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THE UNIVERSITY OF ALBERTA

EAR DIFFERENCES AND SPEECH COMPREHENSION IN CHILDREN WITH LEARNING DISABILITIES

by

MARLENE SPENCER

A THESIS

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....
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....

K. H. Spooner
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Date... 20th September 1988 ....

Dedication

To a paragon, whose reverence for the architecture of life nurtured my interest in the miracle of hearing:

What a piece of work is man!
How Noble in reason!
How infinite in faculties!
In form and moving,
  how express and admirable!
    Hamlet, Act II, Scene 2.

Abstract

For normally hearing persons, listening to speech with both ears usually improves comprehension. There is some disputed evidence in the literature that children with learning disabilities may function more poorly than their normally achieving peers when listening with both ears. Eighteen normally hearing learning disabled boys between the ages of six and eleven years were administered an auditory comprehension test, under headphones, in controlled audiometric conditions. Using each subject as his own control, a single factor analysis of variance for dependent measures revealed no statistically significant differences in mean recall of test stories between left and right ears, although the left ears scored slightly higher than the right. No statistically significant differences between single ear and binaural listening were found, although a mean 14.2% binaural deficit was present. Post hoc analyses using Pearson product-moment correlations indicated that right ear performance was largly responsible for lower binaural scores. Left ear scores were related to intelligence test scores, but age did not affect any measure. When compared to scores reported in the literature, the experimental group demonstrated a statistically significant deficit in total items recalled in all listening conditions compared to normally functioning students. Therefore, listening with the best single ear, the

experimental group experienced a non-significant improvement in speech comprehension of 14.2% over binaural listening conditions, such as are found in home and school environments.

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To the charming, patient boys who participated in this study, and to their parents who contributed time and support in hopes that all children may benifit from the interest students and researchers take in their children.

To Patti, Bruce, Derk, and Andra - who have read, discussed, proofed, argued, guided and improved this paper.

To my mother and daughters - who have been waiting a very long time to read this volume.

To all - please accept my accolades, kudos and thank you.

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I. Introduction

The term *speech comprehension* is used to indicate an individual's intelligent grasp of the meaning of linguistic stimuli presented to the ear. One component of comprehension is the ability to accurately perceive the stimulus in properly sequenced order, and to hold elements of the stimulus in memory for recall upon completion of the message (Cowan, 1984).

A decrement in speech comprehension can be caused by stimulus degradation or alteration, or by the state of the organism, which includes general intellectual ability (Green, 1984a). In fact, a difference in performance may exist within a single individual which is related to the ear of presentation of the stimulus and the method of presentation. The listening condition in which both ears are presented with the same stimulus is a *diotic* task. If the stimuli to each ear are different we say the presentation is *dichotic*. A stimulus presented to one ear alone (monaural listening) is *monotic*. An individual may perform speech comprehension tasks differently under different listening conditions, while listening to different modes of stimulus presentation, or when listening to materials of varying characteristics (Geffen & Quinn, 1984).

Geffen & Quinn (1984) have presented an excellent review of the findings of 71 studies concerning best ear performance (ear advantage), method of stimulation, type of stimulation, and some associated neurological conditions related to this topic. It is clear that many researchers are interested in solving the puzzle of the nature of human auditory processing and understanding the characteristics of various populations as a means of delineating the processes of speech comprehension.

The practical value in understanding the processes of speech comprehension is the application of the resulting knowledge for the benefit of those individuals who experience difficulties with this process in everyday life situations. A finding of interest is one reported by Green (1983). He observed that poor speech comprehension could be improved in certain populations by the placement of an ear-plug in a poorer performing ear:

> It has been found that this procedure does, indeed, produce increases in the everyday understanding and recall of complex speech in patients studied...(p.16).

Green's experimental populations were schizophrenics, at-risk children of schizophrenics, and other psychoneurologic populations (1978, 1983; Green, Hallett, & Hunter, 1983; Green & Kotenko, 1980; Green & Preston, 1981; Hallett & Green, 1983). He used his own Auditory Comprehension Test (ACT, Green & Kramer, 1983) to measure recall of speech elements in stories presented to left, right or both ears under headphones.[1] The experimental groups demonstrated large differences in comprehension between ears as well as a deficit in the binaural listening condition. The subjects' comprehension scores increased by

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[1] The ACT protocol can be found in Appendix A.

the amount of their binaural deficit (compared to better ear scores) when using a wax earplug to occlude the individual's poorer ear during testing in 'free field' listening to speakers in an office.

The implications of being able to improve comprehension of speech by so simple and inexpensive a treatment as an earplug are far-reaching. If significant ear differences or binaural deficit could be found to be characteristic of other populations, and if occluding one ear improved comprehension, almost instant diagnosis and remediation could be provided.

Research initiated by Green's work include an M.A. thesis (Waine, 1984) using items from the Revised Token Test (McNeil & Prescott, 1978) looking for ear advantage or binaural deficit in a population of learning disabled children. None was found. Katz referred to Green's work in his revision of The Handbook of Audiology (1985), and is including the ACT in the learning disabilities test battery used at his clinic at the State University of New York (personal communication, February 23, 1984). The Edmonton Public School Board, Edmonton, Alberta, Canada, has begun a large-scale, longitudinal study of learning disabilities and remediation using earplugs prescribed according to Green's model (A. Hillyard, personal communication, April 3, 1985 and P. Green, February, 1987). Green's work continues at the Alberta Hospital Edmonton as co-workers, such as L. Yeudall, plan to investigate electrical and chemical brain activity during occluded and unoccluded listening by psychiatric patients (Elash, 1985).

One group that could derive significant benefit from improvement in speech comprehension is that population of children identified as having *auditory learning disabilities*. The United States Federal Learning Disabilities Definition (1977) gives a general description of auditory learning disabilities. The main characteristic of this disorder is the presence of achievement not commensurate with age and ability and problems in listening comprehension which are not due to hearing handicap or lack of experience. A more specific definition is provided in U.S. Public Law 94-142:

> Significantly below-average performance in auditory comprehension and listening
> A. Difficulty in following directions
> B. Difficulty in comprehending or following class discussion
> C. Inability to retain information received orally
> D. Difficulty in understanding or comprehending word meanings
> (cited in Gearhart & Weishahn, 1984, p.213)

Although children with auditory learning disabilities have been extensively studied with such tools as the Willeford Battery (Willeford and Billger, 1978) and the Word Intelligibility by Picture Identification Test (Ross & Lerman, 1971), they have not been studied using Green's Auditory Comprehension Test.

In a discussion of the clinical use of natural sentences with children, Willeford and Billger (1978) found that normal children demonstrate a stronger or dominant (higher scores) right ear and that symmetry of ear performance converges until, at the age of 9 years, no ear differences exist in response to dichotic stimulation. They relate unusual performances to different lateralization patterns or to maturational differences in the auditory-cortex. The Willeford Battery (1976a), including tests of 1) dichotically competing sentences, 2) filtered consonant-nucleus-consonant words, 3) binaural fusion of dichotically presented spondiac words, and 4) an alternating speech task, produced a 90% failure rate on one or more tests by 150 learning disabled children referred for testing. Willeford found that greater than a 10% difference between left and right ear scores beyond the age of 9 years was significant and considered abnormal. Unfortunately, aone of the tests in the battery used the diotic mode of stimulus presentation as did Green's ACT. Therefore, binaural listening scores were not comparable with the both ear (BE) scores presented in this paper.

Roush and Tait (1984), using the Word Intelligibility by Picture Identification (Ross & Lerman, 1971), compared both dichotic and diotic fusion and found that children with language-learning disabilities differed from normal controls in all conditions. They performed best with diotic presentation, better with dichotic (low-pass filtered stimuli to the right ear), and least well with dichotic (low-pass filtered stimuli to the left ear). There was no group interaction. The authors found that *diotic enhancement* above 10% of the averaged dichotic (L and R) scores successfully identified the learning disabled subjects.

All test items in the Roush and Tait and Willeford batteries (except the competing messages, which were given dichotically) used single word stimuli. There is a need to look at performance using natural complex speech, diotically presented. This can be done using Green and Kramer's ACT (1983). The present study administered the ACT to 18 male students (7-11 years of age) who had been identified by the University of Alberta Education Clinic as having probable learning disabilities. ACT performance scores under headphones for left, right and both ears were analyzed for ear difference[2] and binaural relative to best ear performance (Binaural Quotient)[3]. An ear difference greater than 10% was to be considered significant. A Binaural Quotient 10% poorer than best ear performance is significantly deficit (Green & Kramer, 1983).

The purpose of the present study was to verify the presence of a binaural deficit or significant ear difference in the speech comprehension of children with auditory learning disabilities as measured by scores on the Auditory Comprehension Test (Green & Kramer, 1983) under headphones. ACT performance scores were analyzed to determine if age or intelligence were factors affecting performance under experimental listening conditions (L,R, Both, Total, ED, or BQ).

2(R-L/R+L)x100=Ear Difference (ED)
3(Both-High Ear/Both)x100=Binaural Quotient (BQ)

II. Prior Research

A. The Routing of Auditory Messages

The lateral differences between left and right ears when hearing complex stimuli reflect the physiological structure of the auditory system. Auditory neurons decussate at the level of the cochlear nucleus (CN); that division and reduplication becoming more elaborate and diffuse at each more central synapse. The crossed fibers are more numerous than the uncrossed. This has been assumed to result in a stronger, more dominant response from the contralateral hemisphere (Bocca, Calearo, & Cassinari, 1955; Geffen & Quinn, 1984; Kimura, 1961a, 1961b, 1967).

Leong (1974) outlined the routes of auditory messages. There are two ipsilateral pathways. One is directly through ipsilateral neurons (see Fig. 1). The other is through the contralateral radiations and back to the ipsilateral temporal lobe through the corpus callosum. This routing may explain the lack of decriment following temporal lobectomy.

The contralateral route is less direct than the ipsilateral, but more direct than the callosal route. This is reflected in research measurements pre- and post-operatively of timed responses by Milner, Taylor, and Sperry (1968) and Efron (1963). Efron found that a 2 to 6 msec differential between ears was needed to judge tones as silmultaneous, the non-dominant hemisphere needing greater time to perceive the tones.

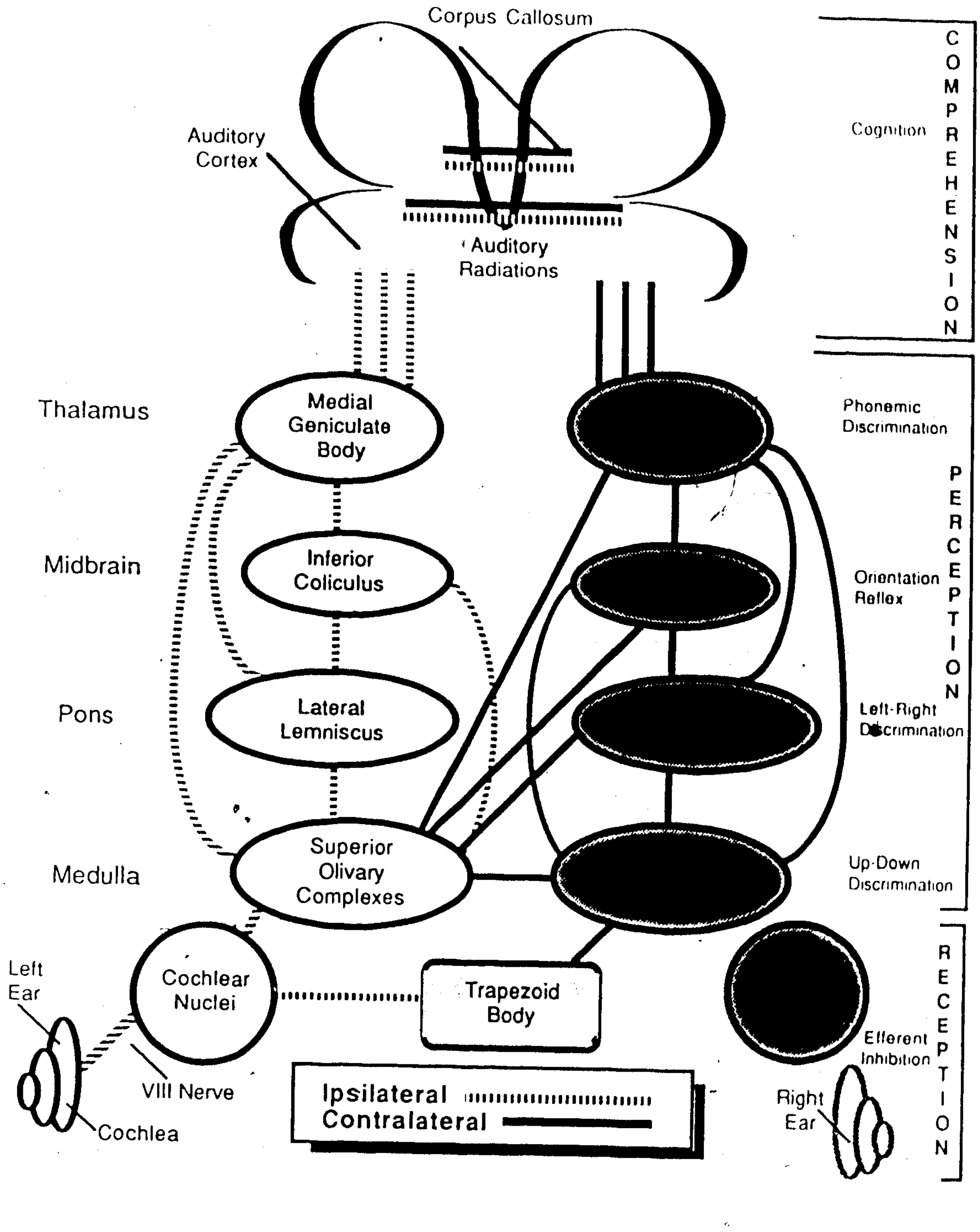

Figure 1. Ascending auditory pathways and levels of processing.

Brain-stem evoked response (BSER) audiometry has measured a conduction time (from ear to cortex) of approximately 4 milliseconds. There was little increase in latency between contralateral and ipsilateral response under monotic or diotic conditions (Skinner, 1978).

The data from laterality experiments show that the auditory system is sensitive to temporal differences equal to 10 microseconds (Yost & Nielsen, 1977). This remarkable resolving power, when considered in light of dichotic verbal stimulus presentation might indicate that the 2 - 6 millisecond ear difference noted by Efron (1963) represents cortical processing time for complex stimuli.

B. Anatomy and Physiology of Binaural Hearing

Binaural hearing is not simply a result of bilateral representation of ascending and descending pathways. From the first decussation, binaural cells can be differentiated from cells that respond to monaural stimulation.

The cochlear nuclei (CN) receive input from a single ear, but projections ascend directly to all higher brainstem nuclei (Eldredge & Miller, 1971; Gelfand & Hochbers, 1976 ; Harrison, 1978; Pickles, 1982; Ravizza & Belmore, 1978; Warr, 1982; Yost & Nielsen, 1977) [4]. The cochlear nuclei are thought to function as simple relays (Pickles, 1982), but three divisions, having different cell types and response characteristics, must serve different functions (Gelfand &

---

[4]Approximately two-thirds of the CN fibers decussate (Yost & Nielsen, 1977).

Hochbers, 1976).

Mylinated projections synapse in the trapezoid body at the calyx of Held, a large, reliable[5] synaptic ending, ideal as a short-latency rapid conductor (Harrison, 1978) which could compensate for the increased transmission time from the contralateral ear. Perhaps this enables the superior olivary complex (SOC) to compare data from the two ears; then, by the direct first-order fibers, receive additional information that would be identified as contralateral in origin. The SOC is the first waystation that receives binaural input. It maintains, as do all nuclei, the frequency map of the cochlear epithelium.

The lateral superior olive (LSO) is ipsilaterally dominant (Eldredge & Miller, 1971). It contains binaural cells which are sensitive to interaural intensity differences, but are not sensitive to overall intensity. Thus stimulation of the ipsilateral ear does not yield a response unless the opposite ear is also stimulated. In this way, the LSO binaural cells can detect the movement of sound in a horizontal plane in environmental space. This is a high frequency system, as it uses intensity cues to operate.[6]

The medial superior olive (MSO) is quite pronounced in man, and in all animals who rely heavily on vision. Harrison

----

[5]Reliable, in that it maintains its integrity when ipsilateral lesions or ablation of the SOC result in deterioration of other peripheral neurons.

[6] According to Harrison (1978), the LSO is small or vestigal in man, probably because man has a large head and poor high frequency hearing. Also it has little biological importance for survival in man.

(1978) found a high correlation both between eye and MSO size and an inverse relationship with LSO size. The MSO is well adapted to carry on interaural time difference analyses by which the organism can identify the direction from which low frequency environmental sounds originate. From the MSO, the lateral lemniscus (LL) and the medial geniculate (MG) receive the information needed to activate an orientating reflex to environmental sound involving the contralateral head, eye and pinna, all of which orient toward transient environmental stimuli.

The MSO receives temporally matched and temporally accurate signals from the two ears (Pickles, 1982). But, unlike the LSO, which is ipsilaterally dominant, the MSO is contralaterally dominant. Unlike the LSO, which is high frequency sensitive, the MSO is middle to low frequency sensitive. Unlike the LSO, which analyzes intensity differences, the MSO analyzes temporal differences. Yet, like the LSO, the MSO is composed of binaural and monaural cells. Under low frequency stimulation all cells reflect interaural time differences by discharge rate and degree of synchrony with phase of the stimuli. Cells phase-lock and summate for maximum firing. When interaural phase differences are greater than 180 degrees, however, discharge rates become lower than for stimulation of either ear alone. This is called *in-phase facilitation* and *out-of-phase inhibition* (Eldredge & Miller, 1971). The system responds in a similar manner to complex sound envelopes such as speech

(Pickles, 1982).

Eldredge says that the Japanese researchers Watanabe, Liao and Katsuki report:

> ...if a tone burst starts in one ear before the other, then the leading ear can *capture* the cell. The cell may be unresponsive to stimulation of the lagging ear for as long as 50 msec. This situation is often asymmetrical...a particular cell may be captured by a leading stimulus to the left but not to the right.(Eldredge & Miller,1971, p.301)

Thus, the SOC is a major processor of binaural information. It is involved with comparative analyses of stimuli time and intensity characteristics which allow it to particpate in the perception of the azimuth of an acoustic environmental event. Localization of auditory stimuli is required for identification.

The source of knowledge regarding the lateral lemniscus (LL) comes primarily from ablation studies, and is based upon hearing abnormalities produced by lesions. Because of the close geographical position of the LL and the inferior colliculus (IC), functions of the two areas are difficult to differentiate.

Harrison (1978) described Masterson's studies in which cats wearing earphones were taught left-right descriminations which disappeared after unilateral lesions of the LL. The cats continued to make left-right (lateralization) discriminations, but could not transfer the L-R task to a L-R/R-L task as they had. However, they could be retained on the L-R/R-L task. Can the LL learn?

The important feature of the cat studies is that for any behavior disrupted by transection of the LL, relearning could take place. It should be pointed out that the LL has the greatest communication with the reticular activating system (RAS) of any auditory nucleus. The RAS receives information from all sensory systems and forms an indirect route of communication between many parts of the brain (Durrant and Lovrinic, 1977; Willeford & Billger, 1978).

All ascending fibers appear to have synapses with neurons in the thalamus at the medial geniculate body (MGB), the last waystation from which the auditory radiations to the temporal lobe in the cortex originate (Durrant & Lovrinic, 1977; Willeford & Burleigh, 1978). The auditory radiations ascend to the homolateral hemisphere without decussation.

As to the function of the MGB, Durrant and Lovrinic reason:

> There is a trend towards increased specialization of neurons in the upper levels of the brainstem auditory pathways which permit them to detect specific features of the stimulus. This, in turn, can and doubtlessly does facilitate the processing of complex sounds such as speech. This capability is very well illustrated by neurons in the cat's medial geniculate which have been found to respond differentially to phonemes. (1977, p.127)

The neurons of the primary auditory cortex appear not to have generated haphazardly, but from a complex representation of the cochlear epithelium along an expanded one-dimensional plane(iso-frequency contour). Middlebrooks, Dykes, & Merzenich (1980) report finding two different populations of neurons arranged in alternate bands transversing the length of the iso frequency contours which may have different functional roles. These are binaural cells, which correlate well with the *binaural interaction columns* identified by Imig and Adrian as *summation units*. These respond better to binaural stimulation than to either ear alone. *Suppression units*, respond better to single contralateral ear stimulation or supression from the ipsilateral ear. Middlebrooks et al. also reported that "Cortical (binaural) neurons are sensitive to interaural intensity differences, while they are relatively insensitive to net binaural intensity (1980, p.46)".

