In terms of alpha attenuation as a sign of cortical engagement, the results of the present experiment were not significant in showing the participants with DS to be RH dominant and the control group to be LH dominant during a language perception task. However, the results of the present experiment were in support of the hypothesis for the theta band, with the participants showing different lateralization patterns for theta enhancement in response to the task. It was found that the participants with DS showed significant theta enhancement in the RH, while the control participants showed significant theta enhancement in the LH during the reading task. Assuming, as suggested by previous research (eg. Klimesch, Dollepmayr, Wimmer, Schwaiger et al., 2001), that theta enhancement is a sign of cortical and working memory activation, analysis of the present experiment suggests that the participants with DS were RH dominant in the processing of the language stimuli and the control participants were LH dominant in the processing of the language stimuli. There were no results to indicate that the DS and control participants were differentially lateralized for the processing of the shape stimuli. This suggests that the DS and control groups may differ in their hemispheric dominance of language stimuli processing but not in their processing of spatial stimuli (c.f. Weeks et al., 1995; Weeks et al., 2002).

5.0 CROSS EXPERIMENTAL COMPARISONS

The present experiments were intended as a means of testing some of the prediction and seeking to extend the functional dissociation model of DS as proposed by Elliott, Weeks et al., (1987). Auditory language processing was assessed (Experiment One) for both control and DS participants using a tone discrimination task as a control. Visual language processing was investigated (Experiment Two) for both control and DS participants while using a visual shape discrimination task as a control. The present section was intended to investigate the results of both Experiments One and Two as well as the participant information data that was collected.

For the most part, the same participants were used in each of the test batteries and experiments allowing for the results from the experiments to be compared with each other (cf. Elliott & Weeks, 1993). It was expected that dichotic listening scores would show indications of a positive relation with RH involvement in both the auditory and visual language tasks, as measured using EEG. In addition, it was expected that participants would show a marked decrease in alpha relative power values during the eyes-open condition (Experiment Two) as compared to the eyes-closed condition (Experiment One).

5.1 Behavioural and Electroencephalographic Indices of Language Processing

Based on previous research, which suggests dichotic listening results can be used to infer laterality of language processing, it was expected that a right ear advantage (positive LI) would be associated with greater LH alpha attenuation as well as LH theta enhancement in response to the language task. The opposite was predicted for participants with a left ear advantage in the dichotic listening task; they were predicted to display greater alpha attenuation and theta enhancement in the RH.

The data were analyzed such that a negative LI from a dichotic listening test suggested a left ear (RH) advantage for the processing of linguistic stimuli (Equation 1). A RH advantage in the EEG alpha band assessment was suggested by a positive laterality of attenuation (Equation 3). Therefore, it was expected that the results of the present experiments would show a negative relation between dichotic LIs and laterality of alpha band attenuation for the language processing trials, as well as a positive correlation between dichotic LI and theta enhancement for the language stimuli.

The results of Experiment One for the control participants suggest that this group was predominantly LH lateralized for the processing of the language stimuli (story trials). For the control participants, language (story) trials in which alpha attenuation was observed, 10 of the 14 trials showed greater alpha band attenuation in the LH (Figure 28). When alpha attenuation was observed during the presentation of the tone trials, 6 of the 12 trials suggested RH processing of the tonal stimuli, while the other 6 suggested greater alpha attenuation in LH (Figure 28). These trends are in a direction which is in agreement with previous research indicating a LH lateralization for language processing and are inconclusive as to laterality of processing the tonal stimuli.