Man is well designed for efficient low-frequency binaural hearing which is suitable for processing speech in noisy environments. In fact, stimulus dominance more accurately reflects functional brain organization than does ear dominance (Geffen & Quinn, 1984). Advantages of binaural over monaural hearing pertain to the ability of the auditory system to use *difference* cues of time and intensity to localize a sound and attend to one acoustic pattern from a milieu of patterns.

Binaural summation refers to the ratio of growth in perceptual loudness between monaural and binaural conditions which grow as a power function of sound pressure with an exponent of about 0.066. In other words, two ears give almost twice as much volume as one, when listening to conversational speech (Reynolds & Stevens, 1960). Loudness at each ear will be different depending on the orientation of the head to a sound source (Harris, 1960).

The time of arrival at each ear of the first sound in a stimulus (first wave front) is important to the ability to localize a sound in external space (Harris, 1960; Yost & Nielsen, 1977). Intensity difference is a more important cue for locating high frequencies, time difference is more important for localization of lower frequencies. Diotic headphone stimulus presentation precludes detection of inter-aural time and intensity difference by limiting head movement around the sound source. Under headphones, binaural sounds are perceived to emanate from within the head. This internal space location is called *lateralization*, to distinguish it from the more normal free field listening space identifications, which we call *localization* (Harris, 1960).

The time and intensity of signals reaching the two ears under normal listening conditions <u>and</u> under headphones must fall within certain limits for the two auditory images to fuse (Harris, 1960). Under headphones, if the left and right images fail to fuse, both can be heard at different locations within the head. No studies have been found that address the problem of fusion failure under normal binaural listening conditions in free field using speech stimuli. Under headphones, the auditory signal fuses when inter-aural phase (time) differences are less than 80 degrees. In free field, binaural intelligibility gain is greatest when there exists a 180 degree phase difference between ears for speech.

Sound reverberation and low level environmental noise provide some masking in everyday situations. Signal identification is improved by a *binaural gain in intelligibility* or *binaural release from masking* (Levitt & Rabiner, 1967). Licklider (1948) pointed out that mere two-ear duplication of information would be relatively useless. When one ear provides somewhat different information which is supplementry to the other, intelligibility is enhanced by the comparison of that information. In this way release from masking is different from the enhancement of signal detection experienced under headphones when a masking noise is introduced and which takes place in the cortex and is not due to additional information supplied by a second ear.

To summarize, individuals with normal hearing are better able to localize and int pret speech in a sound field with two ears than with one. Under headphones second ear increases stimulus intensity. At suprath levels, this factor does not improve an already 'normal'performance of 100% intelligibility. Degredation of performance becomes a function of attention, fatigue or memory. Therefore, binaural speech comprehension scores would be predicted to be equal to "best ear" scores. Binaural enhancement of diotic stimuli would indicate a failure to control phase, intensity or ambient noise in the experimental condition. In this way diotic and monotic performances are comparable.

C. Cortical Processing of Speech and REA

With the presentation of a pair of dichotic[7] stimuli having a stimulus onset asynchrony (SOA) of about 100 milliseconds, the second stimulus is more easily identifiable than the first (lag effect). This is an example of backward masking. The second syllable masks the first. The more acoustically similar the vowels of the stimulus pair are, the greater the backward masking. Conversely, the more similar the consonants, the easier the identification (Yost & Nielsen, 1977).

Studdert-Kennedy and Shankweiler (1981), using consonant-vowel-consonant nonsense syllables presented dichotically to right-handed listeners (Borden, 1980; Oscar-Berman, Zurif, & Blumstein, 1975), verified a small but consistent advantage of stop-vowel syllables, but none for steady state vowels. Further investigation has shown variations based on shared phonemic features of the contrasting consonants; e.g., shared place of articulation yields better accuracy than shared voicing. There was no ear advantage. Both ears recognized stimuli better when more features were shared. It was the vowel *contrast* which gave rise to the REA phenomenon.

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[7] Different stimulli presented to each ear simultaneously.

Molfese and Erwin (1981) found hemispheric differences between evoked response waveforms using both consonantal and steady-state vowel stimuli. No significant intra-hemispheric differences were found for vowel stimuli, but there were differences for consonant stimuli. There were two temporal and one parietal site in each hemisphere that in concert distinguished vowels, one from another.

Electrophysiologic results show similar activity from the right hemisphere whether the task calls for pitch or phoneme discrimination. The left hemisphere, however, shows distinctly different activity when processing according to these two parameters. "Something special is happening in the left hem[illegible]e when we listen to speech"(Borden & Harris, 1980, p.20[illegible]).

Broadbent developed the dichotic presentation technique in 1954 using spoken digits. His purpose was the study of attention and memory. The greatest subsequent use of the technique was in the measurement of hemispheric asymmetries, to locate cerebral lesions, and to further the study of memory, recognition and recall.

Broadbent's informational processing model (1956) has been elaborated by many researchers. Kimura verified a REA for verbal material presented dichotically. "...The right ear is more efficient (at recognition tasks) than the left regardless of the cite of lesion"(1961, p.167). Further, she cited Milner's (1962) findings that indicated tonal pattern perception was slightly better in dextral's left ears (right hemisphere). A large number of studies have supported hemispheric localization or lateralization functions, but most studies have been conducted with patients who had abnormal cortical function, using dichotic stimuli (Kimura 1961a, 1961b; Milner, Taylor, & Sperry, 1968; Oscar-Berman et al., 1975).

Studies using patients who had had partial or complete commissure sections have been valuable in investigating the role of information transfer between hemispheres in auditory perception. Effects of REA due to hemispheric dominance could be separated from effects due to ipsilateral suppression. Milner et al. (1968) and Sparks and Geschwind (1968) found a much greater REA for split-brained subjects than for normal subjects. They also found a neglect for words presented to the left ear, indicating a probable need for information transfer between hemispheres for verbal material. The possibility that the right hemisphere could not respond verbally was suggested. When the task required a manual response, left ear performance improved, indicating that left ear suppression had <u>not</u> occurred (Wale & Geffen, 1983).

Dichotic stimuli presentation cannot yield results comparing right and left ear or binaural performance wi normal listening conditions. When inter-aural competition is less, it operates to facilitate the comprehension of messages in noisy environments.

The literature is inconsistent (Rosser, Millay, & Morrow, 1983; Morris, Bakker, Satz, & Van der Vlugy, 1984) in its findings regarding presence of REA for normally functioning as well as learning disabled children. Three factors affect the consensus. Does cortical organization and/or function/malfunction create conditions that result in asymmetrical ear functions? Are ear differences related to developmental (and perhaps genetic) variables, causing some children to exhibit developmentally delayed ear differences or symmetry or the acquisition of compensatory strategies? What is the role of attention, memory, fatigue, and other individual subject and environmental variables?

Obrzut, Obrzut, Bryden, & Bartels (1985) attempted to test the hypothesis that LD children were more susceptible to attentional bias and used differential information-processing styles. They found that the LD children failed to demonstrate an ear advantage, whereas normal peers had a strong REA. LD children were not biased attenders. That is, the right ear did not maintain superiority either when directed (cued) or undirected, as it had with normal subjects. Instead, a total depressed performance was exhibited by each ear equally. Further, the LD children were less proficient in both simultaneous and sequential information processing. The conclusions suggested that LD subjects were not as well lateralized for speech as normal children. The authors point out that the operational definition of 'lateralization' is a greater number of correct right ear than left ear responses. This presumes REA represents left cortical dominance.

Rosser, et al. (1983) found no group differences for ear asymmetry, age-related auditory capacity, or lag effect (temporal offset of binaural stimuli). They found that with both normal and LD subjects, at simultaneity (0 lag), the REA was present. As lag increased, the lagging ear improved performance. Overall accuracy increased as temporal offsets increased. They found no change in laterality over a four year observation period.

Morris, et al.(1984) noted the contradictory nature of the literature when addressing the findings using developmental models. They felt that discrepancies arose depending upon whether the hypotheses were based on language lateralization, attentional bias or cognitive strategy. The theoretical position determined the methodology, which in turn biased the result. The authors looked for ear asymmetry in 211 normal, righthanded, male children in Holland and Florida. The study involved children from the age of 5 through 12 years. There were no consistent findings across all samples. Between 41% and 64% of the subjects shifted ear preference at least once. Results were reported as 'ear advantage' so the inferences to hemispheric processes would not be implied.

Perhaps our units of measurement are too gross to be of much value when looking for significant ear differences. Audiologists traditionally report differences in milliseconds and microvolts. Measures of cortical function using language, involving as they do symbolization (Protti, 1983), can not be compared to transmission times or neuronal firing in either quality or quantity.

By forcing the bilateral auditory pathways and reception areas to compete with one another dichotic stimulation yielded information regarding dominance of the the system. Dominance patterns varied greatly with stimulus characteristics and other factors such as attention (Geffen & Quinn, 1984). Geffen and Wale (1979), Hiscock and Kinsbourne (1980), and Sexton and Geffen (1979) presented developmental studies showing that normal children could, by the age of 7 years, well identify words presented dichotically to the right ear when asked to attend to the right, but they had difficulty reversing the task (Geffen & Quinn, 1984). This partially supports Willeford and Billger's (1978) REA for children under 9 years of age and their hypothesis that large REA's in children represent maturational lag.

Shadden and Peterson (1982) attempted to clarify the role of attention in ear advantage with a reaction time task where the ear of presentation was "expected" or "unexpected". Under random "expected" presentation, an REA was demonstrated, but under uncertain or "unexpected" conditions a significant LEA was found. The authors attribute this difference to the left-hemisphere's over-analyzing the stimulus for linguistic content when attention is mobilized.

Examining the role of memory on REA, Taylor and Heilman (1982) found that an REA was present in recency (short-term echoic memory) recall, but not in primacy (long-term memory) recall. There was a total absence of REA in their 24 female subjects, which the authors attribute to a difference between sexes in recall strategy. Female subjects had better echoic memory, which resulted in less dependancy of that memory component, so they recalled items from long-term memory first (primacy). Conversely, the male subjects recalled from echoic memory first, before the information was lost. This rationale implies that echoic memory is primarily a left-hemisphere function and long-term memory is a right function.

In a review of developmental studies of speech perception in normal infants and children, Sloan (1986) concludes that maturation of the auditory system proceeds from bottom to top (caudal to cephalad) and is anatomically nearly complete by the age of four years. The interaction of 'nature-nurture' elements favor the former as most important prior to and during language acquisition, replaced by greater importance of learned elements with age. Maturity of the auditory system is reflected in level of language acquisition. Some developmental markers are operative to pubescence. Watson (1985) found the auditory behavior of 13 year old LD children comparable to that of normal 6 to 8 year-olds. They noted a differential age-related capacity for auditory-successive selective attention across LD age groups through 16 years that was not found for visual-simultaneous materials (Willis, 1985). These studies were not addressing ear differences, but do indicate that with other parameters of auditory processing, a developmental pattern exists. Failure to confirm or refute a normal REA for children, normal or LD, possibly lies in the fact that maturation for more caudal characteristics, such as ear symmetry or asymmetry (assuming a brain-stem function) , have reached maturity for most children by the age of first identification of learning problems. Fatigue (Gerger-Gross & Bruder, 1984), memory (vanZyl & Brasier,1976), and attention (Byrne & Wingfield, 1979; Swanson, 1983) have been shown to have little relationship to LD auditory performance.

D. Effects of Binaural Stimulation

Audiologists, being interested in the clinical applications and delineation of the parameters of the auditory system, found a need to supplement conventional auditory tests with something more sensitive for the diagnosis of central auditory lesions. Bocca, and Calearo (1963) articulated this need and developed words and sentences designed to stress the auditory system. Jerger (from 1960), Katz (from 1962), and others in the United States have been working along similar lines.

Dichotic conditions are especially effective for studying speech processing and cortical functions using speech stimuli. Bocca, Calearo, & Cassinari (1954) justified using speech tests because speech put stress upon the auditory system. They found that even severely damaged patients could well handle simple auditory tasks because of the great redundancy within the biophysical system. Language also has great redundancy. Only by stressing can some lesions be identified. Stress can be created by making the stimulus more complex, by limiting the acoustic information contained in a signal, and/or by using novel conditions of stimulus presentation (Willeford & Billger, 1978).

A catalogue of stimuli used in research might contain pure tones, musical phrases, environmental sounds, animal noises, and vocal non-speech sounds (sighing, laughing, crying). Words (including sponde[8], honetically balanced, and digits)and longer utterances, tered, interrupted, accelerated, or distorted would be included. Synthetic sentences and competing messages have also been used. [9]

Dichotic speech tests began with Bocca's distorted speech materials (Bocca, Calearo, & Cassinari, 1954) and Kimura's laterality research with digits (1961a, 1961b). Matzker's dichotic binaural fusion test (1959) was used by Smith and Resnick (1972) to successfully identify brain-stem lesions.

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[8] Two syllable words spoken with equal stress on each syllable.

[9] See Irvine, 1982, pp.61-66, for references and a tabulation of stimuli and conditions used in research.

Binaural fusion tests, now thought to be measures of brain-stem integrity, were found by Roush and Tait (1984) to support their view that binaural fusion was a measure of overall central auditory processing function as their experiments found a general lowering of overall performance for LD children compared to normals controls, with no interaction between diotic and dichotic presentation when low-pass filtered speech was presented to right or left ears. They postulated that the reduced redundancy of speech probably had greater effect on LD performance than their control's. Central auditory nervous system (CANS) testing has generated a battery approach which is gaining in popularity for use with a variety of patients including children with learning disabilities. A review of the tests in this battery can be found in Katz(1978, 1985) and include the use of low-pass filtering, the SSW (Staggered Spondiac Word) test, Willeford's competing sentences (for superficial and deep cerebral lesions) and rapidly alternating speech test (for lower brain stem lesions). Jerger (1975) investigated the validity of CANS testing. He found the SSW to be the best of the procedures used in identifying cerebral lesions, and the SSI (Synthetic Sentences Index) in the ipsilateral competing mode to be the best for locating brain-stem lesions.

The SSI was developed by Jerger (1960) to avoid the use of single words which did not evaluate the auditory system's capacity to manipulate the changing of pattern with time, so characteristic of speech. Synthetic sentences are made of words that are related to each other. In a first order relationship a succeeding word is found frequently following the preceding word in normal speech. A third order relationship describes frequency of occurrence three words subsequent (not necessarily in the same sentence); for example, "Women view men with green paper should." or "Small boat with a picture has become.". These sentences must be identified from a closed set when presented dichotically with a speech narrative (events in the life of Davy Crockett). The task is presented contralaterally and ipsilaterally to each ear at various message-to-competition ratios. Normally functioning individuals perform at the 100% level. In addition to use with neurological patients, this test successfully identifies children with auditory learning disabilities as a statistical population (Willeford & Billger, 1978).

Willeford (1968) developed competing sentences to secure information about "message perception" using real sentences which were designed to minimize reliance upon key words. Precise time matching was not shown to be essential with more complete linguistic material when the same voice was used for the sentence recitation and a message set was used (e.g.weather set: L - "I think we'll have rain today."; R - "There was frost on the ground.").

The SSW was developed by Katz (1977) for use with hearing impaired individuals. The peripheral hearing deficit interfered with most central tests. To circumvent this contamination he used spondaic words which are well-known and essentially 100% intelligible over a wide range of intensities because of the bi-syllabic redundancies. The spondees were recorded in an overlapping fashion (R - "upstairs"; L "downtown" becomes R - "up"; R/L - "stairs/down"; L - "town"). Responses can be scored according to number of incorrect responses, number of reversals, order effect, or ear effect. The SSW clearly distinguishes between patients with lesions associated with the auditory cortex and those with non-auditry reception lesions. Types of errors also make finer distinctions of cite-of-lesion. There are some limitations for use. The SSW has questionable validity for children under the age of 11 years and those over 60 years of age.

E. Auditory Perception Tests

Auditory perception tests are most often used to access children's learning characteristics. The Flowers-Costello Tests of Central Auditory Abilities (Flowers & Costello, 1973) uses dichotic competing messages to evaluate CANS integrity. Competing signal tasks are also used in the Composite Auditory Perception Test (CAPT, Butler, 1973), but not in the dichotic mode. The Goldman-Fristoe-Woodcock Auditory Skills Test Battery (GFWB, Woodcock, 1976) manual considers the dichotic tests to be tests for "selective auditory attention". Despite the evidence of its value primarily as a CANS test of cortical function. In fact, the lack of controls inherent in the three aformentioned tests render them virtually useless. The Illinois Test of Psycholinguistic Abilities (ITPA, Kirk & Kirk, 1968), allegedly evaluates auditory perception, but scores obtained by children with auditory-based learning disabilities often score above their age norms (Willeford & Billger, 1978, p.413).

In general, auditory perception tests are audiological task response items. They are usually administered in uncontrolled environments. They are often interpreted by applying labels to children rather than explaining the nature of the deficits.

F. The Auditory Comprehension Test

Green has attempted to circumvent the limitations imposed by dichotic testing by developing a natural speech test, the Auditory Comprehension Test(Green & Kramer, 1983). Green felt that "everyday speech" was essential to use as a stimulus if practical treatment applications are to be generated by research (1984). The ACT (Appendix A) is composed of short *stories*, organized into sets of six (A through E). Each set is progressively more difficult, increasing in length, vocabulary and syntactic difficulty. Presentation is by stereo-audiotape. A Canadian woman's voice is used to present the items. The subject is instructed to repeat each story immediately following presentation, replicating as much of the story as possible. The phrase "Are you ready?" preceeds each story, orienting the subject to the ear of presentation of the following story. Within each set two stories are presented to the right ear, two to the left, and two to both ears in random order.

Each significant semantic linguistic unit is scored by the administrator if it is repeated by the subject. Semantically identical vocabulary substitutions are allowed. Raw scores indicating the number of ACT items correctly repeated under various conditions are tabulated and reported as both raw scores and as per cent correct.

G. Green's Findings with Schizophrenic Subjects

Green observed that the theories of REA and the contra-lateral lesion effect are paradoxical. Upon dichotic testing, a left temporal lesion would negate an REA and no ear effect would be found, when in fact both effects would be present. He presented a strong argument for use of monaural testing. It does not create an REA by forcing inter-ear competition. He found that the preponderance of evidence indicated that schizophrenics displayed an exaggerated REA. To explain this result, Flor-Henry (1983) suggested *overactivation* of the left-temporal lobe in acute schizophrenia, noting statistically significant correlations associating schizophrenic symptoms with left-temporal lobe epilepsy. Yet not all left-temporal epileptics are schizophrenic, nor are all schizophrenics lateralized to the left hemisphere for speech. Green argues for an explanation involving disruption of inter-hemispheric integration. Callosal dysfunction would also produce exaggerated REA's (1984a). He cited studies using tachistoscopic and intermanual transfer tasks (Hallett & Green, 1983). Using monaural testing procedures, a left-temporal lesion would be predicted to produce a contralateral deficit, not confounded by an REA. If the trans-callosal fibers failed (as with sectioned patients) degradation of performance would be expected in the ear ipsilateral to the language dominant hemisphere.

Using the ACT (Green & Kramer, 1983), Green found no significant L - R or binaural differences with 52 normal adult subjects (mean overall scores = 100.99, SD = 13.31). The magnitude of ear difference was 0.68% (SD = 4.54%). The mean binaural quotient was 3.1% (SD = 9.66%), which means that there was an average non-significant binaural advantage. No significant age or sex differences were noted. Nine subjects were retested between 9 and 14 days. Practice effects were 8.1% over initial scores (Green, 1984b).

As none of the 52 normal subjects produced ear difference scores greater than 10%, with 10% ear difference being >2 SD, 10% was set as the limits of normalcy. The criterion for abnormality for the binaural quotient was set at >-20% to lessen false positive identifications. The normal subjects' mean score was 63% correct responses. The ACT appears not to have a basal or ceiling bias for normal adults.

An overview of experimental populations and summary of main findings submitted by Green (1984a) can be found in Appendix B. More than 100 schizophrenic patients were evaluated over a series of eight experiments from 1973 to 1983. Not only did Green find left ear deficits relative to right ear scores, but overall scores were depressed relative to normal controls. Binaural performance averaged 50% lower than best ear monaural scores. Green found that these results were characteristic not only of acute schizophrenia. A different pattern emerged for chronic schizophrenia and other neuropsychiatric populations, but overall scores were low.