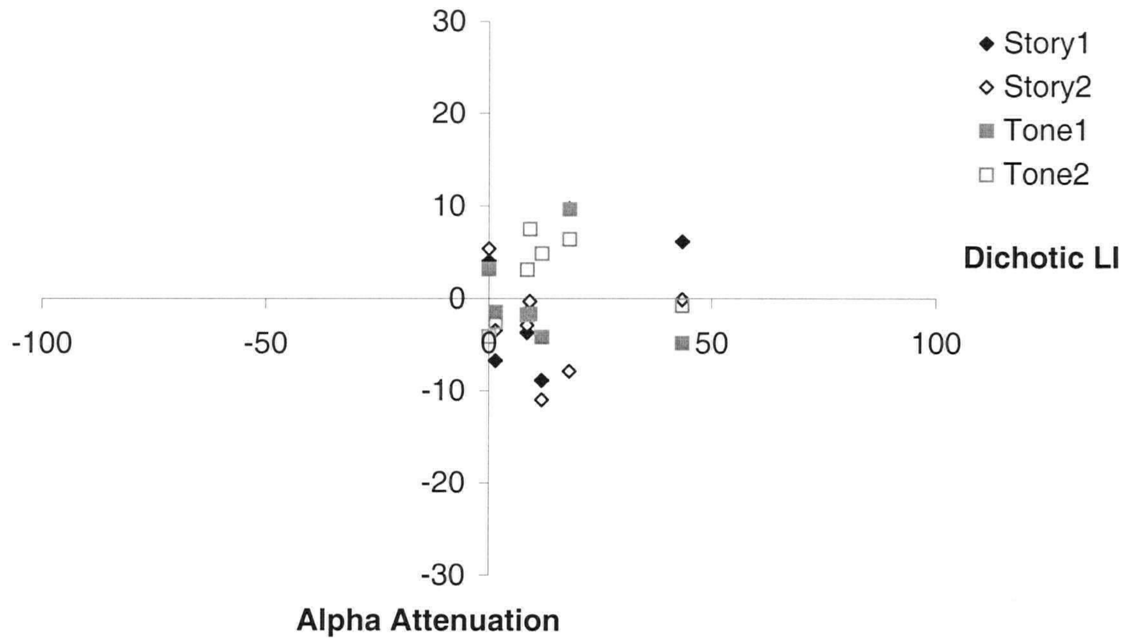

Figure 28 - The dichotic listening laterality indices versus the laterality of alpha attenuation for the control participants for all trials of Experiment One. The data plotted represents all trials in which the participants displayed alpha attenuation in at least one hemisphere. A positive dichotic LI (x-axis) is indicative of LH language processing and a negative alpha attenuation value (y-axis) indicates LH processing of the experimental stimuli.

The results of the dichotic listening task and alpha attenuation measure for the participants with DS were not as clear as for the control participants. Figure 29 displays the results of all the trials from participants with DS who displayed alpha attenuation in at least one hemisphere. In comparison with the control participants, it can be seen that the participants with DS were much more variable in their results. Despite the lack of consistency, 8 of the 11 story trials in which alpha attenuation was observed showed greater alpha attenuation in the RH than the LH. It can also be seen that for the tone trials 6 of the 11 trials suggested RH processing of the tone stimuli. The results of the story trials show trends that are in agreement with the functional dissociation model of DS (Elliott, Weeks et al., 1987).

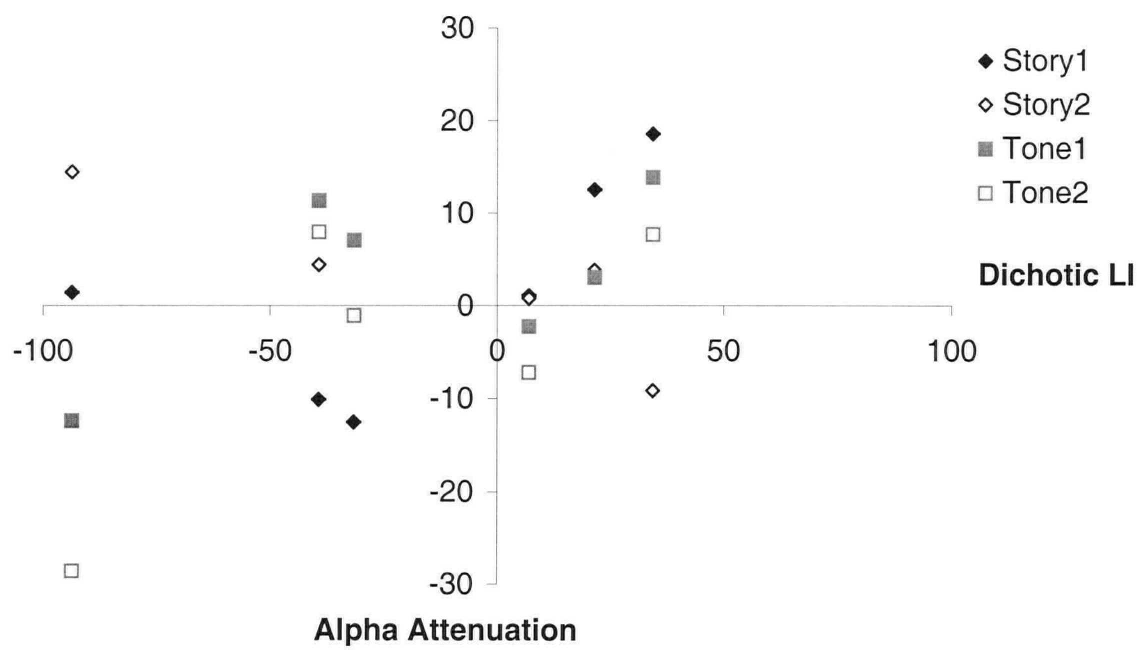

Figure 29 – The dichotic listening laterality indices versus the laterality of alpha attenuation for participants with DS for all trials of Experiment One. The data plotted represents all trials in which the participants displayed alpha attenuation in at least one hemisphere. A negative dichotic LI (x-axis) is indicative of RH language processing and a positive alpha attenuation value (y-axis) indicates RH processing of the test stimuli.

The results of Experiment One show some consistency with previous research. The observation that control participants displayed trends indicative of greater LH and the participants with DS displayed trends indicative of greater RH dominance for auditory language processing is consistent with the functional dissociation model of DS (Elliott, Weeks et al., 1987). The lack of a clear laterality dominance during the tone trials for the control participants is in contrast to the typical RH dominance seen in tonal discrimination tasks (Auzou et al., 1995). There is a lack of research in the area of tonal discrimination lateralization in the DS population. Therefore, it was taken to suggest that the participants with DS would not differ from the control participants in laterality of tonal processing (ie. they would display the typical RH dominance for the tonal discrimination task). Although the DS participants did not show a clear laterality for tonal processing, their pattern of tonal processing was similar to the control participants for Experiment One.

Experiment Two aimed to investigate visual language processing in both the DS and control populations using reading stimuli as the visual language processing task. Based on previous reading studies suggesting greater LH activation during reading (Bizas et al., 1999; Simos et al., 1998) for the general population, it was expected that there would be a negative relation between dichotic index values and laterality of alpha attenuation. Figure 30 shows the results for the control participants' data in which there was alpha attenuation in response to the task in at least one hemisphere. The results for Experiment Two can be seen to display less coherence than the results from Experiment One. The control participants' alpha band activity suggested greater LH engagement during the story (reading) trials during only 5 of the 11 trials that showed alpha attenuation in response to the task. For the shape trials, only 5 of the 9 trials displaying alpha attenuation were in the direction of greater alpha attenuation in the RH, as would be expected based on previous research of spatial processing (Elliott et al., 1995; Muller & Knight, 2002).

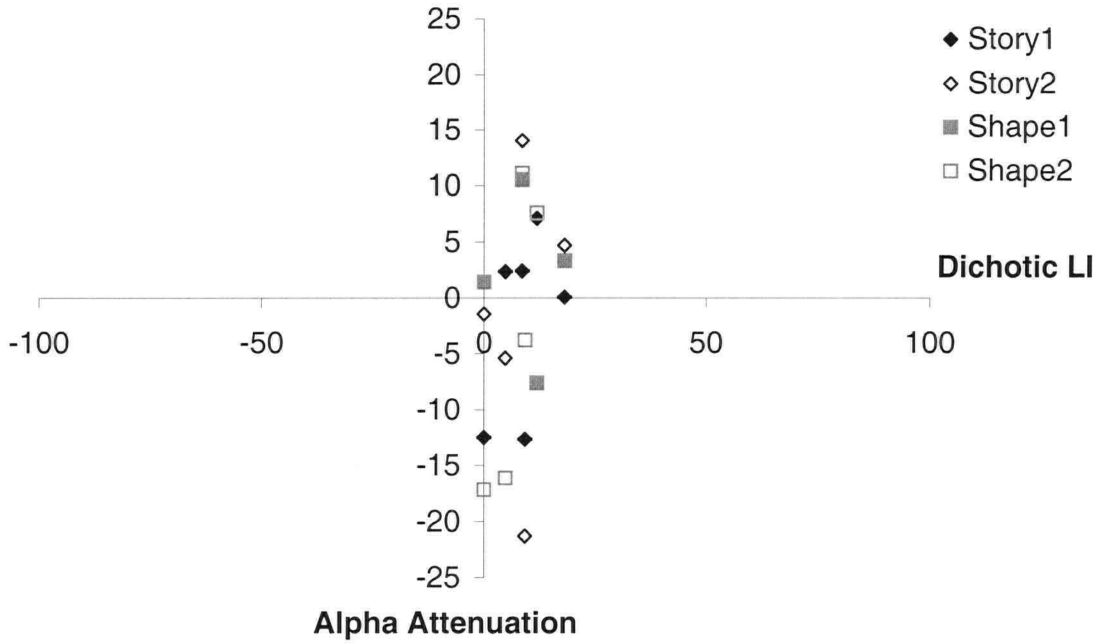

Figure 30 - The dichotic listening laterality indices versus the laterality of alpha attenuation for the Control participants for all trials for Experiment Two. The data plotted represents all trials in which the participants displayed alpha attenuation in at least one hemisphere. A positive dichotic score (x-axis) indicates LH language processing and a negative alpha attenuation value (y-axis) indicates LH processing of the test stimuli.