Green reasoned that an ear plug in a poorer (L) performing ear would create a close approximation to the superior (R) monaural condition and would restore speech comprehension in everyday listening situations to the level of the superior ear performance. Green states:

> There seems to be a failure to combine or integrate binaural stimulation with complex speech. The question is at what level of the auditory system does the failure of integration occur such that the addition of stimulation to the inferior ear interferes with comprehension...(1984a, p.179).

He found the most parsimonious explanation to be at the level of hemispheric integration, as the poor left ear scores clearly indicated problems at that level.

Subsequent occlusion of a poorer left ear with a wax earplug did indeed produce increased scores on the ACT. Moreover, the degree of left relative to right ear deficit predicted the improvement as comprehension was restored to best (R) ear levels.

Hallett and Green (1983) found that the same pattern of binaural deficit (28.8% compared to normal control means of 3.56%) characterized 13 children at risk for schizophrenia (children of schizophrenics).

The replication study by Waine (1984) including 18 learning disabled experimental subjects (12.7 to 14.6 years of age) and 18 matched controls, found no statistically significant differences between monaural and binaural presentations on the performance of 15 commands from The Revised Token Test (McNeil, 1978). These stimuli appeared to be of insufficient difficulty as normal controls achieved 90.7% accuracy and the experimental group achieved a mean of 80.3%. With left, right and binaural presentation, the test only consisted of 5 items per condition. The author predicted a binaural deficit on the basis of interhemispheric interference. Waine's sample showed interesting trends within the experimental group, especially for females, but the limited number of stimuli coupled with small sample size appeared to have been further confounded by the statistical use of group comparisons. No significant group differences were found. The author suggested future studies include a more homogeneous group of learning disabled children, as her sample consisted of both dyslexics and language-disordered subjects.

Waine included several reports of attempts to establish a clear picture of disordered left dominance for speech in learning disabled children. Results were equivocable. All in all, this study was not a replication of Green's work, as not only did the target population vary, but the stimuli were uncontrolled and not comparable to the ACT.

Researchers indeed have had difficulty locating any consistent evidence of cortical organizational differences or lesions in children with learning disabilities. In fact, "hard" neurological signs are repeatedly and consistently absent. Early researchers such as Orton (1937) and Critchley (1969), after searching for cortical signs, had to revise their 'structural deficits' hypotheses, as no signs were found. Both investigators modified their thinking to include possible maturational delays or *developmental lag*. However, no cortical evidence of immaturity was found as the construct of *immaturity* was a vague, untestable physiologic process (Levinson, 1980).

The term *minimal brain dysfunction*(MBD) came to be used for individuals exhibiting no abnormal neurologic signs. Defining a condition by what it is not has only served to delay the identification of what it is. Thus, the U.S. Government has been forced to define learning disabilities (including dyslexia) in educational-behavorial terms. Again, the definition specifies what a learning disability is <u>not</u> with as much vigor as pin-pointing what it <u>is</u>.

H. Rationale for the Present Study

Green's (1983) monaural-binaural testing may, by eliminating the hemispheric dominance elicited by dichotic tests, reveal ear asymmetries or binaural deficit in populations other than the subjects of his studies. Occlusion of a poor ear may alleviate binaural deficit, and although the inter-hemispheric transfer explanation for left ear-binaural deficits for schizophrenics seems reasonable, a brain-stem cite-of-lesion for a learning disabled population would not be incompatable with similar results. A sub-cortical dysfunction affecting binaural integrative processing would be predicted to yield poor binaural performance relative to single ear stimulation under headphones. As the presence or absence of ipsilateral suppression would be of no consequence in a monotic presentation, little difference between ears would be noted. Each monotic condition would be superior to the diotic as the language dominant hemisphere receives complete messages ipsilaterally regardless of route superiority. If however, there were cortical involvement, a right ear advantage should appear (assuming dominant left-temporal speech localization).

This study explored the monotic and diotic speech comprehension performance of children with learning disabilities using Green's ACT (Green & Kramer, 1983) and procedures (1984b).

III. Methods

A. Hypotheses

Studies of human ear differences when listening to speech indicate a normal, slight, non-significant right ear advantage (REA) may be present when listening in the dichotic mode. Children may have larger REA than do adults, which disappears as the auditory system matures (by approximately eight years of age). Learning disabled students may exhibit greater REA than normally functioning students. This has been found to be present when testing involved the use of monotic stimuli (Green, 1983).

Under binaural listening conditions, LD children have been found to perform more poorly than able peers, and more poorly than their own best single ear. This binaural deficit has been postulated to result in auditory disturbances that disrupt signal intelligibility by failure of seperate ear inputs to fuse into one message, reach optimal listening level, or be distorted in such a way as to interfere with comprehension. The demonstration of large ear differences in speech comprehension might imply disturbance in auditory function, remediable clinically by manipulation of stimulus input (e.g., occlusion by ear plug in a poorer performing ear).

This study sought to verify (and quantify) an REA for eighteen boys between the ages of six and eleven years who had experienced classroom learning difficulties.

Verification of the presence of a significant deficit in binaural speech comprehension was also measured.

The hypotheses tested by this study were:

1. There is no statistically significant difference of 18 learning disabled boys (6 to 11 years of age) between left and right ear performance (ED[10]), when listening under headphones, as measured by scores achieved on the Auditory Comprehension Test (Green & Kramer, 1983).

2. There is no statistically significant binaural deficit relative to single ear performance (BQ[11]) of 18 learning disabled boys (6 to 11 years of age), when listening under headphones, as measured by scores achieved on the Auditory Comprehension Test (Green & Kramer, 1983).

B. Research Design

Both study hypotheses were tested using the same subject sample by data collected in a single administration of the ACT (Green & Kramer, 1983). A group comparison of repeated measures design was selected. All subjects took all tests. Sample size was smaller than needed for a randomized design, as each subject served as his own control (Shearer, 1982, p.117).

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[10] (R-L/R+L)x100 =ED (ear difference)
[11] (Both-High Ear/Both)x100=BQ (binaural quotient; binaural advantage or deficit)

The ACT (Green & Kramer, 1983) was designed to be used as a repeated measures test; each story within a set of six yielding equivalent scoreable responses. Therefore, ear conditions L, R and B were balanced in order of presentation. Time and practice effects were controlled.

Traditional group comparison designs were rejected for use with the learning disabled population. In pilot studies, normally functioning students demonstrated large practice effects, whereas students with learning disabilities demonstrated little carryover, even when items were immediately repeated. It was felt that this was partly a function of poor initial performance and partly a function of poor memory or recall. As no normal equivalent peer group existed (the experimental population itself was heterogeneous) for which all variables could be specified or controlled, a design which used only the experimental subjects was used.

Grouped data in this study were raw scores on the ACT under three listening conditions; left (L), right (R), and both ears (B). Ear difference (ED) and binaural verses monaural percentage differences (BQ) were calculated and analyzed as dependent measures.[12]

Analysis of data was achieved using a treatments-by-subjects (TxS) analysis of variance (one-way, or single factor, ANOVA with repeated, or dependent, measures). An assumption of normal distribution was made on

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[12]During data collection for this study, Green made available to the author unpublished raw data from his most recent studies (see Appendix C).

the basis of subject selection criterion of normal intelligence (as determined by WISC-R scores). Relationship between subject variables of Age and IQ (DIQ, Verbal and Performance) and dependent variables (L, R, and B; ED and BQ) were examined using Pearson's Product-Moment Correlation.

C. Subject Selection

Permission to conduct research on human subjects was secured from the University of Alberta, Department of Educational Psychology Ethics Committee. Eighteen right-handed male subjects, between ages 6 to 11 years, were recruited for the study. Because of the sample size, homogeneity of subject characteristics was obtained by controling for IQ , hearing acuity, and a history of diagnosis of and/or special educational placement for remediation of one or more learning disabilities. Children who were receiving ongoing medication were excluded.

Subjects were selected from a population of children who had received psycho-educational assessment at the University of Alberta Faculty of Education, Clinical Services Division between January and June, 1986. Thirty-three letters were sent to parents of children who met criteria for age, sex, IQ and history of diagnosis and/or special educational placement (see Appendix A). Initial direct contact was made by telephone by the parent to the clinician. There were twenty-five responses, from which eighteen children were selected as subjects. Of the children excluded, one child was on medication; one was moving out of the city; two were ill; and three parents declined subsequent participation believing that their child had "...been through enough testing...".

Age

The age range of the eighteen subjects was 6 years 8 months to 11 years 10 months. The mean age was 9 years 3 months (SD = 1 year 5 months); median = 9 years 8.5 months.[13]

Table 1.

SUBJECTS BY AGE

Number	Age in Years
1	6
3	7
2	8
7	9
4	10
1	11
N=18	M = 9yr.3mo. SD = 1yr.5mo.

WISC-R Scores

WISC-R (Weschsler Intelligence Scale for Children-Revised, Weschsler, 1974) Full Scale scores ranged from 89 to 114. Mean and median = 102, SD=8. WISC-R normative data placed these scores within one standard

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[13] Data tables provided in Appendix B report age in months.

deviation of the norms (M=100[14];SD=15). Verbal IQ scores ranged from 84 to 119 (M=102; median=101; SD=12). Performance IQ scores ranged from 78 to 123 (M and median=102, SD=12). All values fell within the normal range for the WISC-R normative population.

Individual subject differences between Verbal and Performance scores ranged from a 35 point superiority of Performance over Verbal, to a 23 point superiority of Verbal over Performance, but the mean difference was only 1 point. Nine subjects had higher Verbal than Performance scores, and nine had higher Performance than Verbal scores. However, nine (50%) subjects had a difference greater than 1 SD between scales, which is a greater number than found in the WISC-R normative samples. The standard error of measurement on the Verbal and Performance scales was 3.60 and 4.66 respectively. Wechsler (1974) compares individual sub-tests by age group, not by scale score differences for the total sample, therefore comparisons could not be made.

D. Pre-Testing

Eighteen boys between the ages of six and eleven were included on the basis of academic history, psychological assessment and having IQ scores within one standard deviation of the mean. A brief explanation of the purpose of testing was given, and an initial interview conducted. An appointment for a testing period of 2 hours at the Minerva

[14] M=Mean

Hearing Research Clinic at the University of Alberta, Department of Educational Psychology was scheduled. At the appointed time, the nature and purpose of the study was explained more fully to each parent and child, after which, permission to include the particular child was obtained and the parent signed a consent form (see Apendix A). A short medical-educational history was secured. Each child had previously exhibited difficulties performing in a regular classroom, and had been diagnosed as having 'learning difficulties' by the school psychologist or by a clinician in the University's Education Clinic. Current WISC-R scores on Performance, Verbal and Total IQ were secured as an indication of 'normal' intelligence. Some mention of auditory processing, perceptual problems, or language delay appeared in the student's school records or the psychologist's report for each boy selected.

A traditional hearing evaluation, including bilateral pure tone thresholds at 500, 1000, and 2000 Hertz; speech reception thresholds; speech discrimination in quiet and noise (0dB s/n)[15]; and impedance audiometry, was performed to rule out peripheral hearing problems as a confounding variable. Assessment was conducted on an individual basis in a 2 X 2 metre IAC (Industrial Acoustics Company, Inc.) Model 403-A audiometric suite (with less than 7dB SPL ambient noise) using a Madsen OB822 audiometer and a Sony TC-250A reel-to-reel tape recorder. Normal hearing for pure tones

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[15] 0dB s/n indicates the signal and noise were presented at the same loudness level.

and speech[16] using TDH-39P(Madsen) headphones was verified. Impedance information[17] was gathered using an MD-1 analyzer.

E. Stimulus Preparation

The ACT consists of 30 stories in 5 sets of 6 stories each. Tests A to E involve increasing items of information (see Appendix A).

> "...A & B, 10 items per story; C, 15 items; D, 20 items...Within each test each story has been found to be of equivalent difficulty to every other story..."(Green, 1984b, p.5)

The commercial tape produced by Green and Kramer (1983) was re-recorded using a Sony TC-126 stereo cassette recorder to deliver the signal to a Sony TC-630 stereo center. An Audioscan Programmer was used to record a 1000 Hz callibration tone, after which each section of the original tape (each story) was routed and re-recorded. The input channels were monitored on a VU meter during the re-recording process to ensure a constant intensity level. During presentation of items to the subject the signal was routed through the audiometer, which again ensured a constant output through the headphones.

Pilot testing revealed that children fatigued and became bored and discouraged when the length of the ACT included Tests A through E. Split-half scoring indicated that performance remained at a constant level regardless of the

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[16] Greater than 20dB HL and speech discrimintation in quiet over 90%.
[17] Normal tympanograms, Jerger Type A, and the presence of the ipsilateral acoustic reflex at 105dB SPL at 1000 Hz.

number or length of stories used. [18] Using 3 male, and 3 female learning disabled children, and 2 normally functioning students who were volunteer children of university students, pilot testing in the Minerva Clinic indicated that their ACT performance scores increased with age. Therefore, it was felt that use of ACT Tests A, B, C, and D would provide reliable results which would be comparable to prior reports.

This study employed ACT tests A, B, C, and D:

> Test A consisted of six 22-word stories, each containing 10 scorable linguistic elements.
>
> Test B consisted of six 26-word stories, each containing 10 scorable elements.
>
> Test C consisted of six 33-word stories, each containing 15 scorable elements.
>
> Test D consisted of six 45-word stories, each containing 20 scorable elements.

The total of 24 stories contained 330 scorable linguistic elements to be recalled and reported by each subject. By omitting Test E, six stories, each containing 25 scorable elements for a total of 150 additional points, were eliminated.

F. Scoring

Each subject immediately recalled as much as possible of the story he had just heard. The observer recorded responses, by pen with a tick placed in a circle following each protocol item correctly repeated (see Appendix A).

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[18] This is in agreement with Green's findings (1984b).

Criteria for scoring items as correct followed those recommended by Green (1984b). Thus, substitutions of vocabulary items of equivalent meaning (e.g. "baby cat" for "kitten") were accepted as correctly recalled. Green suggested noting the number of 'intrusions'. He describes two types: order of recall and substitutions which alter the meaning of the story. Wrongful order seldom produced semantic changes to the material during this study. Occasionally some element was recalled and reported long after initial response. Scores were always corrected to include credit for late recall, as failure to report promptly was not due to perceptual or encoding failure if the child later reported omitted items. Often spurious names were substituted for story names. These intrusions were not accepted even though the linguistic elements (e.g. noun forms) were identical. The subject had introduced semantic information which was external to the story(e.g. different names refer to different persons). The linguistic 'class' of the word substituted could be inferred from the structure of the utterance; thus, there was insufficient evidence that the auditory signal was perceived and/or processed. Analyses of intrusions was deferred for a later study.

Observer training was conducted on two occasions. Criterion was reached when the observer and Green achieved 90% consistency in point-by-point scores from two subjects.

G. Procedures and Apparatus

All equipment was calibrated to ANSI-79 standards. Standard audiometric procedures were used, with the subject sitting in a 2 X 2 metre sound-attenuating suite. Each child had performed within normal limits on the standard audiometric evaluation prior to being selected as a subject for study. The pre-recorded ACT stimuli, calibrated to a 1000 Hertz tone, were replicated and checked on a VU meter during playback through the Madsen OB822 audiometer to TDH-39 headphones placed on the subject. The subject and experimenter were within view of one another through a small window throughout testing. The parent(s) observed the testing session from a position behind the experimenter.

At each session, all subject responses were recorded on tape from the monitor output of the audiometer to a Sony TC-126 stereo-cassette tape recorder. Observer agreement over time was checked by rescoring, from tape-recorded responses from five subjects two weeks after the first administration of the test. Observer agreement exceeded the 90% level for each rescoring. Only three scoring discrepancies occurred on the five protocols. Initial scores were not altered.

Each subject received a total of two stories per condition per set. Conditions[19] were administered in the following order to each subject to minimize order and

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[19] L = left ear
R = right ear
B = both ears

practice effects:

SET A: B - L - R - L - R - B

SET B: R - B - L - R - L - B

SET C: L - B - R - B - R - L

This pattern was repeated continuously throughout the study so that the pattern repeated on Test D for the first subject B - L - R - L - R - B. The second subject began Test A with R - B - L, etc.. In this way, any bias generated by a particular story would be more or less evenly distributed throughout the data, as would any undetected equipment artifact. Therefore, the stories were administered in the same order to each subject, but not necessarily to the same ear.

Each subject was told that he would hear some stories . "At the end of each story you are to tell the story back to me. Tell me all you can remember about the story, just the way you heard it." Listening attention was secured by the carrier phrase, "Now listen carefully..." to the test ear(s). At the end of each story the tape was stopped and the child was encouraged to respond, if needed, by a visual cue (eye contact, raised eyebrows, or pointing) from the clinician.

Following administration of the ACT, results of the pre-test hearing evaluation and ACT performance were discussed with the child and parent(s). They were thanked for their participation and dismissed.

IV. Results

The primary purpose of this study is to determine whether a significant ear difference or binaural deficit was exhibited by a sample of learning disabled boys when recalling stories contained in the Auditory Comprehension Test (Green & Kramer, 1983). The data were analyzed using the statistical program ANOV14 provided by the Division of Educational Research Services (DERS), University of Alberta, using the University's Amdahl computer and the Michigan Terminal System (MTS).

Data analysis included a one-way analysis of variance with repeated measures for ear conditions. Relationships were explored with Pearson product-moment correlation coefficients for all variables (Age; DIQ, Verbal and Performance WISC-R scores; L, R, B, and Total ACT scores). Ear Difference (ED) in percent correct scores between L and R ears, as well as Binaural Quotient (BQ)(the percentage of the best single ear's advantage or deficit to binaural (B) performance was included on the matrix.

A. ACT Scores

When divided between L, R and B conditions, a total possible ACT score was 110 per condition with a maximum total score of 330. Percent correct scores for L, R, B, and Total score, as well as ear difference (ED) and binaural quotient (BQ), are reported in Table 2. Raw scores are also reported.

Table 2.

AUDITORY COMPREHENSION TEST SCORES (N=18)

Variable	Percent Mean	Mean	Raw Score Median	SD	Range
Left	43.9	48.3	49.5	11.3	32 - 72
Right	43.6	47.9	49.0	11.3	23 - 66
Both	41.8	46.0	45.5	10.3	30 - 61
Total	43.1	142.3	149.5	27.9	87 -180
ED	-01.1				-30.9 - 16.1%
BQ	-14.2				-48.8 - 16.6%

Negative numbers ED indicate left ear advantage.
Negative numbers BQ indicate B lower than highest scoring single ear.

Using the DERS ANOV14 program, a one-way ANOVA for the repeated measures, L, R, and B, the ACT scores did not reach statistical significance (F=0.57; df 2, 34; p≤.05). See Table 3.

Table 3.

ONE-WAY ANALYSIS OF VARIANCE WITH REPEATED MEASURES

Source	SS	df	MS	F	P
Rept.Meas.	56.25	2	28.13	0.57	0.569
Residual	1668.44	34	49.07		

B. Correlations

All variables (Age, Full Scale IQ, Verbal IQ, Performance IQ; L, R, B, and Total ACT scores, ED and BQ)were correlated on a Pearson Product-Moment Correlation Coefficient matrix using SPSS-X (Table 4).

Age did not significantly correlate with any variable, including total ACT scores. As expected, Verbal and Performance IQ were closely associated with Full Scale IQ, but not significantly correlated with one another (r=-.1224; p=.314). Full Scale IQ was, however, related to L (r=.4030; p=.049). In other words, left ear ACT performance was the best predictor of Full Scale IQ or visa-versa.

Table 4

PEARSON CORRELATION COEFFICIENTS

	Age	DIQ	Verb	Perf	Left	Right	Both	Total	ED
DIQ	.284								
Verb	.229	.646							
Perf	.145	.675	-.122						
Left	.291	.403	.242	.305					
Right	.338	.245	.369	-.029	.502				
Both	.265	.296	.216	.161	.674	.600			
Total	.351	.371	.325	.172	.855	.822	.882		
ED	.107	.016	.302	.273	.457	.495	-.044	-.007	
BQ	-.157	-.181	-.144	-.149	-.340	-.217	.345	-.096	.114

DIQ=WISC-R Inteligence Quotient
Verb=WISC-R Verbal Scale
Perf=WISC-R Performance Scale

This study found ACT conditions L, R, B and Total to be closely related, as was ED ((R-L/R+L) x 100 = ED). with L and R, from which it is derived. The ED score failed to significantly correlate with the B and Total (L+R+B = Total) scores which themselves were closely associated (r=.8820; p=.000).