At first glance, the participants with DS again showed less consistency as a group than did the control participants, when both dichotic and laterality of alpha attenuation is investigated (Figure 31). However with closer inspection of Figure 31, it can be seen that for the reading trials in which the participants with DS displayed alpha attenuation, 7 of the 9 trials resulted in a trend in a direction indicative of RH processing. For the shape discrimination trials, 6 of 10 trials were in a direction suggesting RH processing of the stimuli. Although the shape trials results are largely inconclusive, the trends resulting from the readings trials are in agreement with the functional dissociation model for DS (Elliott, Weeks et al., 1987).

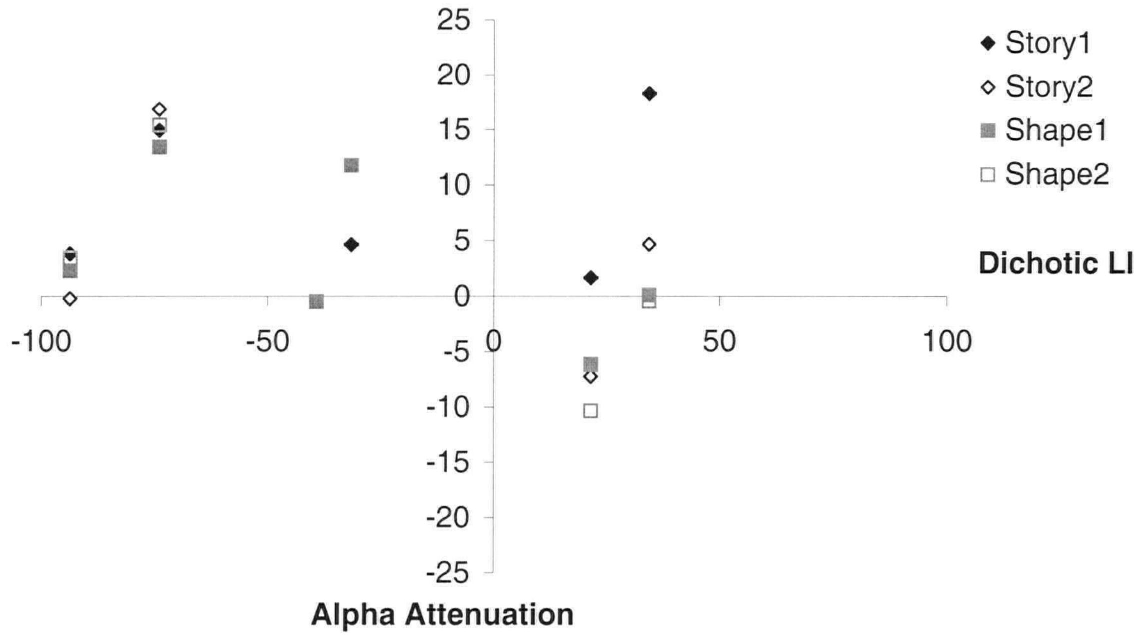

Figure 31 - The dichotic listening laterality indices versus the laterality of alpha attenuation for the DS participants for all trials of Experiment Two. The data plotted represents all trials in which the participants displayed alpha attenuation in at least one hemisphere. A negative dichotic score (x-axis) indicates RH language processing and a positive alpha attenuation value (y-axis) indicates RH processing of test stimuli.

Because of the promising results attained based on the theta band during Experiment Two, dichotic listening values were investigated further as a function of theta enhancement. Because theta enhancement is believed to reflect cognitive activity (Klimesch, 1999), it was expected that there would be a positive relation between dichotic listening results and laterality of theta enhancement (Equation 3). The results of the control and DS participants' trials demonstrating theta enhancement in at least one hemisphere are in Figure 32 and Figure 33 respectively.

The control participants' results are again fairly consistent. Figure 32 shows that there was a general shift from positive theta enhancement values during the story trials (suggesting LH language processing) towards negative theta enhancement values for the shape discrimination trials (suggesting RH processing of spatial processing). This trend is in a direction indicative of LH language processing (7 of 9 trials) and RH spatial processing (6 of 9) in the control population is in agreement with previous research (Elliott et al., 1995; Muller & Knight, 2002).