The Total score was related only to L, R, and B, from which it was derived. While the BQ variable did not correlate significantly with any other variable, it was more closely related to L and B (r=-.3396; p=.084 and r=.3449; p=.081) than to R (r=.2174; p=.193). This indicated the high ear (HE) scores in the BQ calculation were predominately L scores. Upon inspection of the raw data, 77.8% of the sample (13 of 18 subjects) exhibited L over R ear superiority. This was not reflected in ear - age correlations, but may explain the significant Full Scale IQ - L correlation (r=.403; p=.049) and failure of Verbal - Performance scores to correlate as might be expected (r=-.1224; p=.314). It may be more appropriate to refer to R ear deficit (or disorder) rather than L ear superiority or advantage as the R ear carried greater responsibility for lower Total and Binaural scores than did the L ear. This study fount that left ear performance was least likely to lower Total or Binaural scores.

Hypothesis 1 stated that there was no statistically significant difference between ears in ACT performance. None was found. Hypothesis 2 stated that there was no statistically significant difference between binaural and single ear performance. None was found. However, it is interesting to note that there was a trend toward lower binaural scores. In fact, an average binaural deficit of 14.2% over single best ear performance was found. Right ear performance was deficit to left ear performance in the binaural listening condition.

V. Discussion

This study sought to replicate and expand upon work initiated by Green (1983), following his suggestion that learning disabled populations might demonstrate a unique pattern of ear difference and binaural deficit in a task requiring recall of common speech. Green hypothesized that significant ear differences and/or a binaural deficit would result from inter-hemispheric transfer disturbances through the corpus callosum. He depended heavily upon models of cortical specialization and information exchange between hemispheres. His was a 'top-down' neurological approach (Dunchan & Katz, 1983), focusing on 'processor', the mechanism of audition, rather than linguistics or the acoustic signal.

In exploring the processing model, the present project used a 'bottom-up' approach, which, by applying a measure of experimental control over environmental and subject variables, focused also on processor[20] in an effort to replicate Green's unpublished work with children with learning disabilities. The bottom-up approach attempts to systematically search for explanations of aberrant auditory behavior from the link between the external world through the auditory mechanism, the brain stem structures, then the auditory cortices.

As a result of the current study, four points of interest emerged. 1) No significant ear differences were

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[20]Neither linguistic nor acoustic characteristics of the signal were controled.

found. 2) Results indicated a non-significant trend toward binaural deficit. 3) Left ear scores were related to Full Scale WISC-R scores (DIQ), regardless of pattern of Performance and Verbal sub-test scores. 4) When compared to 35 normally functioning boys matched for handedness and age, the experimental subjects' ACT scores in all listening conditions were greatly depressed. The level of total performance deficit was reflected in an independent matched sample of 18 boys with auditory learning disabilities (see Appendix C).

First, there is a failure to find a significant ear differences in this sample of boys. No right ear advantage was manifest as Kimura (1961b) and Green (1983) had predicted. Green spoke of left ear deficit, rather than right ear advantage, but for learning disabled youngsters, both ears appeared to be deficit. Left ear mean scores slightly exceeded right ear mean scores. We might view the lower right ear scores as indicative of right ear 'misbehavior' (or deficit), recalling that the right ear failed to correlate significantly with WISC-R scores, while the left did correlate.

Secondly, no significant binaural deficit (BQ) was found in this experimental data, although a trend toward poorer diotic performance was found. Upon visual inspection of the data (Appendix B), it can be seen that five boys had binaural deficits greater than -20%; the level set by Green (1984b) below which clinically abnormal function exists.

(Green has found subjects falling below this level profit from occlusion of the poorer performing ear by increasing free field speech comprehension scores to the level of single best ear scores under headphones.) These five boys comprise 27% of the subjects in this study. This is consistant with Green's LD sample, 35% of which demonstrated clinically abnormal binaural performance. Future studies may confirm that those individuals who demonstrate abnormal (≤20%) binaural deficit form an important and objectively identifiable sub-group within the LD population. One is cautioned in the literature about problems that may arise from heterogeneity within LD groups and the possibility of rejecting a true hypothesis. Using ACT performance scores to select homogeneous subject samples might provide a more conrollable selection criterion than the assumption and labeling of learning disability by various individuals from various disciplines, useing various behavorial criteria.

Green postulated that poor binaural performance was the result of failure of information to transfer betw hemispheres properly. The auditory images from e ar would fail to fuse into one auditory image. The literature reports that right hemisphere lesions produce depressed left ear scores, and left hemispheric lesions tend to produce more binaural errors (Bergman, Hirsch, and Solzi, 1987). Binaural fusion failure could also produce increased binaural errors. Prediction of results of binaural testing based on behavioral abnormalities is purely speculative.

However, a new theoretical offering has been made by Levinson (1980), a neurologist who saw the "soft" neurological signs of disorders of balance, coordination and direction as "hard" localizing signs of a cerebellar-vestibular (c-v) dysfunction. Certainly the visual-occular problems often seen in dyslexics are as easily explained by c-v disorders as by cortical problems. Fusion failure occurring sub-cortically would result in subtle disability and be expected to be often associated with other evidence of brainstem dysfunction such as balance, motor and visual abnormalities.

The third, and perhaps the most surprising relationship delineated by the present study, is the relation of left ear scores to Full Scale WISC-R scores, and the failure of right ear scores to relate. Replication and investigation of WISC-R subtest scores in relationship to ear performance would be fertile ground for further study. One might argue that the average scores LD students achieved on the WISC-R indicate normal cortical function for language.

The fourth result is most widely supported by the literature. That is, learning disabled children appear to perform more poorly than their normal peers on a majority of language-related auditory measures. However, the failure of Total scores to correlate with Age is contrary to reports of age-related increase in auditory capacity of normal children found by Roeser, Millay, and Marrow (1983). Green's groups also demonstrated age-related improvement in Total performance. Roesser et al. (1983) and Obrzut et al.(1985) express the difference between LD and normal performance as difference in processor capacity which is possibly developmentally based. This study, however, found no basis for assuming an age-related improvement in the auditory processing skills of LD subjects. Since many assessment measures are predicated on evidence of age-capacity improvement, global performance deficits for LD children (Swanson,1983; Roush and Tait,1984; Obrzut et al., 1985; Watson and Rastatter,1985; Willeford and Burleigh,1985; Willis,1985; Ferre and Wilber,1986) may be the result of using testing instruments inappropriate to the learning patterns of the LD population.

What children do not hear may be more important than what they do hear. The method of counting only correct responses may be misleading and as such, should be viewed as a weakness in this work. If one were to compare only double correct (each ear response correct on comparable items) against correct/incorrect (one ear responding correctly, the other not), the effect of depressed overall performance would be removed.

The ability to listen selectively requires the capacity to filter extraneous stimulation. Therefore, dysfunction might occur were the subject either to under- or over-attend. This would result in lower scores. Furthermore, the ability to listen selectively might be asymmetrical, which would then produce asymmetrical ear scores. Of the five children in the present study who produced greater than 20% binaural deficit, only two had greater than 10% ear difference (Green's criterion for abnormality). One had a greatly deficit right ear performance; the other, a deficit left ear. The three other subjects having greater than 10% ear difference did not demonstrate deficits in the binaural condition. Ear difference alone, would not appear to interfere with speech comprehension and would not be considered clinical y significant.

The traditional audiometric battery administered as pre-test in this study left many questions unanswered. The use of middle-ear screening rather than full tympanometry, including tracings of acoustic reflex action, has resulted in an inability to isolate the lower brain-stem and receptor organs as possible sites of abnormality. Such information might well uncover sub-groups from the heterogeneous sample.

Audiometrics do not attend to an evaluation of the ability of the auditory system to differentially handle high and low frequency information. The system's architecture contains two complimentary but distinct processors, designed to respond differently to the phase characteristics of low frequency sound or the intensity characteristics of higher frequency sound. Hearing is, in many ways, analogous to vision. The inner and outer hair cells of the cochlea are comparable to the rods and cones to the eye. The cerebral hemispheres are accessed through the right and left hemifields of each eye. By what means may we access auditory cognitive areas without bilateral interference? The left-right dichotomy that marks the visual system may be, in the auditory system, analogous to high-low and fast-slow continua.

This paper has mentioned several authors who were investigating 'successive processing' skills. Luria (1973), and subsequently Das, Kirby, and Jarman (1975), have proposed a 'simultaneous-successive processing' model with which we might recast our thinking. Luria's model suggests that information is processed, according to stimulus characteristics, in a sequential (successive, temporal) or simultaneous (spacial) manner which diminishes in specificity of sensory modality from receptor to cortex. Applied to audition, which principally (although not exclusively) uses successive processing, the characteristics of speech and the the auditory system processor present us with new appreciation for the unity and concordance of our internal and external realities.

In information processing terms, successive and simultaneous processing systems work much like a computer's disk operating system. The computer uses different programming 'languages' to analyze different types of data. Perception, then, would be facilitated by a type of processing appropriate to the characteristics of the stimuli. One might speculate as to whether there are other types of processing. Or do we use parallel processing or switch from one mode to the other? Perhaps, with a new theoretical model, we will be able to bring order to the voluminous research already in our coffers.

Finally, due to features such as redundancy, reduplication, single channel capacity, and perceptual 'trading'[21] disruption of auditory processing should be no more than temporary. The brain of man is capable of perceptual re-coding following insult. As the brain re-codes visual-perceptual information and reorganizes the reaction systems following virtiginous triggers to altered visual-proprioceptive information, so should the brain engage compensatory strategies to handle auditory-perceptual aberrations. This might explain why the literatures of several disciplines (Education, Psychology, Audiology) reflect lack of consensus when dealing with auditory learning disabilities. Numerous studies have been unable to answer the seemingly simple question, "Is there an ear difference in speech comprehension?".

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[21], Variables may substitute for one another, e.g. lacking sufficient frequency resolution, increased intensity renders the information intelligible, and visa-versa.

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Appendix A

SUBTEST A 22 Word Stories BEFORE TEST - CHECK HEADSET DIRECTION

10.1 L R B
Kitten
The children O were watching O a policeman O climbing O up a tree. O He was rescuing O a white O kitten O that was sitting O on a branch. O

10.2 L R B
Channel
A 12 year old O boy O from Washington O broke O a world record O on Saturday. O He swam across O the English Channel O in four O hours. O

10.3 L R B
Birthday
Kathy's O father O gave her O a present O for her birthday. O She had expected O some chocolates O but in the box O there was O a dress. O

10.4 L R B
Arrest
A 15 year old O girl O stole O some jewelry O from a department O store. O A detective O followed her O into the street O and arrested her. O

10.5 L R B
Zoo
The children O spent an hour O looking at O animals O in the Zoo. O One gorilla O reached out O of his cage O and touched O the teacher. O

10.6 L R B
Charity
Twenty-seven O Canadian O children O collected O over $1000.00 O for charity. O The money was sent O to a school O for the blind O and the handicapped. O

SUBTEST B 26 Word Stories

10.1 L R B
Christmas
The presents O were opened O on Christmas day. O Peter O got a bicycle O from his father O and Annie O got a video game O from her great-uncle O in Scotland. O

10.2 L R B
Holiday
John O and Mary O went on holiday O with their parents. O In the aeroplane O they sat O near a window O and looked down O at the ships O in the sea. O

10.3 L R B
Classroom
Michael O was sitting O at the back O of the classroom. O When the teacher O turned around O and wrote O on the blackboard O he took a bite O from his sandwich. O

10.4 L R B
Dog Show
Janet O entered O her terrier O in a dog show. O The first prize O went to a bull dog O with no tail O but Janet's dog O won O the second prize. O

10.5 L R B
Squirrel
A squirrel O came down O from an oak tree O into the garden O and found O some peanuts. O Now the grey squirrel O comes back O every day O for more food. O

10.6 L R B
Circus
Roger O went to the circus O with his mother O and his sister O on Sunday. O They saw a monkey O on a trapeze O and a dog O riding O a horse. O

SUBTEST C 33 Word Stories

15.1 **Wolves**
L
R
B

Young O animals O play games O in order to practice O skills O which they will need O to survive. O Packs O of young wolves O sometimes capture O a deer O but instead of O killing it O they allow it O to escape. O

15.2 **Baby**
L
R
B

Jack O was going O to school O when he saw O a baby carriage O rolling O toward the road. O Dropping O his bag, O he ran O to save the baby O from rolling O into the path O of a speeding O truck. O

15.3 **Puppies**
L
R
B

When Roy O came home O he found O a basket O full O of clothes O on the porch. O When he took it O into the house O he heard O a squeak. O Inside the clothes O there were two O black O puppies. O

15.4 **Camping**
L
R
B

Carol O and Doug O were camping O near a river. O While they were cooking O their supper O they heard O a splash. O A fisherman O had fallen O out of his boat. O Doug O waded out O and pulled him O ashore. O

15.5 **Bears**
L
R
B

Car drivers O and motorcyclists O had stopped O on the roadside O in the park. O They were watching O a mother O bear O and three O cubs O which had come O from the forest O to eat O berries O in the ditch. O

15.6 **Strike**
L
R
B

Many O holidaymakers O were disappointed O when they arrived O at the airport O this weekend. O Passengers O on flights O to Florida O and Spain O were told O that the air traffic O controllers O had gone on strike O for higher pay. O

SUBTEST D 45 Word Stories

20.1 **Fishermen**
L
R
B

Three O fishermen O were stranded O when their engine O broke down O in the Atlantic. O Air Force O Helicopters O searched O for a week O but were unable to find them. O After 90 days, O two O survivors O were washed ashore O in their boat. O They had been living on O fish, O rain O and seawater. O

20.2 **Kidnap**
L
R
B

A month ago O a German O businessman, O who was staying O at an hotel O in Rome O was kidnapped. O This week O his wife O flew to O Italy O and announced O in a television O interview O that she would pay O the million dollar O ransom O if her husband O was returned to her O unharmed. O

20.3 **Caffeine**
L
R
B

The drug O caffeine O which is present O in coffee O can lead to O loss of sleep, O headaches O and depression. O These symptoms O can last O up to 2 days O after the last drink O of coffee. O Caffeine O is also found O in chocolate, O some cola drinks, O headache tablets O and frozen O puddings. O

20.4 **Racquetball**
L
R
B

Scientists O at the University of O Toronto O have been studying O hundreds O of eye O injuries O in racquetball players. O In 70 cases O the ball, O travelling O at 100 mph O had hit the eye directly, O causing damage O requiring a week O in hospital. O The players O had not been wearing O protective O glasses. O

20.5 **Prime Minister**
L
R
B

An Austrian O man O was arrested O when he was banging O on the Prime Minister's O door O with a rock on Thursday. O He was protesting O about being unemployed O and homeless. O The judge O found him O guilty O of causing O a public O nuisance O and sentenced him O to one month O in prison. O

20.6 **Pope**
L
R
B

While escaping O from detectives O a guerilla O suspect O was hit O by a car. O He told O security O forces O that there was a plot O to kill O the Pope O on his tour O of El Salvador. O Then he handed over O the passports O of 18 O sharpshooters O who had entered O the country. O

SUBTEST E 56 Word Stories

25.1 **Hijack**

L
R
B

The pilot O of a hijacked O Libyan O D.C. 10 O airliner O was told O to fly O to Malta. O When the plane landed O in Paris O to refuel, O a blizzard O grounded the aircraft O for 24 hours. O Eleven O children O and one woman O were allowed to leave O the plane. O Minutes later, O the hijackers O surrendered O after a surprise O assault O by an anti-terrorist squad. O

Railway

B

murder O suspect O drove a O stolen O red O convertible O at high speeds O after escaping O from police O on Saturday. O It sped toward a railway crossing O at the same time O as an express O train. O The engineer O braked O but the track O was icy. O The car O was thrown O across the road O and stopped O in the flower bed O of a children's O hospital. O

25.3 **Fire**

L
R
B

Many people O watched O the Fire Department O using ladders O for the rescue of O office O workers O from a burning O building O on McDonald Street. O As the fire chief O helped O an injured O man O into an ambulance O an explosion O threw him O to the ground. O A woman O who lit O a cigarette O near a damaged O gas pump O was accused O of starting the fire. O

25.4 **Airbrakes**

L
R
B

The co-pilot O of a medium-sized O plane O caught sight O of the airfield O when he noticed O that he was flying O too low. O He had to act quickly O to avoid O collision O with a skycraper. O He banked O right O sharply. O then circled O the airport. O Sighing O with relief, O he pulled O a lever O to lower O the wheels O and touched down O safely. O

25.5 **Bank**

L
R
B

Mary Robinson O of south O Calgary, O a bank O manager, O arrived first O on Friday O morning. O In the entrance O there were three O men O wearing masks O and carrying O shotguns. O They forced her O to open the safe O and then they tied O her hands. O At the rear exit O the police O stopped O the bank robbers O while questioning O the driver O of the getaway car. O

25.6 **Storm**

L
R
B

Expecting O the sunny O weather O to last all day, O a group O of inexperienced O climbers O proceeded O to the top O of the mountain. O Though they sheltered O behind a wall, O they were cold O and frightened O when a storm O arose. O For two O hours O they suffered O wind O and rain O and they came very close O to being struck O by lightning O near the peak. O

University of Alberta
Edmonton
Canada T6G 2G5

Faculty of Education
Clinical Services
1-135 Education North, Telephone (403) 43

August 8, 1986

Dear Mr. and Mrs. [redacted]:

Marlene Spencer-Noble, a graduate student in our department, is conducting a study to determine if some children have more difficulty understanding speech with one ear than the other; or if understanding is poorer when listening with both ears than with one ear. Several children between the ages of seven and ten years of age are needed as volunteers to participate in the study.

The study will involve screening each child's hearing to verify normal hearing sensitivity. If a child does not pass the hearing test, assistance will be given in referring the child to the appropriate agency or medical authority for further investigation of auditory function, if the parents so desire. Each child whose hearing is within normal limits will be fitted with headphones and asked to listen to several tape-recorded stories. He will then be asked to repeat what he has just heard. The elements of the stories that have been recalled and repeated will be analyzed according to the ear to which the story was presented. The entire proceedure should take between 1 and 1 1/2 hours. All information obtained on your child will be treated in the strictest confidence.

Testing will be done in the North Education Building on the University of Alberta campus. Mrs. Noble hopes to complete testing by the end of September. A copy of the results of the study will be available to parents by the end of the year.

If you would be willing to allow your child to participate in this study, please contact Mrs. Noble during the day by leaving a message at 432-5213, or call 455-2066 after 3:00 p.m. for an appointment or further information.

Thank you for your consideration.

Sincerely,

J. G. Paterson, Ed.D.
Coordinator

University of Alberta
Edmonton

Canada T6G 2G5

Department of Educational Psychology
Faculty of Education

6-102 Education North, Telephone (403) 432-5245

I understand that assessment of hearing in this laboratory is conducted by and for the primary benefit of students of the University of Alberta who are not qualified audiologists.

Information may be used for teaching purposes, but my privacy will be respected and confidentiality maintained. Information may be released upon my request to persons of my designation.

Client: [redacted]

Date: Aug 16/86.

Address: [redacted].

Phone: [redacted]

To Whom It May Concern:

I, ______________________________, give my permission to Marlene S. Noble to include my child, ______________________________, as a subject in her thesis study. She may publish the results, but will maintain our privacy and use good taste in her representation of the data. I authorize my child's school and/or doctor to make available any information that might relate directly to Mrs. Noble's study.

____
Name

____
Relationship to subject

____
Date

UNIVERSITY OF ALBERTA
Hearing Impaired Program
AUDIOMETRIC EVALUATION

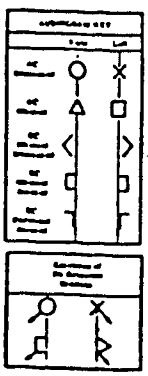
Name________________ Phone________ B.D.__________ Date__________

Address ________________ City__________ Examiner__________

Parents __________ Referred by ________________ Address__________

SPEECH AUDIOMETRY

	R	L	SF
AVE. P.T.	dB	dB	
SRT	dB	dB	dB
MCL	dB	dB	dB
Sp. Disc	%	%	%
Disc/ Noise	%	%	%
UCL	dB	dB	dB



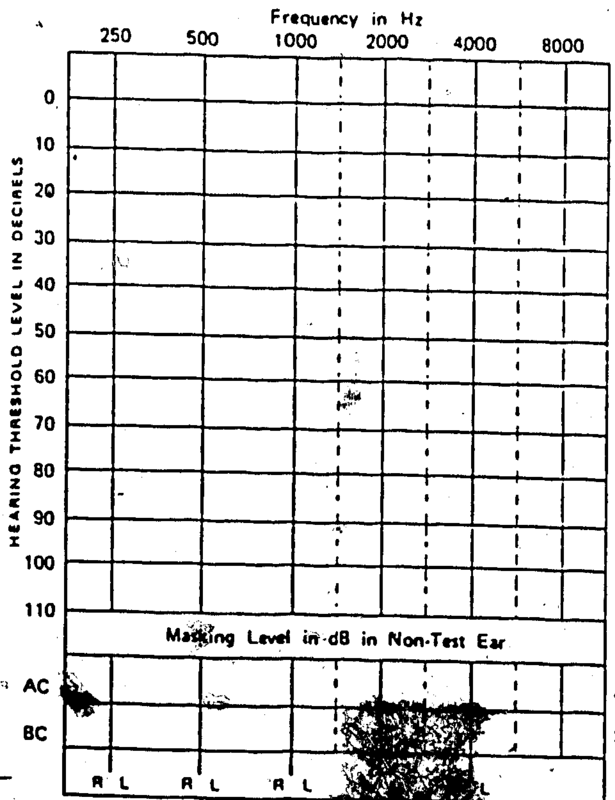
RELIABILITY: __________

AUDIOMETER: __________

COMMENTS: __________

AMPLIFICATION __________

PURE TONE AUDIOGRAM
(ANSI 1969)



SPEECH DISCRIMINATION

WIPI W22 PBK OTHER LV REC

Rt __________ % at __________

Lt __________ % at __________

Field __________ % at __________ db (unaided)

__________ % at __________ db (aided)

SPEECH RECEPTION / AWARENESS THRESHOLD

LIVE VOICE SPONDEES OTHER

RT __________ dB Lt __________

FIELD: __________ dB (unaided)

__________ dB (aided)

90

100

110

AC

BC

IMPEDANCE AUDIOMETRY

	Frequency 500	1000	2000	4000
R	dB	dB	dB	dB
L	dB	dB	dB	dB

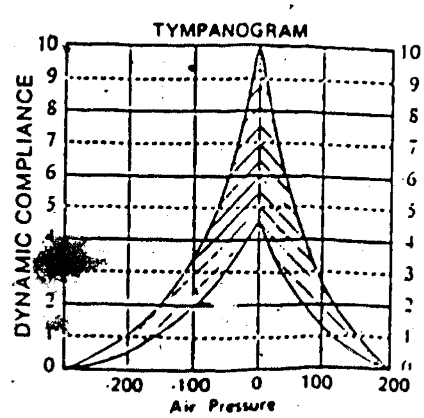
ACOUSTIC REFLEX

STATIC COMPLIANCE

	C_1	C_2	C_x
R	cc	cc	cc
L	cc	cc	cc

Normal Range For C_x: .27-1.5cc

TYMPANOGRAM



SUBJECT SUMMARY SHEET

Name: ____________ Date of Testing: ____________

Date of Birth: ____________

Exact Age: ____________

Parents Name: ____________

____

Phone Number: ____________

Sex: ________ Grade: ________

School: ____________

Special Program: ____________

Address: ____________

____

WISC-R VS= ______ PS= ______ FS= ______

History: ____________

____

____

PTA(L) = _____dB HL; PTA(R) = _____dB HL

SRT(L) = _____dB HL; SRT(R) = _____dB HL

SRT (Both) = _____dB HL; FF= _____dB HL

SD-Q(L) = _____%; SD-Q(R) = _____%

SD-Q(Both) _____%; FF= _____%

SD-N(L) = _____%; SD-N(R) = _____%(s/n-0)

Tymps(L) _____ Tymps(R) _____

Reflex(L) _____dB; Reflex(R) _____dB Cont.

Otoscopic: ____________

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				

Total Score = _____%

Ear Difference = _____%

Binaural quotient = _____%

	FREE FIELD		
	occ	∅occ	
A			
B			
C			
D			

FREE FIELD

SRT dB		SDQ - %		ACT	
Occ	∅Occ	Occ	∅Occ	Occ	∅Occ

Ear occluded: L R

Lead Condition: occ ∅occ

Blank Score Sheets

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				

Total Score = ______ %

Ear Difference = ______ %

Binaural quotient = ______ %

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				
E				

Total Score = ______ %

Ear Difference = ______ %

Binaural quotient = ______ %

Perfect Scores Tabulated

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A	10	10	10	30
B	10	10	10	30
C	15	15	15	45
D	20	20	20	60
	55	55	55	165

Total Score = 100 % $\frac{100}{165} \times 165 =$

Ear Difference = 0 % $\frac{R-L}{R+L} \times 100 =$

Binaural quotient = 0 % $\frac{B-HS}{B} \times 100 =$

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A	10	10	10	30
B	10	10	10	30
C	15	15	15	45
	20	20	20	60
	25	25	25	75
	80	80	80	240

Total Score = 100 % $\frac{100}{240} \times 240 =$

Ear Difference = 0 % $\frac{80-80}{80-80} \times 100 =$

Binaural quotient = 0 % $\frac{80-80}{80} \times 100 =$

Appendix B

SUBJECT DATA

(N=18)

AGE

Months	Freq.	%	Cum.%
80	1	5.6	5.6
82	1	5.6	11.1
89	2	11.1	22.2
99	1	5.6	27.8
103	1	5.6	33.3
114	2	11.1	44.4
115	1	5.6	50.0
118	1	5.6	55.6
119	3	16.7	72.2
122	1	5.6	77.8
123	1	5.6	83.3
126	1	5.6	88.9
132	1	5.6	94.4
142	1	5.6	100.0

Mean=111.39, SD=17.39

DIQ

Value	Freq.	%	Cum.%
89	2	11.1	11.1
90	1	5.6	16.7
93	1	5.6	22.2
96	1	5.6	27.8
98	1	5.6	33.3
100	1	5.6	38.9
101	2	11.1	50.0
103	1	5.6	55.6
105	1	5.6	61.1
107	1	5.6	66.7
109	3	16.7	83.3
110	1	5.6	88.9
111	1	5.6	94.4
114	1	5.6	100.0

Mean=101.89, SD=8.01

VERBAL

Value	Freq.	%	Cum.%
84	1	5.6	5.6
85	1	5.6	11.1
87	1	5.6	16.7
95	1	5.6	22.2
96	1	5.6	27.8
98	1	5.6	33.3
100	2	5.6	44.4
101	2	11.1	55.6
103	1	5.6	61.1
108	2	11.1	72.2
112	2	11.1	83.3
113	1	5.6	88.9
115	1	5.6	94.4
119	1	5.6	100.0

Mean=102.06, SD=10.29

PERFORMANCE

Value	Freq.	%	Cum.%
78	1	5.6	5.6
87	1	5.6	11.1
90	1	5.6	16.7
92	1	5.6	22.2
93	1	5.6	27.8
95	1	5.6	33.3
96	2	11.1	44.4
100	1	5.6	50.0
104	2	11.1	61.1
108	1	5.6	66.7
109	1	5.[illegible]	72.2
111	1	5.6	77.8
112	1	5.6	83.3
118	1	5.6	84.9
120	1	5.6	94.4
123	1	5.6	100.0

Mean=102.00, SD=12.24

LEFT EAR

Score	Freq.	%	Cum.%
32	1	5.6	5.6
34	1	5.6	11.1
36	3	16.7	27.8
39	1	5.6	33.3
44	1	5.6	38.9
47	1	5.6	44.4
49	1	5.6	50.0
50	1	5.6	55.6
51	2	11.1	66.7
56	1	5.6	72.2
57	2	11.1	83.3
58	1	5.6	88.9
65	1	5.6	94.4
72	1	5.6	100.0

Mean=48.33, SD=11.36

RIGHT EAR

Score	Freq.	%	Cum.%
23	1	5.6	5.6
32	1	5.6	11.1
37	1	5.6	16.7
38	2	11.1	27.8
45	1	5.6	33.3
47	1	5.6	38.9
48	2	11.1	50.0
50	1	5.6	55.6
51	1	5.6	61.1
52	1	5.6	66.7
54	1	5.6	77.2
55	1	5.6	72.8
57	1	5.6	83.3
61	2	11.1	94.4
66	1	5.6	100.0

Mean=47.94, SD=11.03

BOTH EARS

Value	Freq.	%	Cum.%
30	1	5.6	5.6
32	1	5.6	11.1
33	1	5.6	16.7
34	1	5.6	22.2
36	1	5.6	27.8
41	2	11.1	38.9
43	1	5.6	44.4
44	1	5.6	50.0
47	1	5.6	55.6
51	2	11.1	66.7
53	1	5.6	72.2
55	1	5.6	77.8
58	2	11.1	88.9
60	1	5.6	94.4
61	1	5.6	100.0

Mean=46.00, SD=10.34

TOTAL SCORE

Value	Freq.	%	Cum.%
87	1	5.6	5.6
96	1	5.6	11.1
106	1	5.6	16.7
108	1	5.6	22.2
125	1	5.6	27.8
132		5.6	33.3
140	[illegible]	11.1	44.4
148	1	[illegible]	[illegible]
151	1	[illegible]	[illegible]
157	1	[illegible]	[illegible]
159	1	5.6	62.7
160	1	5.6	77.2
162	1	5.6	73.8
165	1	5.6	84.3
167	1	5.6	84.9
178	1	5.6	90.4
180	1	5.6	100.0

Mean=142.28, SD=27.91

EAR DIFFERENCE

%Score	Freq.	%	Cum.%
-30.9	1	5.6	5.6
-19.3	1	5.6	11.1
-07.7	1	5.6	16.7
-06.9	1	5.6	22.2
-06.6	1	5.6	27.8
-05.5	1	5.6	33.3
-03.0	1	5.6	38.9
-02.1	1	5.6	44.4
00.0	1	5.6	50.0
01.4	1	5.6	55.6
02.7	1	5.6	61.1
03.1	1	5.6	66.7
03.3	1	5.6	72.2
03.4	1	5.6	77.8
07.3	1	5.6	83.3
11.1	1	5.6	88.9
13.8	1	5.6	94.4
16.1	1	5.6	100.0

Mean=-01.10, SD=11.36

BINAURAL QUOTIENT

%Score	Freq.	%	Cum.%
48.8	1	5.6	5.6
41.5	1	5.6	11.1
-36.1	1	5.6	16.7
-30.9	1	5.6	22.2
-29.4	1	5.6	27.8
-16.3	1	5.6	33.3
-14.9	1	5.6	38.9
-13.3	1	5.6	44.4
-12.1	2	11.1	55.6
-11.8	1	5.6	61.1
-07.8	1	5.6	66.7
-02.7	1	5.6	72.2
-01.7	1	5.6	77.8
00.0	1	5.6	83.3
03.4	1	5.6	88.9
03.7	1	5.6	94.4
16.6	1	5.6	100.0

Mean=-14.21, SD=17.26

Appendix

Green had assessed 36 learning disabled children who had been referred to him by various sources, primarily parents who had read about his work. The children were distinguished by the fact that they were "...thought by school staff or parents to have prominent auditory discrimination or memory deficits..."(personal communication, February, 1987). Of these thirty-six children, eighteen were boys of similar age to the subjects of this study. These eighteen were used as a comparison group in post hoc analyses.

Of the 132 normal Edmonton school children originally reported by Green (1986), thirty-five were males between the ages of 7 and 11 years. Raw ACT scores were also made available to this author for use as control data. Thus, three groups of data were available for post hoc analyses:

<u>Group 1</u> - Experimental learning disabled

<u>Group 2</u> - Normal control (EPSB)[22]

<u>Group 3</u> - Green's learning disabled (St.A)[23]

Permission to use the data for thesis purposes was given. The information was unanalyzed, and was from a larger study. Selected data were used in this report, some of which have been transformed to be comparable with the abbreviated (A through D) ACT scores obtained for the experimental group reported in the body of this paper.

The purpose of analysis was to determine if the experimental group (Group 1) performed significantly

----

[22] Edmonton Public School Board students.
[23] St. Albert school students.

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THE UNIVERSITY OF ALBERTA

EAR DIFFERENCES AND SPEECH COMPREHENSION IN CHILDREN WITH LEARNING DISABILITIES

by

MARLENE SPENCER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF EDUCATION

IN

SPECIAL EDUCATION

DEPARTMENT OF EDUCATIONAL PSYCHOLOGY

EDMONTON, ALBERTA

FALL 1988

ISBN 0-315-45798-8

THE UNIVERSITY OF ALBERTA

RELEASE FORM

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DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF EDUCATION

YEAR THIS DEGREE GRANTED 1988

(SIGNED) Marlene Spencer

PERMANENT ADDRESS:

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Edmonton Alberta

Canada

DATED September 21 1988

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled EAR DIFFERENCES AND SPEECH COMPREHENSION IN CHILDREN WITH LEARNING DISABILITIES submitted by MARLENE SPENCER in partial fulfilment of the requirements for the degree of MASTER OF EDUCATION in SPECIAL EDUCATION.

M. Rodda
....
Supervisor

....

....

Date...20th September 1988...

Dedication

To a paragon, whose reverence for the architecture of life nurtured my interest in the miracle of hearing:

What a piece of work is man!
How Noble in reason!
How infinite in faculties!
In form and moving,
  how express and admirable!
    Hamlet, Act II, Scene 2.

Abstract

For normally hearing persons, listening to speech with both ears usually improves comprehension. There is some disputed evidence in the literature that children with learning disabilities may function more poorly than their normally achieving peers when listening with both ears. Eighteen normally hearing learning disabled boys between the ages of six and eleven years were administered an auditory comprehension test, under headphones, in controlled audiometric conditions. Using each subject as his own control, a single factor analysis of variance for dependent measures revealed no statistically significant differences in mean recall of test stories between left and right ears, although the left ears scored slightly higher than the right. No statistically significant differences between single ear and binaural listening were found, although a mean 14.2% binaural deficit was present. Post hoc analyses using Pearson product-moment correlations indicated that right ear performance was largly responsible for lower binaural scores. Left ear scores were related to intelligence test scores, but age did not affect any measure. When compared to scores reported in the literature, the experimental group demonstrated a statistically significant deficit in total items recalled in all listening conditions compared to normally functioning students. Therefore, listening with the best single ear, the

experimental group experienced a non-significant improvement in speech comprehension of 14.2% over binaural listening conditions, such as are found in home and school environments.

Acknowledgements

To Dr. Michael Rodda - for the support and many fascinating academic experiences provided during my studies.

To Dr. Ken Gough - for his breadth of knowledge which is exceeded only by his depth of friendship.

To Dr. Dick Sobsey - from whom I have received alternate aid, learned alternate strategies, and seen alternate futures.

To Dr. Paul Green - whose enthusiasm and hard work have provided the provocative base from which this study has sprung.

To Dr. Dwight Harley and Dave Brown - who have helped extend my analytical skills to cover the task at hand.

To Dr. John Paterson and the Education Clinic staff - for aiding in the search for subjects.

To the Computing Services consultants, CMPA staff, and library staff - for facilitating search and construction.

To the charming, patient boys who participated in this study, and to their parents who contributed time and support in hopes that all children may benifit from the interest students and researchers take in their children.

To Patti, Bruce, Derk, and Andra - who have read, discussed, proofed, argued, guided and improved this paper.

To my mother and daughters - who have been waiting a very long time to read this volume.

To all - please accept my accolades, kudos and thank you.

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I. Introduction

The term *speech comprehension* is used to indicate an individual's intelligent grasp of the meaning of linguistic stimuli presented to the ear. One component of comprehension is the ability to accurately perceive the stimulus in properly sequenced order, and to hold elements of the stimulus in memory for recall upon completion of the message (Cowan, 1984).

A decrement in speech comprehension can be caused by stimulus degradation or alteration, or by the state of the organism, which includes general intellectual ability (Green, 1984a). In fact, a difference in performance may exist within a single individual which is related to the ear of presentation of the stimulus and the method of presentation. The listening condition in which both ears are presented with the same stimulus is a *diotic* task. If the stimuli to each ear are different we say the presentation is *dichotic*. A stimulus presented to one ear alone (monaural listening) is *monotic*. An individual may perform speech comprehension tasks differently under different listening conditions, while listening to different modes of stimulus presentation, or when listening to materials of varying characteristics (Geffen & Quinn, 1984).

Geffen & Quinn (1984) have presented an excellent review of the findings of 71 studies concerning best ear performance (ear advantage), method of stimulation, type of stimulation, and some associated neurological conditions related to this topic. It is clear that many researchers are interested in solving the puzzle of the nature of human auditory processing and understanding the characteristics of various populations as a means of delineating the processes of speech comprehension.

The practical value in understanding the processes of speech comprehension is the application of the resulting knowledge for the benefit of those individuals who experience difficulties with this process in everyday life situations. A finding of interest is one reported by Green (1983). He observed that poor speech comprehension could be improved in certain populations by the placement of an ear-plug in a poorer performing ear:

> It has been found that this procedure does, indeed, produce increases in the everyday understanding and recall of complex speech in patients studied...(p.16).

Green's experimental populations were schizophrenics, at-risk children of schizophrenics, and other psychoneurologic populations (1978, 1983; Green, Hallett, & Hunter, 1983; Green & Kotenko, 1980; Green & Preston, 1981; Hallett & Green, 1983). He used his own <u>Auditory Comprehension Test</u> (ACT, Green & Kramer, 1983) to measure recall of speech elements in stories presented to left, right or both ears under headphones.[1] The experimental groups demonstrated large differences in comprehension between ears as well as a deficit in the binaural listening condition. The subjects' comprehension scores increased by

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[1] The ACT protocol can be found in Appendix A.

the amount of their binaural deficit (compared to better ear scores) when using a wax earplug to occlude the individual's poorer ear during testing in 'free field' listening to speakers in an office.

The implications of being able to improve comprehension of speech by so simple and inexpensive a treatment as an earplug are far-reaching. If significant ear differences or binaural deficit could be found to be characteristic of other populations, and if occluding one ear improved comprehension, almost instant diagnosis and remediation could be provided.

Research initiated by Green's work include an M.A. thesis (Waine, 1984) using items from the Revised Token Test (McNeil & Prescott, 1978) looking for ear advantage or binaural deficit in a population of learning disabled children. None was found. Katz referred to Green's work in his revision of The Handbook of Audiology(1985), and is including the ACT in the learning disabilities test battery used at his clinic at the State University of New York (personal communication, February 23, 1984). The Edmonton Public School Board, Edmonton, Alberta, Canada, has begun a large-scale, longitudinal study of learning disabilities and remediation using earplugs prescribed according to Green's model (A. Hillyard, personal communication, April 3, 1985 and P. Green, February, 1987). Green's work continues at the Alberta Hospital Edmonton as co-workers, such as L. Yeudall, plan to investigate electrical and chemical brain activity during occluded and unoccluded listening by psychiatric patients (Elash, 1985).

One group that could derive significant benefit from improvement in speech comprehension is that population of children identified as having *auditory learning disabilities*. The United States Federal Learning Disabilities Definition (1977) gives a general description of auditory learning disabilities. The main characteristic of this disorder is the presence of achievement not commensurate with age and ability and problems in listening comprehension which are not due to hearing handicap or lack of experience. A more specific definition is provided in U.S. Public Law 94-142:

> Significantly below-average performance in auditory comprehension and listening
> A. Difficulty in following directions
> B. Difficulty in comprehending or following class discussion
> C. Inability to retain information received orally
> D. Difficulty in understanding or comprehending word meanings
> (cited in Gearhart & Weishahn, 1984, p.213)

Although children with auditory learning disabilities have been extensively studied with such tools as the Willeford Battery (Willeford and Billger, 1978) and the Word Intelligibility by Picture Identification Test (Ross & Lerman, 1971), they have not been studied using Green's Auditory Comprehension Test.

In a discussion of the clinical use of natural sentences with children, Willeford and Billger (1978) found that normal children demonstrate a stronger or dominant (higher scores) right ear and that symmetry of ear performance converges until, at the age of 9 years, no ear differences exist in response to dichotic stimulation. They relate unusual performances to different lateralization patterns or to maturational differences in the auditory-cortex. The Willeford Battery (1976a), including tests of 1) dichotically competing sentences, 2) filtered consonant-nucleus-consonant words, 3) binaural fusion of dichotically presented spondiac words, and 4) an alternating speech task, produced a 90% failure rate on one or more tests by 150 learning disabled children referred for testing. Willeford found that greater than a 10% difference between left and right ear scores beyond the age of 9 years was significant and considered abnormal. Unfortunately, aone of the tests in the battery used the diotic mode of stimulus presentation as did Green's ACT. Therefore, binaural listening scores were not comparable with the both ear (BE) scores presented in this paper.

Roush and Tait (1984), using the Word Intelligibility by Picture Identification (Ross & Lerman, 1971), compared both dichotic and diotic fusion and found that children with language-learning disabilities differed from normal controls in all conditions. They performed best with diotic presentation, better with dichotic (low-pass filtered stimuli to the right ear), and least well with dichotic (low-pass filtered stimuli to the left ear). There was no group interaction. The authors found that *diotic enhancement* above 10% of the averaged dichotic (L and R) scores successfully identified the learning disabled subjects.