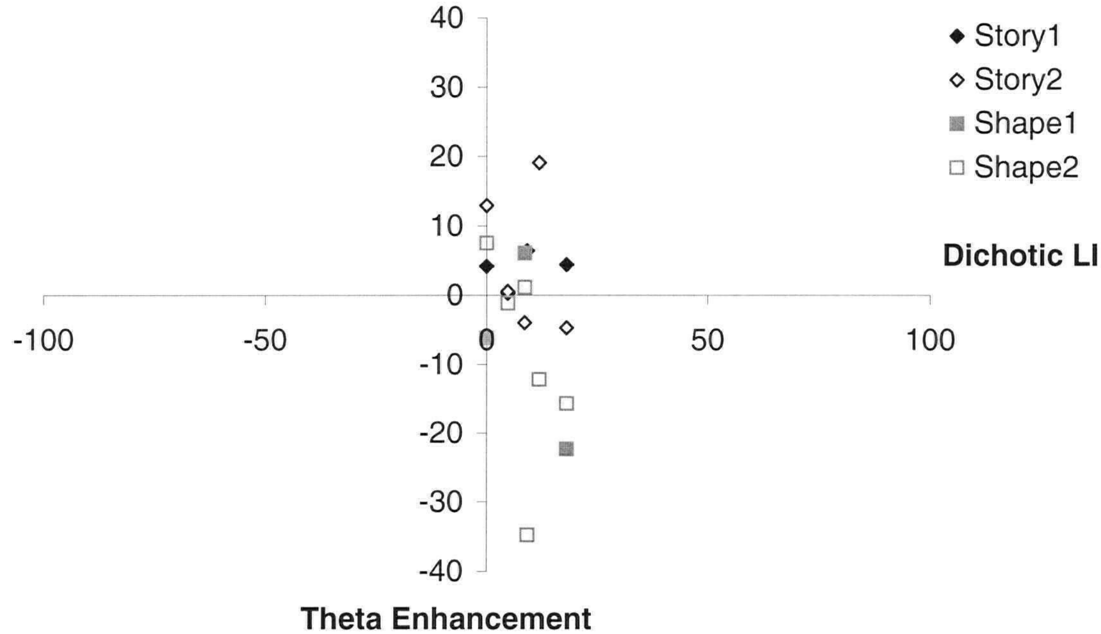

Figure 32 - The dichotic listening laterality indices versus the laterality of theta enhancement for the control participants for all trials of Experiment Two. The data plotted represents all trials in which the participants displayed theta enhancement in at least one hemisphere. A positive dichotic score (x-axis) indicates LH language processing and a positive theta enhancement value (y-axis) indicates LH language processing.

The laterality of theta enhancement for the participants with DS showed 6 of 9 story trials (in which theta enhancement occurred in at least one of the hemispheres) suggesting greater theta enhancement in the RH. RH theta enhancement is in agreement with the functional dissociation model of DS, which suggests that persons with DS process language stimuli in their RH (Elliott, Weeks et al., 1987). The spatial processing trials (shape) for the DS participants resulted in inconclusive laterality for spatial processing with 6 of 12 trials suggesting RH processing and 6 of 12 trials suggesting LH processing of spatial stimuli.