All test items in the Roush and Tait and Willeford batteries (except the competing messages, which were given dichotically) used single word stimuli. There is a need to look at performance using natural complex speech, diotically presented. This can be done using Green and Kramer's ACT (1983). The present study administered the ACT to 18 male students (7-11 years of age) who had been identified by the University of Alberta Education Clinic as having probable learning disabilities. ACT performance scores under headphones for left, right and both ears were analyzed for ear difference[2] and binaural relative to best ear performance (Binaural Quotient)[3]. An ear difference greater than 10% was to be considered significant. A Binaural Quotient 10% poorer than best ear performance is significantly deficit (Green & Kramer, 1983).

The purpose of the present study was to verify the presence of a binaural deficit or significant ear difference in the speech comprehension of children with auditory learning disabilities as measured by scores on the Auditory Comprehension Test (Green & Kramer, 1983) under headphones. ACT performance scores were analyzed to determine if age or intelligence were factors affecting performance under experimental listening conditions (L,R, Both, Total, ED, or BQ).

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[2] (R-L/R+L)x100=Ear Difference (ED)
[3] (Both-High Ear/Both)x100=Binaural Quotient (BQ)

II. Prior Research

A. The Routing of Auditory Messages

The lateral differences between left and right ears when hearing complex stimuli reflect the physiological structure of the auditory system. Auditory neurons decussate at the level of the cochlear nucleus (CN); that division and reduplication becoming more elaborate and diffuse at each more central synapse. The crossed fibers are more numerous than the uncrossed. This has been assumed to result in a stronger, more dominant response from the contralateral hemisphere (Bocca, Calearo, & Cassinari, 1955; Geffen & Quinn, 1984; Kimura, 1961a, 1961b, 1967).

Leong (1974) outlined the routes of auditory messages. There are two ipsilateral pathways. One is directly through ipsilateral neurons (see Fig. 1). The other is through the contralateral radiations and back to the ipsilateral temporal lobe through the corpus callosum. This routing may explain the lack of decriment following temporal lobectomy.

The contralateral route is less direct than the ipsilateral, but more direct than the callosal route. This is reflected in research measurements pre- and post-operatively of timed responses by Milner, Taylor, and Sperry (1968) and Efron (1963). Efron found that a 2 to 6 msec differential between ears was needed to judge tones as silmultaneous, the non-dominant hemisphere needing greater time to perceive the tones.

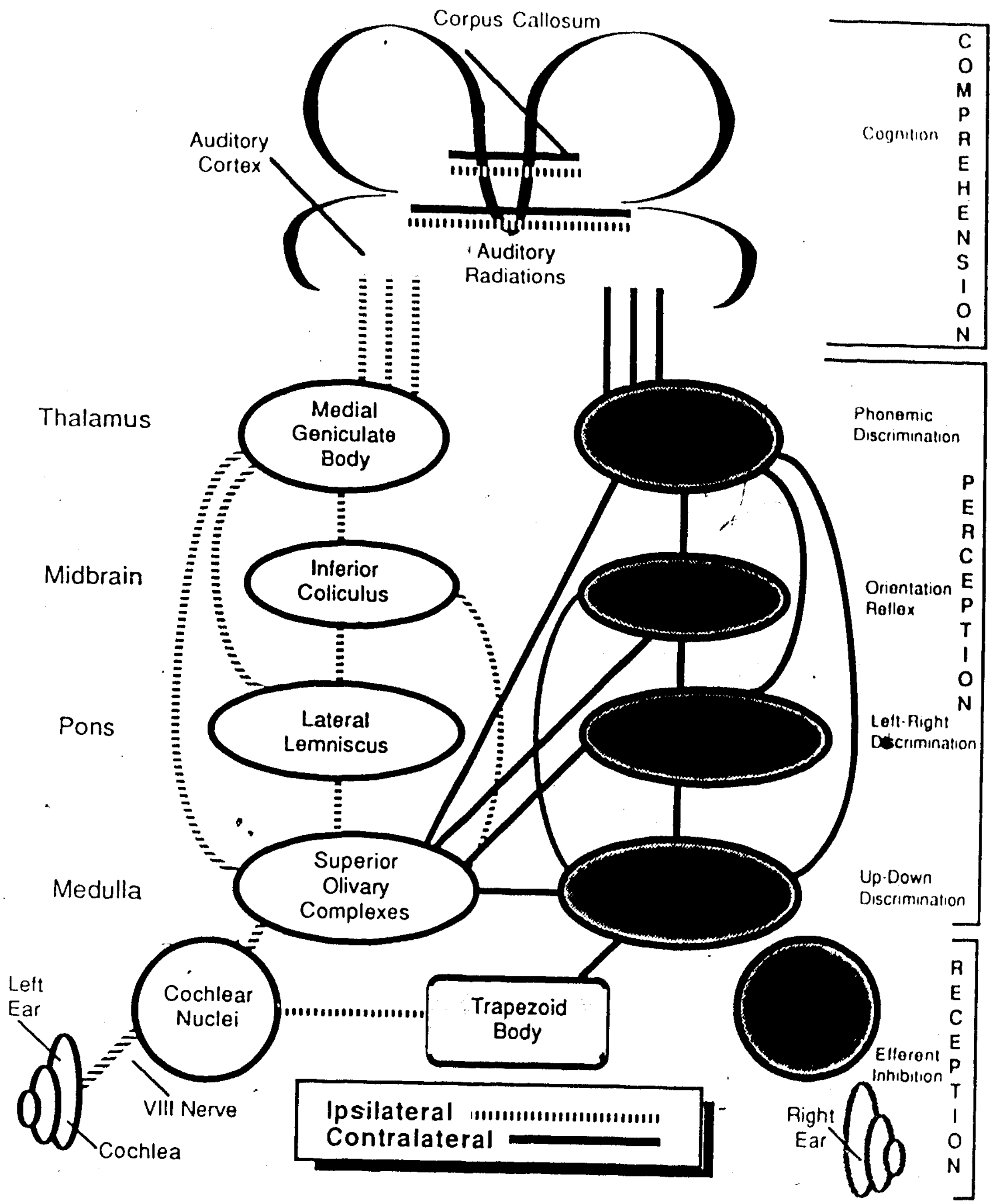

Figure 1. Ascending auditory pathways and levels of processing.

Brain-stem evoked response (BSER) audiometry has measured a conduction time (from ear to cortex) of approximately 4 milliseconds. There was little increase in latency between contralateral and ipsilateral response under monotic or diotic conditions (Skinner, 1978).

The data from laterality experiments show that the auditory system is sensitive to temporal differences equal to 10 microseconds (Yost & Nielsen, 1977). This remarkable resolving power, when considered in light of dichotic verbal stimulus presentation might indicate that the 2 - 6 millisecond ear difference noted by Efron (1963) represents cortical processing time for complex stimuli.

B. Anatomy and Physiology of Binaural Hearing

Binaural hearing is not simply a result of bilateral representation of ascending and descending pathways. From the first decussation, binaural cells can be differentiated from cells that respond to monaural stimulation.

The cochlear nuclei (CN) receive input from a single ear, but projections ascend directly to all higher brainstem nuclei (Eldredge & Miller, 1971; Gelfand & Hochbers, 1976 ; Harrison, 1978; Pickles, 1982; Ravizza & Belmore, 1978; Warr, 1982; Yost & Nielsen, 1977) [4]. The cochlear nuclei are thought to function as simple relays (Pickles, 1982), but three divisions, having different cell types and response characteristics, must serve different functions (Gelfand &

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[4]Approximately two-thirds of the CN fibers decussate (Yost & Nielsen, 1977).

Hochbers, 1976).

Mylinated projections synapse in the trapezoid body at the calyx of Held, a large, reliable[5] synaptic ending, ideal as a short-latency rapid conductor (Harrison, 1978) which could compensate for the increased transmission time from the contralateral ear. Perhaps this enables the superior olivary complex (SOC) to compare data from the two ears; then, by the direct first-order fibers, receive additional information that would be identified as contralateral in origin. The SOC is the first waystation that receives binaural input. It maintains, as do all nuclei, the frequency map of the cochlear epithelium.

The lateral superior olive (LSO) is ipsilaterally dominant (Eldredge & Miller, 1971). It contains binaural cells which are sensitive to interaural intensity differences, but are not sensitive to overall intensity. Thus stimulation of the ipsilateral ear does not yield a response unless the opposite ear is also stimulated. In this way, the LSO binaural cells can detect the movement of sound in a horizontal plane in environmental space. This is a high frequency system, as it uses intensity cues to operate.[6]

The medial superior olive (MSO) is quite pronounced in man, and in all animals who rely heavily on vision. Harrison

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[5]Reliable, in that it maintains its integrity when ipsilateral lesions or ablation of the SOC result in deterioration of other peripheral neurons.

[6] According to Harrison (1978), the LSO is small or vestigal in man, probably because man has a large head and poor high frequency hearing. Also it has little biological importance for survival in man.

(1978) found a high correlation both between eye and MSO size and an inverse relationship with LSO size. The MSO is well adapted to carry on interaural time difference analyses by which the organism can identify the direction from which low frequency environmental sounds originate. From the MSO, the lateral lemniscus (LL) and the medial geniculate (MG) receive the information needed to activate an orientating reflex to environmental sound involving the contralateral head, eye and pinna, all of which orient toward transient environmental stimuli.

The MSO receives temporally matched and temporally accurate signals from the two ears (Pickles, 1982). But, unlike the LSO, which is ipsilaterally dominant, the MSO is contralaterally dominant. Unlike the LSO, which is high frequency sensitive, the MSO is middle to low frequency sensitive. Unlike the LSO, which analyzes intensity differences, the MSO analyzes temporal differences. Yet, like the LSO, the MSO is composed of binaural and monaural cells. Under low frequency stimulation all cells reflect interaural time differences by discharge rate and degree of synchrony with phase of the stimuli. Cells phase-lock and summate for maximum firing. When interaural phase differences are greater than 180 degrees, however, discharge rates become lower than for stimulation of either ear alone. This is called *in-phase facilitation* and *out-of-phase inhibition* (Eldredge & Miller, 1971). The system responds in a similar manner to complex sound envelopes such as speech

(Pickles, 1982).

Eldredge says that the Japanese researchers Watanabe, Liao and Katsuki report:

> ...if a tone burst starts in one ear before the other, then the leading ear can *capture* the cell. The cell may be unresponsive to stimulation of the lagging ear for as long as 50 msec. This situation is often asymmetrical...a particular cell may be captured by a leading stimulus to the left but not to the right.(Eldredge & Miller,1971, p.301)

Thus, the SOC is a major processor of binaural information. It is involved with comparative analyses of stimuli time and intensity characteristics which allow it to particpate in the perception of the azimuth of an acoustic environmental event. Localization of auditory stimuli is require for identification.

The source of knowledge regarding the lateral lemniscus (LL) comes primarily from ablation studies, and is based upon hearing abnormalities produced by lesions. Because of the close geographical position of the LL and the inferior colliculus (IC), functions of the two areas are difficult to differentiate.

Harrison (1978) described Masterson's studies in which cats wearing earphones were taught left-right descriminations which disappeared after unilateral lesions of the LL. The cats continued to make left-right (lateralization) discriminations, but could not transfer the L-R task to a L-R/R-L task as they had. However, they could be retained on the L-R/R-L task. Can the LL learn?

The important feature of the cat studies is that for any behavior disrupted by transection of the LL, relearning could take place. It should be pointed out that the LL has the greatest communication with the reticular activating system (RAS) of any auditory nucleus. The RAS receives information from all sensory systems and forms an indirect route of communication between many parts of the brain (Durrant and Lovrinic, 1977; Willeford & Billger, 1978).

All ascending fibers appear to have synapses with neurons in the thalamus at the medial geniculate body (MGB), the last waystation from which the auditory radiations to the temporal lobe in the cortex originate (Durrant & Lovrinic, 1977; Willeford & Burleigh, 1978). The auditory radiations ascend to the homolateral hemisphere without decussation.

As to the function of the MGB, Durrant and Lovrinic reason:

> There is a trend towards increased specialization of neurons in the upper levels of the brainstem auditory pathways which permit them to detect specific features of the stimulus. This, in turn, can and doubtlessly does facilitate the processing of complex sounds such as speech. This capability is very well illustrated by neurons in the cat's medial geniculate which have been found to respond differentially to phonemes. (1977, p.127)

The neurons of the primary auditory cortex appear not to have generated haphazardly, but from a complex representation of the cochlear epithelium along an expanded one-dimensional plane(iso-frequency contour). Middlebrooks, Dykes, & Merzenich (1980) report finding two different populations of neurons arranged in alternate bands transversing the length of the iso frequency contours which may have different functional roles. These are binaural cells, which correlate well with the *binaural interaction columns* identified by Imig and Adrian as *summation units*. These respond better to binaural stimulation than to either ear alone. *Suppression units*, respond better to single contralateral ear stimulation or supression from the ipsilateral ear. Middlebrooks et al. also reported that "Cortical (binaural) neurons are sensitive to interaural intensity differences, while they are relatively insensitive to net binaural intensity (1980, p.46)".

Man is well designed for efficient low-frequency binaural hearing which is suitable for processing speech in noisy environments. In fact, stimulus dominance more accurately reflects functional brain organization than does ear dominance (Geffen & Quinn, 1984). Advantages of binaural over monaural hearing pertain to the ability of the auditory system to use *difference* cues of time and intensity to localize a sound and attend to one acoustic pattern from a milieu of patterns.

Binaural summation refers to the ratio of growth in perceptual loudness between monaural and binaural conditions which grow as a power function of sound pressure with an exponent of about 0.066. In other words, two ears give almost twice as much volume as one, when listening to conversational speech (Reynolds & Stevens, 1960). Loudness at each ear will be different depending on the orientation of the head to a sound source (Harris, 1960).

The time of arrival at each ear of the first sound in a stimulus (first wave front) is important to the ability to localize a sound in external space (Harris, 1960; Yost & Nielsen, 1977). Intensity difference is a more important cue for locating high frequencies, time difference is more important for localization of lower frequencies. Diotic headphone stimulus presentation precludes detection of inter-aural time and intensity difference by limiting head movement around the sound source. Under headphones, binaural sounds are perceived to emanate from within the head. This internal space location is called *lateralization*, to distinguish it from the more normal free field listening space identifications, which we call *localization* (Harris, 1960).

The time and intensity of signals reaching the two ears under normal listening conditions <u>and</u> under headphones must fall within certain limits for the two auditory images to fuse (Harris, 1960). Under headphones, if the left and right images fail to fuse, both can be heard at different locations within the head. No studies have been found that address the problem of fusion failure under normal binaural listening conditions in free field using speech stimuli. Under headphones, the auditory signal fuses when inter-aural phase (time) differences are less than 80 degrees. In free field, binaural intelligibility gain is greatest when there exists a 180 degree phase difference between ears for speech.

Sound reverberation and low level environmental noise provide some masking in everyday situations. Signal identification is improved by a *binaural gain in intelligibility* or *binaural release from masking* (Levitt & Rabiner, 1967). Licklider (1948) pointed out that mere two-ear duplication of information would be relatively useless. When one ear provides somewhat different information which is supplementry to the other, intelligibility is enhanced by the comparison of that information. In this way release from masking is different from the enhancement of signal detection experienced under headphones when a masking noise is introduced and which takes place in the cortex and is not due to additional information supplied by a second ear.

To summarize, individuals with normal hearing are better able to localize and int pret speech in a sound field with two ears than with one. Under headphones second ear increases stimulus intensity. At suprath levels, this factor does not improve an already 'normal' performance of 100% intelligibility. Degredation of performance becomes a function of attention, fatigue or memory. Therefore, binaural speech comprehension scores would be predicted to be equal to "best ear" scores. Binaural enhancement of diotic stimuli would indicate a failure to control phase, intensity or ambient noise in the experimental condition. In this way diotic and monotic performances are comparable.

C. Cortical Processing of Speech and REA

With the presentation of a pair of dichotic[7] stimuli having a stimulus onset asynchrony (SOA) of about 100 milliseconds, the second stimulus is more easily identifiable than the first (lag effect). This is an example of backward masking. The second syllable masks the first. The more acoustically similar the vowels of the stimulus pair are, the greater the backward masking. Conversely, the more similar the consonants, the easier the identification (Yost & Nielsen, 1977).

Studdert-Kennedy and Shankweiler (1981), using consonant-vowel-consonant nonsense syllables presented dichotically to right-handed listeners (Borden, 1980; Oscar-Berman, Zurif, & Blumstein, 1975), verified a small but consistent advantage of stop-vowel syllables, but none for steady state vowels. Further investigation has shown variations based on shared phonemic features of the contrasting consonants; e.g., shared place of articulation yields better accuracy than shared voicing. There was no ear advantage. Both ears recognized stimuli better when more features were shared. It was the vowel *contrast* which gave rise to the REA phenomenon.

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[7] Different stimulli presented to each ear simultaneously.

Molfese and Erwin (1981) found hemispheric differences between evoked response waveforms using both consonantal and steady-state vowel stimuli. No significant intra-hemispheric differences were found for vowel stimuli, but there were differences for consonant stimuli. There were two temporal and one parietal site in each hemisphere that in concert distinguished vowels, one from another.

Electrophysiologic results show similar activity from the right hemisphere whether the task calls for pitch or phoneme discrimination. The left hemisphere, however, shows distinctly different activity when processing according to these two parameters. "Something special is happening in the left hem[illegible]e when we listen to speech"(Borden & Harris, 1980, p.20[illegible]).

Broadbent developed the dichotic presentation technique in 1954 using spoken digits. His purpose was the study of attention and memory. The greatest subsequent use of the technique was in the measurement of hemispheric asymmetries, to locate cerebral lesions, and to further the study of memory, recognition and recall.

Broadbent's informational processing model (1956) has been elaborated by many researchers. Kimura verified a REA for verbal material presented dichotically. "...The right ear is more efficient (at recognition tasks) than the left regardless of the cite of lesion"(1961, p.167). Further, she cited Milner's (1962) findings that indicated tonal pattern perception was slightly better in dextral's left ears (right hemisphere). A large number of studies have supported hemispheric localization or lateralization functions, but most studies have been conducted with patients who had abnormal cortical function, using dichotic stimuli (Kimura 1961a, 1961b; Milner, Taylor, & Sperry, 1968; Oscar-Berman et al., 1975).

Studies using patients who had had partial or complete commissure sections have been valuable in investigating the role of information transfer between hemispheres in auditory perception. Effects of REA due to hemispheric dominance could be separated from effects due to ipsilateral suppression. Milner et al. (1968) and Sparks and Geschwind (1968)found a much greater REA for split-brained subjects than for normal subjects. They also found a neglect for words presented to the left ear, indicating a probable need for information transfer between hemispheres for verbal material. The possibility that the right hemisphere could not respond verbally was suggested. When the task required a manual response, left ear performance improved, indicating that left ear suppression had <u>not</u> occurred (Wale & Geffen, 1983).

Dichotic stimuli presentation cannot yield results comparing right and left ear or binaural performance wi normal listening conditions. When inter-aural competition is less, it operates to facilitate the comprehension of messages in noisy environments.

The literature is inconsistent (Rosser, Millay, & Morrow, 1983; Morris, Bakker, Satz, & Van der Vlugy, 1984) in its findings regarding presence of REA for normally functioning as well as learning disabled children. Three factors affect the consensus. Does cortical organization and/or function/malfunction create conditions that result in asymmetrical ear functions? Are ear differences related to developmental (and perhaps genetic) variables, causing some children to exhibit developmentally delayed ear differences or symmetry or the acquisition of compensatory strategies? What is the role of attention, memory, fatigue, and other individual subject and environmental variables?

Obrzut, Obrzut, Bryden, & Bartels (1985) attempted to test the hypothesis that LD children were more susceptible to attentional bias and used differential information-processing styles. They found that the LD children failed to demonstrate an ear advantage, whereas normal peers had a strong REA. LD children were not biased attenders. That is, the right ear did not maintain superiority either when directed (cued) or undirected, as it had with normal subjects. Instead, a total depressed performance was exhibited by each ear equally. Further, the LD children were less proficient in both simultaneous and sequential information processing. The conclusions suggested that LD subjects were not as well lateralized for speech as normal children. The authors point out that the operational definition of 'lateralization' is a greater number of correct right ear than left ear responses. This presumes REA represents left cortical dominance.

Rosser, et al. (1983) found no group differences for ear asymmetry, age-related auditory capacity, or lag effect (temporal offset of binaural stimuli). They found that with both normal and LD subjects, at simultaneity (0 lag), the REA was present. As lag increased, the lagging ear improved performance. Overall accuracy increased as temporal offsets increased. They found no change in laterality over a four year observation period.

Morris, et al.(1984) noted the contradictory nature of the literature when addressing the findings using developmental models. They felt that discrepancies arose depending upon whether the hypotheses were based on language lateralization, attentional bias or cognitive strategy. The theoretical position determined the methodology, which in turn biased the result. The authors looked for ear asymmetry in 211 normal, righthanded, male children in Holland and Florida. The study involved children from the age of 5 through 12 years. There were no consistent findings across all samples. Between 41% and 64% of the subjects shifted ear preference at least once. Results were reported as 'ear advantage' so the inferences to hemispheric processes would not be implied.

Perhaps our units of measurement are too gross to be of much value when looking for significant ear differences. Audiologists traditionally report differences in milliseconds and microvolts. Measures of cortical function using language, involving as they do symbolization (Protti, 1983), can not be compared to transmission times or neuronal firing in either quality or quantity.

By forcing the bilateral auditory pathways and reception areas to compete with one another dichotic stimulation yielded information regarding dominance of the the system. Dominance patterns varied greatly with stimulus characteristics and other factors such as attention (Geffen & Quinn, 1984). Geffen and Wale (1979), Hiscock and Kinsbourne (1980), and Sexton and Geffen (1979) presented developmental studies showing that normal children could, by the age of 7 years, well identify words presented dichotically to the right ear when asked to attend to the right, but they had difficulty reversing the task (Geffen & Quinn, 1984). This partially supports Willeford and Billger's (1978) REA for children under 9 yars of age and their hypothesis that large REA's in children represent maturational lag.

Shadden and Peterson (1982) attempted to clarify the role of attention in ear advantage with a reaction time task where the ear of presentation was "expected" or "unexpected". Under random "expected" presentation, an REA was demonstrated, but under uncertain or "unexpected" conditions a significant LEA was found. The authors attribute this difference to the left-hemisphere's over-analyzing the stimulus for linguistic content when attention is mobilized.

Examining the role of memory on REA, Taylor and Heilman (1982) found that an REA was present in recency (short-term echoic memory) recall, but not in primacy (long-term memory) recall. There was a total absence of REA in their 24 female subjects, which the authors attribute to a difference between sexes in recall strategy. Female subjects had better echoic memory, which resulted in less dependancy of that memory component, so they recalled items from long-term memory first (primacy). Conversely, the male subjects recalled from echoic memory first, before the information was lost. This rationale implies that echoic memory is primarily a left-hemisphere function and long-term memory is a right function.

In a review of developmental studies of speech perception in normal infants and children, Sloan (1986) concludes that maturation of the auditory system proceeds from bottom to top (caudal to cephalad) and is anatomically nearly complete by the age of four years. The interaction of 'nature-nurture' elements favor the former as most important prior to and during language acquisition, replaced by greater importance of learned elements with age. Maturity of the auditory system is reflected in level of language acquisition. Some developmental markers are operative to pubescence. Watson (1985) found the auditory behavior of 13 year old LD children comparable to that of normal 6 to 8 year-olds. They noted a differential age-related capacity for auditory-successive selective attention across LD age groups through 16 years that was not found for visual-simultaneous materials (Willis, 1985). These studies were not addressing ear differences, but do indicate that with other parameters of auditory processing, a developmental pattern exists. Failure to confirm or refute a normal REA for children, normal or LD, possibly lies in the fact that maturation for more caudal characteristics, such as ear symmetry or asymmetry (assuming a brain-stem function) , have reached maturity for most children by the age of first identification of learning problems. Fatigue (Gerger-Gross & Bruder, 1984), memory (vanZyl & Brasier,1976), and attention (Byrne & Wingfield, 1979; Swanson, 1983) have been shown to have little relationship to LD auditory performance.

D. Effects of Binaural Stimulation

Audiologists, being interested in the clinical applications and delineation of the parameters of the auditory system, found a need to supplement conventional auditory tests with something more sensitive for the diagnosis of central auditory lesions. Bocca, and Calearo (1963) articulated this need and developed words and sentences designed to stress the auditory system. Jerger (from 1960), Katz (from 1962), and others in the United States have been working along similar lines.

Dichotic conditions are especially effective for studying speech processing and cortical functions using speech stimuli. Bocca, Calearo, & Cassinari (1954) justified using speech tests because speech put stress upon the auditory system. They found that even severely damaged patients could well handle simple auditory tasks because of the great redundancy within the biophysical system. Language also has great redundancy. Only by stressing can some lesions be identified. Stress can be created by making the stimulus more complex, by limiting the acoustic information contained in a signal, and/or by using novel conditions of stimulus presentation (Willeford & Billger, 1978).

A catalogue of stimuli used in research might contain pure tones, musical phrases, environmental sounds, animal noises, and vocal non-speech sounds (sighing, laughing, crying). Words (including spondees[8], phonetically balanced, and digits)and longer utterances, filtered, interrupted, accelerated, or distorted would be included. Synthetic sentences and competing messages have also been used. [9]

Dichotic speech tests began with Bocca's distorted speech materials (Bocca, Calearo, & Cassinari, 1954) and Kimura's laterality research with digits (1961a, 1961b). Matzker's dichotic binaural fusion test (1959) was used by Smith and Resnick (1972) to successfully identify brain-stem lesions.

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[8] Two syllable words spoken with equal stress on each syllable.

[9] See Irvine, 1982, pp.61-66, for references and a tabulation of stimuli and conditions used in research.

Binaural fusion tests, now thought to be measures of brain-stem integrity, were found by Roush and Tait (1984) to support their view that binaural fusion was a measure of overall central auditory processing function as their experiments found a general lowering of overall performance for LD children compared to normals controls, with no interaction between diotic and dichotic presentation when low-pass filtered speech was presented to right or left ears. They postulated that the reduced redundancy of speech probably had greater effect on LD performance than their control's. Central auditory nervous system (CANS) testing has generated a battery approach which is gaining in popularity for use with a variety of patients including children with learning disabilities. A review of the tests in this battery can be found in Katz(1978, 1985) and include the use of low-pass filtering, the SSW (Staggered Spondiac Word) test, Willeford's competing sentences (for superficial and deep cerebral lesions) and rapidly alternating speech test (for lower brain stem lesions). Jerger (1975) investigated the validity of CANS testing. He found the SSW to be the best of the procedures used in identifying cerebral lesions, and the SSI (Synthetic Sentences Index) in the ipsilateral competing mode to be the best for locating brain-stem lesions.

The SSI was developed by Jerger (1960) to avoid the use of single words which did not evaluate the auditory system's capacity to manipulate the changing of pattern with time, so characteristic of speech. Synthetic sentences are made of words that are related to each other. In a first order relationship a succeeding word is found frequently following the preceding word in normal speech. A third order relationship describes frequency of occurrence three words subsequent (not necessarily in the same sentence); for example, "Women view men with green paper should." or "Small boat with a picture has become.". These sentences must be identified from a closed set when presented dichotically with a speech narrative (events in the life of Davy Crockett). The task is presented contralaterally and ipsilaterally to each ear at various message-to-competition ratios. Normally functioning individuals perform at the 100% level. In addition to use with neurological patients, this test successfully identifies children with auditory learning disabilities as a statistical population (Willeford & Billger, 1978).

Willeford (1968) developed competing sentences to secure information about "message perception" using real sentences which were designed to minimize reliance upon key words. Precise time matching was not shown to be essential with more complete linguistic material when the same voice was used for the sentence recitation and a message set was used (e.g.weather set: L - "I think we'll have rain today."; R - "There was frost on the ground.").

The SSW was developed by Katz (1977) for use with hearing impaired individuals. The peripheral hearing deficit interfered with most central tests. To circumvent this contamination he used spondaic words which are well-known and essentially 100% intelligible over a wide range of intensities because of the bi-syllabic redundancies. The spondees were recorded in an overlapping fashion (R - "upstairs"; L "downtown" becomes R - "up"; R/L - "stairs/down"; L - "town"). Responses can be scored according to number of incorrect responses, number of reversals, order effect, or ear effect. The SSW clearly distinguishes between patients with lesions associated with the auditory cortex and those with non-auditry reception lesions. Types of errors also make finer distinctions of cite-of-lesion. There are some limitations for use. The SSW has questionable validity for children under the age of 11 years and those over 60 years of age.

E. Auditory Perception Tests

Auditory perception tests are most often used to access children's learning characteristics. The Flowers-Costello Tests of Central Auditory Abilities(Flowers & Costello, 1973) uses dichotic competing messages to evaluate CANS integrity. Competing signal tasks are also used in the Composite Auditory Perception Test (CAPT, Butler, 1973), but not in the dichotic mode. The Goldman-Fristoe-Woodcock Auditory Skills Test Battery(GFWB, Woodcock, 1976) manual considers the dichotic tests to be tests for "selective auditory attention". Despite the evidence of its value primarily as a CANS test of cortical function. In fact, the lack of controls inherent in the three aformentioned tests render them virtually useless. The Illinois Test of Psycholinguistic Abilities (ITPA, Kirk & Kirk, 1968), allegedly evaluates auditory perception, but scores obtained by children with auditory-based learning disabilities often score above their age norms (Willeford & Billger, 1978, p.413).

In general, auditory perception tests are audiological task response items. They are usually administered in uncontrolled environments. They are often interpreted by applying labels to children rather than explaining the nature of the deficits.

F. The Auditory Comprehension Test

Green has attempted to circumvent the limitations imposed by dichotic testing by developing a natural speech test, the Auditory Comprehension Test(Green & Kramer, 1983). Green felt that "everyday speech" was essential to use as a stimulus if practical treatment applications are to be generated by research (1984). The ACT (Appendix A) is composed of short *stories*, organized into sets of six (A through E). Each set is progressively more difficult, increasing in length, vocabulary and syntactic difficulty. Presentation is by stereo-audiotape. A Canadian woman's voice is used to present the items. The subject is instructed to repeat each story immediately following presentation, replicating as much of the story as possible. The phrase "Are you ready?" preceeds each story, orienting the subject to the ear of presentation of the following story. Within each set two stories are presented to the right ear, two to the left, and two to both ears in random order.

Each significant semantic linguistic unit is scored by the administrator if it is repeated by the subject. Semantically identical vocabulary substitutions are allowed. Raw scores indicating the number of ACT items correctly repeated under various conditions are tabulated and reported as both raw scores and as per cent correct.

G. Green's Findings with Schizophrenic Subjects

Green observed that the theories of REA and the contra-lateral lesion effect are paradoxical. Upon dichotic testing, a left temporal lesion would negate an REA and no ear effect would be found, when in fact both effects would be present. He presented a strong argument for use of monaural testing. It does not create an REA by forcing inter-ear competition. He found that the preponderance of evidence indicated that schizophrenics displayed an exaggerated REA. To explain this result, Flor-Henry (1983) suggested *overactivation* of the left-temporal lobe in acute schizophrenia, noting statistically significant correlations associating schizophrenic symptoms with left-temporal lobe epilepsy. Yet not all left-temporal epileptics are schizophrenic, nor are all schizophrenics lateralized to the left hemisphere for speech. Green argues for an explanation involving disruption of inter-hemispheric integration. Callosal dysfunction would also produce exaggerated REA's (1984a). He cited studies using tachistoscopic and intermanual transfer tasks (Hallett & Green, 1983). Using monaural testing procedures, a left-temporal lesion would be predicted to produce a contralateral deficit, not confounded by an REA. If the trans-callosal fibers failed (as with sectioned patients) degradation of performance would be expected in the ear ipsilateral to the language dominant hemisphere.

Using the ACT (Green & Kramer, 1983), Green found no significant L - R or binaural differences with 52 normal adult subjects (mean overall scores = 100.99, SD = 13.31). The magnitude of ear difference was 0.68% (SD = 4.54%). The mean binaural quotient was 3.1% (SD = 9.66%), which means that there was an average non-significant binaural advantage. No significant age or sex differences were noted. Nine subjects were retested between 9 and 14 days. Practice effects were 8.1% over initial scores (Green, 1984b).

As none of the 52 normal subjects produced ear difference scores greater than 10%, with 10% ear difference being >2 SD, 10% was set as the limits of normalcy. The criterion for abnormality for the binaural quotient was set at >-20% to lessen false positive identifications. The normal subjects' mean score was 63% correct responses. The ACT appears not to have a basal or ceiling bias for normal adults.

An overview of experimental populations and summary of main findings submitted by Green (1984a) can be found in Appendix B. More than 100 schizophrenic patients were evaluated over a series of eight experiments from 1973 to 1983. Not only did Green find left ear deficits relative to right ear scores, but overall scores were depressed relative to normal controls. Binaural performance averaged 50% lower than best ear monaural scores. Green found that these results were characteristic not only of acute schizophrenia. A different pattern emerged for chronic schizophrenia and other neuropsychiatric populations, but overall scores were low.

Green reasoned that an ear plug in a poorer (L) performing ear would create a close approximation to the superior (R) monaural condition and would restore speech comprehension in everyday listening situations to the level of the superior ear performance. Green states:

> There seems to be a failure to combine or integrate binaural stimulation with complex speech. The question is at what level of the auditory system does the failure of integration occur such that the addition of stimulation to the inferior ear interferes with comprehension...(1984a, p.179).

He found the most parsimonious explanation to be at the level of hemispheric integration, as the poor left ear scores clearly indicated problems at that level.

Subsequent occlusion of a poorer left ear with a wax earplug did indeed produce increased scores on the ACT. Moreover, the degree of left relative to right ear deficit predicted the improvement as comprehension was restored to best (R) ear levels.

Hallett and Green (1983) found that the same pattern of binaural deficit (28.8% compared to normal control means of 3.56%) characterized 13 children at risk for schizophrenia (children of schizophrenics).

The replication study by Waine (1984) including 18 learning disabled experimental subjects (12.7 to 14.6 years of age) and 18 matched controls, found no statistically significant differences between monaural and binaural presentations on the performance of 15 commands from <u>The Revised Token Test</u> (McNeil, 1978). These stimuli appeared to be of insufficient difficulty as normal controls achieved 90.7% accuracy and the experimental group achieved a mean of 80.3%. With left, right and binaural presentation, the test only consisted of 5 items per condition. The author predicted a binaural deficit on the basis of interhemispheric interference. Waine's sample showed interesting trends within the experimental group, especially for females, but the limited number of stimuli coupled with small sample size appeared to have been further confounded by the statistical use of group comparisons. No significant group differences were found. The author suggested future studies include a more homogeneous group of learning disabled children, as her sample consisted of both dyslexics and language-disordered subjects.

Waine included several reports of attempts to establish a clear picture of disordered left dominance for speech in learning disabled children. Results were equivocable. All in all, this study was not a replication of Green's work, as not only did the target population vary, but the stimuli were uncontrolled and not comparable to the ACT.

Researchers indeed have had difficulty locating any consistent evidence of cortical organizational differences or lesions in children with learning disabilities. In fact, "hard" neurological signs are repeatedly and consistently absent. Early researchers such as Orton (1937) and Critchley (1969), after searching for cortical signs, had to revise their 'structural deficits' hypotheses, as no signs were found. Both investigators modified their thinking to include possible maturational delays or *developmental lag*. However, no cortical evidence of immaturity was found as the construct of *immaturity* was a vague, untestable physiologic process (Levinson, 1980).

The term *minimal brain dysfunction*(MBD) came to be used for individuals exhibiting no abnormal neurologic signs. Defining a condition by what it is not has only served to delay the identification of what it is. Thus, the U.S. Government has been forced to define learning disabilities (including dyslexia) in educational-behavorial terms. Again, the definition specifies what a learning disability is <u>not</u> with as much vigor as pin-pointing what it <u>is</u>.

H. Rationale for the Present Study

Green's (1983) monaural-binaural testing may, by eliminating the hemispheric dominance elicited by dichotic tests, reveal ear asymmetries or binaural deficit in populations other than the subjects of his studies. Occlusion of a poor ear may alleviate binaural deficit, and although the inter-hemispheric transfer explanation for left ear-binaural deficits for schizophrenics seems reasonable, a brain-stem cite-of-lesion for a learning disabled population would not be incompatable with similar results. A sub-cortical dysfunction affecting binaural integrative processing would be predicted to yield poor binaural performance relative to single ear stimulation under headphones. As the presence or absence of ipsilateral suppression would be of no consequence in a monotic presentation, little difference between ears would be noted. Each monotic condition would be superior to the diotic as the language dominant hemisphere receives complete messages ipsilaterally regardless of route superiority. If however, there were cortical involvement, a right ear advantage should appear (assuming dominant left-temporal speech localization).

This study explored the monotic and diotic speech comprehension performance of children with learning disabilities using Green's ACT (Green & Kramer, 1983) and procedures (1984b).

III. Methods

A. Hypotheses

Studies of human ear differences when listening to speech indicate a normal, slight, non-significant right ear advantage (REA) may be present when listening in the dichotic mode. Children may have larger REA than do adults, which disappears as the auditory system matures (by approximately eight years of age). Learning disabled students may exhibit greater REA than normally functioning students. This has been found to be present when testing involved the use of monotic stimuli (Green, 1983).

Under binaural listening conditions, LD children have been found to perform more poorly than able peers, <u>and</u> more poorly than their own best single ear. This binaural deficit has been postulated to result in auditory disturbances that disrupt signal intelligibility by failure of seperate ear inputs to fuse into one message, reach optimal listening level, or be distorted in such a way as to interfere with comprehension. The demonstration of large ear differences in speech comprehension might imply disturbance in auditory function, remediable clinically by manipulation of stimulus input (e.g., occlusion by ear plug in a poorer performing ear).

This study sought to verify (and quantify) an REA for eighteen boys between the ages of six and eleven years who had experienced classroom learning difficulties.

Verification of the presence of a significant deficit in binaural speech comprehension was also measured.

The hypotheses tested by this study were:

1. There is no statistically significant difference of 18 learning disabled boys (6 to 11 years of age) between left and right ear performance (ED[10]), when listening under headphones, as measured by scores achieved on the Auditory Comprehension Test (Green & Kramer, 1983).

2. There is no statistically significant binaural deficit relative to single ear performance (BQ[11]) of 18 learning disabled boys (6 to 11 years of age), when listening under headphones, as measured by scores achieved on the Auditory Comprehension Test (Green & Kramer, 1983).

B. Research Design

Both study hypotheses were tested using the same subject sample by data collected in a single administration of the ACT (Green & Kramer, 1983). A group comparison of repeated measures design was selected. All subjects took all tests. Sample size was smaller than needed for a randomized design, as each subject served as his own control (Shearer, 1982, p.117).

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[10] $(R-L/R+L)x100$ =ED (ear difference)
[11] (Both-High Ear/Both)x100=BQ (binaural quotient; binaural advantage or deficit)

The ACT (Green & Kramer, 1983) was designed to be used as a repeated measures test; each story within a set of six yielding equivalent scoreable responses. Therefore, ear conditions L, R and B were balanced in order of presentation. Time and practice effects were controlled.

Traditional group comparison designs were rejected for use with the learning disabled population. In pilot studies, normally functioning students demonstrated large practice effects, whereas students with learning disabilities demonstrated little carryover, even when items were immediately repeated. It was felt that this was partly a function of poor initial performance and partly a function of poor memory or recall. As no normal equivalent peer group existed (the experimental population itself was heterogeneous) for which all variables could be specified or controlled, a design which used only the experimental subjects was used.

Grouped data in this study were raw scores on the ACT under three listening conditions; left (L), right (R), and both ears (B). Ear difference (ED) and binaural verses monaural percentage differences (BQ) were calculated and analyzed as dependent measures.[12]

Analysis of data was achieved using a treatments-by-subjects (TxS) analysis of variance (one-way, or single factor, ANOVA with repeated, or dependent, measures). An assumption of normal distribution was made on

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[12]During data collection for this study, Green made available to the author unpublished raw data from his most recent studies (see Appendix C).

the basis of subject selection criterion of normal intelligence (as determined by WISC-R scores). Relationship between subject variables of Age and IQ (DIQ, Verbal and Performance) and dependent variables (L, R, and B; ED and BQ) were examined using Pearson's Product-Moment Correlation.

C. Subject Selection

Permission to conduct research on human subjects was secured from the University of Alberta, Department of Educational Psychology Ethics Committee. Eighteen right-handed male subjects, between ages 6 to 11 years, were recruited for the study. Because of the sample size, homogeneity of subject characteristics was obtained by controling for IQ , hearing acuity, and a history of diagnosis of and/or special educational placement for remediation of one or more learning disabilities. Children who were receiving ongoing medication were excluded.