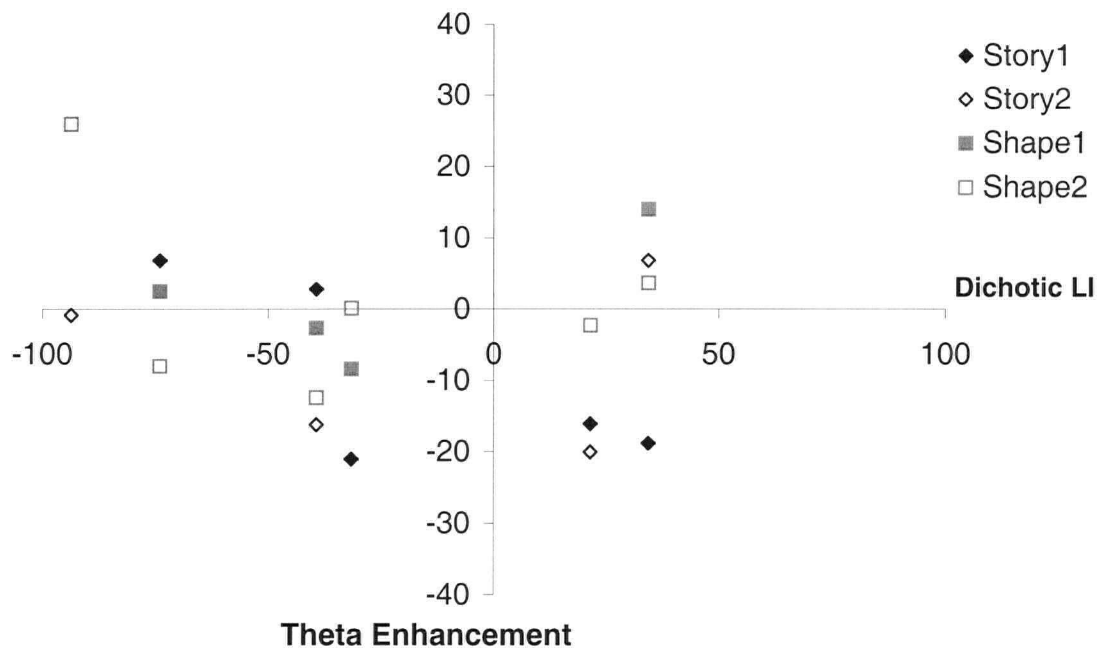

Figure 33 - The dichotic listening laterality indices versus the laterality of theta enhancement for the DS participants for all trials of Experiment Two. The data plotted represents all trials in which the participants displayed theta enhancement in at least one hemisphere. A negative dichotic score (x-axis) indicates RH language processing and a negative theta enhancement value (y-axis) indicates RH processing of test stimuli.

The results for the visual-language processing task (reading) from Experiment Two have shown trends that are in general in agreement with previous research. The trend of the participants with DS displaying greater RH activation for visual processing is consistent with the functional dissociation model of DS (Elliott, Weeks et al., 1987). Similar to Experiment One, there was a lack of clear laterality dominance for the control trials for either the control or DS participants. Again this lack of significance is in contrast to previous research, indicating a RH superiority for the processing of spatial stimuli (Elliott et al., 1995; Muller & Knight, 2002). It is possible that the tone and shape trials were not difficult or engaging enough as to produce a significant lateralization effect. Despite the lack of hemispheric dominance for spatial processing, the fact that both the control and DS participants failed to show a hemispheric dominance may be indicative of research, which suggests that the atypical lateralization in persons with DS is limited to linguistic processing (Elliott, Weeks & Chua, 1994).

In conclusion, for the present experiments the control group was a much more cohesive group when dichotic listening results were compared with cortical activation patterns as measured with EEG. A major contribution to the lack of coherence in the participants with DS is the large variability present in the dichotic listening results. The present section has revealed some trends whose directions are, in general, consistent with predictions of the dissociation model (Elliott, Weeks et al., 1987). However, it is important to remember that these trends were not found to be significant during the ANOVA analysis. This discrepancy may have been a result of the small sample size recruited for the present studies.

5.2 Alpha attenuation

It is a generally accepted result that alpha band power is attenuated in response to an eyes-open condition, as compared to an eyes-closed condition (Birch, 1997; Senf, 1988; Shaw, 1996). Through cross-experimental comparisons it was possible to investigate alpha attenuation in response to an eyes-open condition for the participants in the present experiments.

The alpha band relative power (non-transformed) was compared from experiment One (eyes-closed) to Experiment Two (eyes-open). The data analyzed were from the first control portion of the first story for all participants whose data were used for both Experiment One and Two.

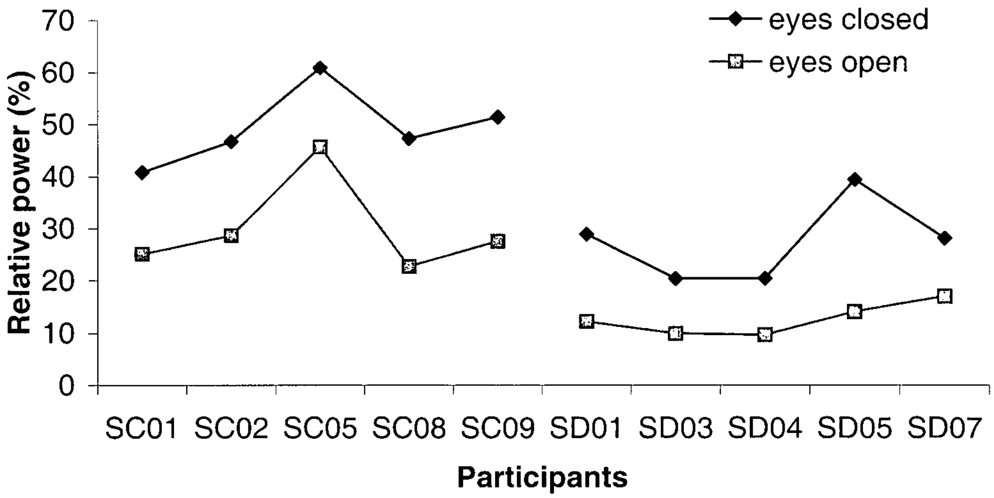

Figure 34 – Alpha attenuation in response to an eyes-open condition – Shows the alpha band relative powers during both the eyes-open and the eyes-closed conditions. The dotted line separates the control (SC) and DS (SD) participants.

As expected, all participants displayed alpha attenuation in response to an eyes-open condition, when compared to an eyes-closed condition (Figure 34). The decreased alpha band relative power in the participants with DS is also evident in Figure 34.

The results of the present experiments are in support of previous research, which has found alpha attenuation in response to an eyes-open condition (Birch, 1997; Senf, 1988; Shaw, 1996). A decreased level of alpha band power was also found across both eyes-open and eyes-closed conditions for the participants with DS as compared to the control participants during a relaxed state.

6.0 GENERAL DISCUSSION

The purpose of the present experiments was to assess the lateralization of language perception in a population with DS in a novel manner. There has been extensive research regarding the lateralization of language processing in persons with Down syndrome (for a review see Elliott et al., 1994). With the exception of Weeks et al (2002) all of these previous studies have attempted to infer laterality of language processing based on behavioural and coordinative actions of persons with DS as compared to a non-DS population (Elliott, Weeks et al., 1987; Elliott et al., 1994; Weeks et al., 1995). The present experiments were intended to extend previous neuropsychological and behavioural studies by examining, more directly, lateralization of language perception through the use of electroencephalography. The present experiments were designed to assess cerebral activity associated with both auditory and visual perception of language.

There has been little previous research with which to directly compare the results of the present experiment (cf. Weeks et al., 2002). Therefore, the results of the present experiments have been compared to a number of different studies and hypotheses have been based on a combination of extensive previous research in a number of different fields.

The initial analysis of the data collected during the present experiments showed a predominance of alpha activity during an eyes-closed and relaxed condition and relative power values comparable to normative values and alpha attenuation in response to an eyes-open condition. Results of the present experiment also showed that the participants with DS displayed significantly less alpha band relative power than the control participants. These results were all found to be in support of previous EEG research (Birch, 1997; Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Röhm et al., 2001; Senf, 1988; Shaw, 1996) and suggests that the data, from the present experiments, were collected, and analyzed in an appropriate manner.

In addition to these expected patterns of EEG activity, it was found that the participants with DS displayed significantly less relative power in the experimental bands (alpha, beta, theta and 40Hz) than did the control participants. These results indicate that the participants with DS have a higher percentage of their relative power content in EEG bands not investigated in the present experiments, than did the control group. Over the course of these two experiments EEG bands ranging from theta (4Hz) to 40Hz (44 Hz) were investigated. Previous EEG research involving participants with DS has shown that this special population is characterized by increased power in the slow wave (delta and theta) bands (Katada et al., 2000; Locatelli et al., 1996). During Experiment Two, the theta band power was assessed and, although not significant, participants with DS were found to display a trend toward greater relative power in the theta band. As a result, it is reasonable to assume that the participants with DS in the present experiments displayed relative power values higher than the control population for the delta band, thus accounting for the decreased relative power values in the participants with DS.

Previous research has found that cognitive activity is associated with both alpha attenuation as well as theta and beta enhancement (Birch, 1997; Bizas et al., 1999; Klimesch, 1999; Klimesch, Doppelmayr, Wimmer, Gruber et al., 2001; Klimesch, Doppelmayr, Wimmer, Schwaiger et al., 2001; Röhm et al., 2001; Senf, 1988; Shaw, 1996). The results of the present experiments showed that in response to both the auditory and visual language tasks, the participants showed significant alpha attenuation. In addition, analysis of individual frequency bands revealed significant beta enhancement during auditory language processing and significant beta attenuation during the visual language processing task. The beta enhancement in response to the auditory language processing was as expected based on previous research indicating beta enhancement associated with cortical engagement. The results of beta attenuation in response to visual language processing were not expected. Further research is required in this field in order to assess whether the results of the present visual language processing experiment can be replicated in a larger participant group. The present experiments found no significant hemispheric effects for the presentation of either the tone or shape trials. The non-significance found in the present experiments taken together with previous research suggesting RH lateralization for both of these processes (Auzou, 1995; Elliott et al., 1995; Muller & Knight, 2002), suggests that perhaps the tone and shape trials were not difficult or engaging enough as to produce significant changes in EEG activity.

Based on the dissociation model of DS (Elliott et al., 1987) it was hypothesized that the results of the present experiments would show that the participants with DS and control participants differed in their lateralization of activation in response to the language processing tasks. It was found, for the visual language processing task, that the two groups differed in their hemispheric activation patterns. Results indicated that the control group displayed significant theta enhancement in the LH and the participants with DS displayed significant theta enhancement in the RH. Based on previous research (Klimesch, 1999), these results were interpreted as the control participants showing greater LH engagement and the participants with DS showing greater RH engagement for the processing of visual language. These results are in support of the dissociation model of language processing in the DS population (Elliott, Weeks et al., 1987) and aid in generalizing the atypical lateralization of language processing in the DS population to language processing in general and not auditory language specifically.

Statistically there were no significant laterality differences for alpha band attenuation between the control and DS participants. However, when the trials that produced alpha band attenuation were isolated for the two groups a pattern of RH activation for the participants with DS and LH activation for the control participants in response to auditory language stimuli emerges. The results of the visual language task showed a pattern of RH processing for the DS and a lack of clear dominance for the control participants. The trend of RH dominance in the reading task for the participants with DS is consistent with the dissociation model (Elliott, Weeks et al., 1987).

There are a number of possible explanations as to the non-significant findings regarding the atypical lateralization of language processing in persons with DS. For the present experiments, only 4 of the 7 participants with DS displayed a left ear (RH) advantage in the dichotic listening task. Previous research (Elliott & Weeks, 1993) suggests that greater than 80% of participants with DS typically display a left ear (RH) advantage. The greater representation of right ear (LH) findings suggest that the group of participants with DS in the present experiment may not have been truly representative of the general population of persons with DS. These differences are likely due to the limited sample size that was available for the present experiments.

The sample sizes for the present experiments were also limiting factors in the analysis of the data. The small sample size resulted in low power and thus may have resulted in masking some of the significant findings. The large between-subject variability typically found within the DS population necessitates that a large sample size (larger than what would typically be required for a control population) is required for the present experiments. However, during the course of the present studies, we were not able to recruit more participants with DS to take part in the experiments.

In general, the present experiments have yielded some results that can lend support to the dissociation model of language processing in the DS population (Elliott, Weeks et al., 1987). There were a number of limiting factors in the present experiment and further research is warranted in order to further assess the dissociation model of language processing using more direct methods for the interpretation of language processing such as electroencephalography and magnetoencephalography.

Future Directions

Because the present experiments were novel in their approach to the investigation of language processing in the DS population, they have provided insight for further investigations. The results of the present experiments have been largely in the predicted direction suggested by the dissociation model of DS. Future studies will require larger sample populations in an attempt to increase statistical power and determine the significance of the trends that emerged in the present experiments. Experimental designs could make use of the latest technologies (such as MEG) to gain a closer look into the functioning of the language processing areas of the brain.

Klimesch (1999) suggested that there can be individual differences in the designation of frequency band parameters. Previous research indicates that for greatest accuracy, individual EEG band parameters should be calculated for each participant within an experiment (see Klimesch, 1999 for review). By using average parameters for the frequency band analysis (according to traditional methods) it is possible that some of the desired frequency activity is misrepresented in the overall analysis, and this may have resulted in some of the actual alpha band activity being analyzed as either lower beta or higher theta activity. Because cognitive activity is associated with opposite effects in these bands (Birch, 1997; Bizas et al., 1999; Klimesch, 1999), inaccurate band allocation may result in masking many effects that are in fact present.

A number of investigators have cautioned against using EEG as a means of localizing activity due to the fact that EEG activity recorded at a particular electrode arises from both local and distant sources (American Academy of Neurology, 1989[iii]; Nuwer, 1996) resulting in topographic maps which present an inaccurate representation of local brain activity. There are a number of researchers who have suggested that both anterior and posterior measures of activation are related to dichotic listening performance but in opposite directions; they suggest that there is a positive correlation between ear advantage and prefrontal activation and a negative correlation between ear advantage and posterior cerebral activation (Davidson, 1996; Hugdahl, 2000). These opposite activation patterns may help to account for the lack of a clear correlation when whole hemisphere is taken as the measured variable. Thus, looking for lateralization with more localized areas, such as frontal and posterior leads may prove beneficial in future studies.

Because the stimuli for the auditory language task were the same for both the control and DS groups and the stimuli were made in order to be appropriate for all participants, it is possible that some of the stimuli may not have been difficult or highly engaging of the control group or some of the higher functioning participants with DS. It may be the case that the tasks were difficult enough as to require minimal processing, thus eliciting a condition effect, but not difficult enough as to elicit a hemispheric lateralization of processing to the language processing specialized areas. The results of both of the present experiments revealed that the control group had greater relative power in the bands investigated (particularly in the alpha band). Future studies should seek to investigate more of the EEG spectrum, specifically the slower wave frequencies such as delta (and theta which was only analyzed for Experiment Two). Future studies would benefit by having a larger sample size for both the control and DS participants, using a wider variety of the EEG frequency spectrum, modifying task difficulty for all participants and calculating frequency band parameters on an individual basis.

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Footnotes

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