Subjects were selected from a population of children who had received psycho-educational assessment at the University of Alberta Faculty of Education, Clinical Services Division between January and June, 1986. Thirty-three letters were sent to parents of children who met criteria for age, sex, IQ and history of diagnosis and/or special educational placement (see Appendix A). Initial direct contact was made by telephone by the parent to the clinician. There were twenty-five responses, from which eighteen children were selected as subjects. Of the children excluded, one child was on medication; one was moving out of the city; two were ill; and three parents declined subsequent participation believing that their child had "...been through enough testing...".

Age

The age range of the eighteen subjects was 6 years 8 months to 11 years 10 months. The mean age was 9 years 3 months (SD = 1 year 5 months); median = 9 years 8.5 months.[13]

Table 1.

SUBJECTS BY AGE

Number	Age in Years
1	6
3	7
2	8
7	9
4	10
1	11
N=18	M = 9yr.3mo. SD = 1yr.5mo.

WISC-R Scores

WISC-R (<u>Weschsler Intelligence Scale for Children-Revised</u>, Weschsler, 1974) Full Scale scores ranged from 89 to 114. Mean and median = 102, SD=8. WISC-R normative data placed these scores within one tandard

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[13] Data tables provided in Appendix B report age in months.

deviation of the norms (M=100[14];SD=15). Verbal IQ scores ranged from 84 to 119 (M=102; median=101; SD=12). Performance IQ scores ranged from 78 to 123 (M and median=102, SD=12). All values fell within the normal range for the WISC-R normative population.

Individual subject differences between Verbal and Performance scores ranged from a 35 point superiority of Performance over Verbal, to a 23 point superiority of Verbal over Performance, but the mean difference was only 1 point. Nine subjects had higher Verbal than Performance scores, and nine had higher Performance than Verbal scores. However, nine (50%) subjects had a difference greater than 1 SD between scales, which is a greater number than found in the WISC-R normative samples. The standard error of measurement on the Verbal and Performance scales was 3.60 and 4.66 respectively. Wechsler (1974) compares individual sub-tests by age group, not by scale score differences for the total sample, therefore comparisons could not be made.

D. Pre-Testing

Eighteen boys between the ages of six and eleven were included on the basis of academic history, psychological assessment and having IQ scores within one standard deviation of the mean. A brief explanation of the purpose of testing was given, and an initial interview conducted. An appointment for a testing period of 2 hours at the Minerva

[14] M=Mean

Hearing Research Clinic at the University of Alberta, Department of Educational Psychology was scheduled. At the appointed time, the nature and purpose of the study was explained more fully to each parent and child, after which, permission to include the particular child was obtained and the parent signed a consent form (see Apendix A). A short medical-educational history was secured. Each child had previously exhibited difficulties performing in a regular classroom, and had been diagnosed as having 'learning difficulties' by the school psychologist or by a clinician in the University's Education Clinic. Current WISC-R scores on Performance, Verbal and Total IQ were secured as an indication of 'normal' intelligence. Some mention of auditory processing, perceptual problems, or language delay appeared in the student's school records or the psychologist's report for each boy selected.

A traditional hearing evaluation, including bilateral pure tone thresholds at 500, 1000, and 2000 Hertz; speech reception thresholds; speech discrimination in quiet and noise (0dB s/n)[15]; and impedance audiometry, was performed to rule out peripheral hearing problems as a confounding variable. Assessment was conducted on an individual basis in a 2 X 2 metre IAC (Industrial Acoustics Company, Inc.) Model 403-A audiometric suite (with less than 7dB SPL ambient noise) using a Madsen OB822 audiometer and a Sony TC-250A reel-to-reel tape recorder. Normal hearing for pure tones

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[15] 0dB s/n indicates the signal and noise were presented at the same loudness level.

and speech[16] using TDH-39P(Madsen) headphones was verified. Impedance information[17] was gathered using an MD-1 analyzer.

E. Stimulus Preparation

The ACT consists of 30 stories in 5 sets of 6 stories each. Tests A to E involve increasing items of information (see Appendix A).

> "...A & B, 10 items per story; C, 15 items; D, 20 items...Within each test each story has been found to be of equivalent difficulty to every other story..."(Green, 1984b, p.5)

The commercial tape produced by Green and Kramer (1983) was re-recorded using a Sony TC-126 stereo cassette recorder to deliver the signal to a Sony TC-630 stereo center. An Audioscan Programmer was used to record a 1000 Hz callibration tone, after which each section of the original tape (each story) was routed and re-recorded. The input channels were monitored on a VU meter during the re-recording process to ensure a constant intensity level. During presentation of items to the subject the signal was routed through the audiometer, which again ensured a constant output through the headphones.

Pilot testing revealed that children fatigued and became bored and discouraged when the length of the ACT included Tests A through E. Split-half scoring indicated that performance remained at a constant level regardless of the

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[16] Greater than 20dB HL and speech discrimintation in quiet over 90%.
[17] Normal tympanograms, Jerger Type A, and the presence of the ipsilateral acoustic reflex at 105dB SPL at 1000 Hz.

number or length of stories used.[18] Using 3 male, and 3 female learning disabled children, and 2 normally functioning students who were volunteer children of university students, pilot testing in the Minerva Clinic indicated that their ACT performance scores increased with age. Therefore, it was felt that use of ACT Tests A, B, C, and D would provide reliable results which would be comparable to prior reports.

This study employed ACT tests A, B, C, and D:

> Test A consisted of six 22-word stories, each containing 10 scorable linguistic elements.
>
> Test B consisted of six 26-word stories, each containing 10 scorable elements.
>
> Test C consisted of six 33-word stories, each containing 15 scorable elements.
>
> Test D consisted of six 45-word stories, each containing 20 scorable elements.

The total of 24 stories contained 330 scorable linguistic elements to be recalled and reported by each subject. By omitting Test E, six stories, each containing 25 scorable elements for a total of 150 additional points, were eliminated.

F. Scoring

Each subject immediately recalled as much as possible of the story he had just heard. The observer recorded responses, by pen with a tick placed in a circle following each protocol item correctly repeated (see Appendix A).

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[18] This is in agreement with Green's findings (1984b).

Criteria for scoring items as correct followed those recommended by Green (1984b). Thus, substitutions of vocabulary items of equivalent meaning (e.g. "baby cat" for "kitten") were accepted as correctly recalled. Green suggested noting the number of 'intrusions'. He describes two types: order of recall and substitutions which alter the meaning of the story. Wrongful order seldom produced semantic changes to the material during this study. Occasionally some element was recalled and reported long after initial response. Scores were always corrected to include credit for late recall, as failure to report promptly was not due to perceptual or encoding failure if the child later reported omitted items. Often spurious names were substituted for story names. These intrusions were not accepted even though the linguistic elements (e.g. noun forms) were identical. The subject had introduced semantic information which was external to the story(e.g. different names refer to different persons). The linguistic 'class' of the word substituted could be inferred from the structure of the utterance; thus, there was insufficient evidence that the auditory signal was perceived and/or processed. Analyses of intrusions was deferred for a later study.

Observer training was conducted on two occasions. Criterion was reached when the observer and Green achieved 90% consistency in point-by-point scores from two subjects.

G. Procedures and Apparatus

All equipment was calibrated to ANSI-79 standards. Standard audiometric procedures were used, with the subject sitting in a 2 X 2 metre sound-attenuating suite. Each child had performed within normal limits on the standard audiometric evaluation prior to being selected as a subject for study. The pre-recorded ACT stimuli, calibrated to a 1000 Hertz tone, were replicated and checked on a VU meter during playback through the Madsen OB822 audiometer to TDH-39 headphones placed on the subject. The subject and experimenter were within view of one another through a small window throughout testing. The parent(s) observed the testing session from a position behind the experimenter.

At each session, all subject responses were recorded on tape from the monitor output of the audiometer to a Sony TC-126 stereo-cassette tape recorder. Observer agreement over time was checked by rescoring, from tape-recorded responses from five subjects two weeks after the first administration of the test. Observer agreement exceeded the 90% level for each rescoring. Only three scoring discrepancies occurred on the five protocols. Initial scores were not altered.

Each subject received a total of two stories per condition per set. Conditions[19] were administered in the following order to each subject to minimize order and

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[19] L = left ear
R = right ear
B = both ears

practice effects:

SET A: B - L - R - L - R - B

SET B: R - B - L - R - L - B

SET C: L - B - R - B - R - L

This pattern was repeated continuously throughout the study so that the pattern repeated on Test D for the first subject B - L - R - L - R - B. The second subject began Test A with R - B - L, etc.. In this way, any bias generated by a particular story would be more or less evenly distributed throughout the data, as would any undetected equipment artifact. Therefore, the stories were administered in the same order to each subject, but not necessarily to the same ear.

Each subject was told that he would hear some stories . "At the end of each story you are to tell the story back to me. Tell me all you can remember about the story, just the way you heard it." Listening attention was secured by the carrier phrase, "Now listen carefully..." to the test ear(s). At the end of each story the tape was stopped and the child was encouraged to respond, if needed, by a visual cue (eye contact, raised eyebrows, or pointing) from the clinician.

Following administration of the ACT, results of the pre-test hearing evaluation and ACT performance were discussed with the child and parent(s). They were thanked for their participation and dismissed.

IV. Results

The primary purpose of this study is to determine whether a significant ear difference or binaural deficit was exhibited by a sample of learning disabled boys when recalling stories contained in the Auditory Comprehension Test (Green & Kramer, 1983). The data were analyzed using the statistical program ANOV14 provided by the Division of Educational Research Services (DERS), University of Alberta, using the University's Amdahl computer and the Michigan Terminal System (MTS).

Data analysis included a one-way analysis of variance with repeated measures for ear conditions. Relationships were explored with Pearson product-moment correlation coefficients for all variables (Age; DIQ, Verbal and Performance WISC-R scores; L, R, B, and Total ACT scores). Ear Difference (ED) in percent correct scores between L and R ears, as well as Binaural Quotient (BQ)(the percentage of the best single ear's advantage or deficit to binaural (B) performance was included on the matrix.

A. ACT Scores

When divided between L, R and B conditions, a total possible ACT score was 110 per condition with a maximum total score of 330. Percent correct scores for L, R, B, and Total score, as well as ear difference (ED) and binaural quotient (BQ), are reported in Table 2. Raw scores are also reported.

Table 2.

AUDITORY COMPREHENSION TEST SCORES (N=18)

Variable	Percent Mean	Raw Score Mean	Raw Score Median	SD	Range
Left	43.9	48.3	49.5	11.3	32 - 72
Right	43.6	47.9	49.0	11.3	23 - 66
Both	41.8	46.0	45.5	10.3	30 - 61
Total	43.1	142.3	149.5	27.9	87 -180
ED	-01.1				-30.9 - 16.1%
BQ	-14.2				-48.8 - 16.6%

Negative numbers ED indicate left ear advantage.
Negative numbers BQ indicate B lower than highest scoring single ear.

Using the DERS ANOV14 program, a one-way ANOVA for the repeated measures, L, R, and B, the ACT scores did not reach statistical significance (F=0.57; df 2, 34; p≤.05). See Table 3.

Table 3.

ONE-WAY ANALYSIS OF VARIANCE WITH REPEATED MEASURES

Source	SS	df	MS	F	P
Rept.Meas.	56.25	2	28.13	0.57	0.569
Residual	1668.44	34	49.07		

B. Correlations

All variables (Age, Full Scale IQ, Verbal IQ, Performance IQ; L, R, B, and Total ACT scores, ED and BQ)were correlated on a Pearson Product-Moment Correlation Coefficient matrix using SPSS-X (Table 4).

Age did not significantly correlate with any variable, including total ACT scores. As expected, Verbal and Performance IQ were closely associated with Full Scale IQ, but not significantly correlated with one another ($r=-.1224$; $p=.314$). Full Scale IQ was, however, related to L ($r=.4030$; $p=.049$). In other words, left ear ACT performance was the best predictor of Full Scale IQ or visa-versa.

Table 4

PEARSON CORRELATION COEFFICIENTS

	Age	DIQ	Verb	Perf	Left	Right	Both	Total	ED
DIQ	.284								
Verb	.229	.646							
Perf	.145	.675	-.122						
Left	.291	.403	.242	.305					
Right	.338	.245	.369	-.029	.502				
Both	.265	.296	.216	.161	.674	.600			
Total	.351	.371	.325	.172	.855	.822	.882		
ED	.107	.016	.302	.273	.457	.495	-.044	-.007	
BQ	-.157	-.181	-.144	-.149	-.340	-.217	.345	-.096	.114

DIQ=WISC-R Inteligence Quotient
Verb=WISC-R Verbal Scale
Perf=WISC-R Performance Scale

This study found ACT conditions L, R, B and Total to be closely related, as was ED ((R-L/R+L) x 100 = ED). with L and R, from which it is derived. The ED score failed to significantly correlate with the B and Total (L+R+B = Total) scores which themselves were closely associated ($r=.8820$; $p=.000$).

The Total score was related only to L, R, and B, from which it was derived. While the BQ variable did not correlate significantly with any other variable, it was more closely related to L and B (r=-.3396; p=.084 and r=.3449; p=.081) than to R (r=.2174; p=.193). This indicated the high ear (HE) scores in the BQ calculation were predominately L scores. Upon inspection of the raw data, 77.8% of the sample (13 of 18 subjects) exhibited L over R ear superiority. This was not reflected in ear - age correlations, but may explain the significant Full Scale IQ - L correlation (r=.403; p=.049) and failure of Verbal - Performance scores to correlate as might be expected (r=-.1224; p=.314). It may be more appropriate to refer to R ear deficit (or disorder) rather than L ear superiority or advantage as the R ear carried greater responsibility for lower Total and Binaural scores than did the L ear. This study fount that left ear performance was least likely to lower Total or Binaural scores.

Hypothesis 1 stated that there was no statistically significant difference between ears in ACT performance. None was found. Hypothesis 2 stated that there was no statistically significant difference between binaural and single ear performance. None was found. However, it is interesting to note that there was a trend toward lower binaural scores. In fact, an average binaural deficit of 14.2% over single best ear performance was found. Right ear performance was deficit to left ear performance in the binaural listening condition.

V. Discussion

This study sought to replicate and expand upon work initiated by Green (1983), following his suggestion that learning disabled populations might demonstrate a unique pattern of ear difference and binaural deficit in a task requiring recall of common speech. Green hypothesized that significant ear differences and/or a binaural deficit would result from inter-hemispheric transfer disturbances through the corpus callosum. He depended heavily upon models of cortical specialization and information exchange between hemispheres. His was a 'top-down' neurological approach (Dunchan & Katz, 1983), focusing on 'processor', the mechanism of audition, rather than linguistics or the acoustic signal.

In exploring the processing model, the present project used a 'bottom-up' approach, which, by applying a measure of experimental control over environmental and subject variables, focused also on processor[20] in an effort to replicate Green's unpublished work with children with learning disabilities. The bottom-up approach attempts to systematically search for explanations of aberrant auditory behavior from the link between the external world through the auditory mechanism, the brain stem structures, then the auditory cortices.

As a result of the current study, four points of interest emerged. 1) No significant ear differences were

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[20]Neither linguistic nor acoustic characteristics of the signal were controled.

found. 2) Results indicated a non-significant trend toward binaural deficit. 3) Left ear scores were related to Full Scale WISC-R scores (DIQ), regardless of pattern of Performance and Verbal sub-test scores. 4) When compared to 35 normally functioning boys matched for handedness and age, the experimental subjects' ACT scores in all listening conditions were greatly depressed. The level of total performance deficit was reflected in an independent matched sample of 18 boys with auditory learning disabilities (see Appendix C).

First, there is a failure to find a significant ear differences in this sample of boys. No right ear advantage was manifest as Kimura (1961b) and Green (1983) had predicted. Green spoke of left ear deficit, rather than right ear advantage, but for learning disabled youngsters, both ears appeared to be deficit. Left ear mean scores slightly exceeded right ear mean scores. We might view the lower right ear scores as indicative of right ear 'misbehavior' (or deficit), recalling that the right ear failed to correlate significantly with WISC-R scores, while the left did correlate.

Secondly, no significant binaural deficit (BQ) was found in this experimental data, although a trend toward poorer diotic performance was found. Upon visual inspection of the data (Appendix B), it can be seen that five boys had binaural deficits greater than -20%; the level set by Green (1984b) below which clinically abnormal function exists.

(Green has found subjects falling below this level profit from occlusion of the poorer performing ear by increasing free field speech comprehension scores to the level of single best ear scores under headphones.) These five boys comprise 27% of the subjects in this study. This is consistant with Green's LD sample, 35% of which demonstrated clinically abnormal binaural performance. Future studies may confirm that those individuals who demonstrate abnormal (≤20%) binaural deficit form an important and objectively identifiable sub-group within the LD population. One is cautioned in the literature about problems that may arise from heterogeneity within LD groups and the possibility of rejecting a true hypothesis. Using ACT performance scores to select homogeneous subject samples might provide a more conrollable selection criterion than the assumption and labeling of learning disability by various individuals from various disciplines, useing various behavorial criteria.

Green postulated that poor binaural performance was the result of failure of information to transfer betw[illegible] hemispheres properly. The auditory images from ea[illegible] ear would fail to fuse into one auditory image. The literature reports that right hemisphere lesions produce depressed left ear scores, and left hemispheric lesions tend to produce more binaural errors (Bergman, Hirsch, and Solzi, 1987). Binaural fusion failure could also produce increased binaural errors. Prediction of results of binaural testing based on behavioral abnormalities is purely speculative.

However, a new theoretical offering has been made by Levinson (1980), a neurologist who saw the "soft" neurological signs of disorders of balance, coordination and direction as "hard" localizing signs of a cerebellar-vestibular (c-v) dysfunction. Certainly the visual-occular problems often seen in dyslexics are as easily explained by c-v disorders as by cortical problems. Fusion failure occurring sub-cortically would result in subtle disability and be expected to be often associated with other evidence of brainstem dysfunction such as balance, motor and visual abnormalities.

The third, and perhaps the most surprising relationship delineated by the present study, is the relation of left ear scores to Full Scale WISC-R scores, and the failure of right ear scores to relate. Replication and investigation of WISC-R subtest scores in relationship to ear performance would be fertile ground for further study. One might argue that the average scores LD students achieved on the WISC-R indicate normal cortical function for language.

The fourth result is most widely supported by the literature. That is, learning disabled children appear to perform more poorly than their normal peers on a majority of language-related auditory measures. However, the failure of Total scores to correlate with Age is contrary to reports of age-related increase in auditory capacity of normal children found by Roeser, Millay, and Marrow (1983). Green's groups also demonstrated age-related improvement in Total performance. Roesser et al. (1983) and Obrzut et al.(1985) express the difference between LD and normal performance as difference in processor capacity which is possibly developmentally based. This study, however, found no basis for assuming an age-related improvement in the auditory processing skills of LD subjects. Since many assessment measures are predicated on evidence of age-capacity improvement, global performance deficits for LD children (Swanson,1983; Roush and Tait,1984; Obrzut et al., 1985; Watson and Rastatter,1985; Willeford and Burleigh,1985; Willis,1985; Ferre and Wilber,1986) may be the result of using testing instruments inappropriate to the learning patterns of the LD population.

What children do not hear may be more important than what they do hear. The method of counting only correct responses may be misleading and as such, should be viewed as a weakness in this work. If one were to compare only double correct (each ear response correct on comparable items) against correct/incorrect (one ear responding correctly, the other not), the effect of depressed overall performance would be removed.

The ability to listen selectively requires the capacity to filter extraneous stimulation. Therefore, dysfunction might occur were the subject either to under- or over-attend. This would result in lower scores. Furthermore, the ability to listen selectively might be asymmetrical, which would then produce asymmetrical ear scores. Of the five children in the present study who produced greater than 20% binaural deficit, only two had greater than 10% ear difference (Green's criterion for abnormality). One had a greatly deficit right ear performance; the other, a deficit left ear. The three other subjects having greater than 10% ear difference did not demonstrate deficits in the binaural condition. Ear difference alone, would not appear to interfere with speech comprehension and would not be considered clinical significant.

The traditional audiometric battery administered as pre-test in this study left many questions unanswered. The use of middle-ear screening rather than full tympanometry, including tracings of acoustic reflex action, has resulted in an inability to isolate the lower brain-stem and receptor organs as possible sites of abnormality. Such information might well uncover sub-groups from the heterogeneous sample.

Audiometrics do not attend to an evaluation of the ability of the auditory system to differentially handle high and low frequency information. The system's architecture contains two complimentary but distinct processors, designed to respond differently to the phase characteristics of low frequency sound or the intensity characteristics of higher frequency sound. Hearing is, in many ways, analogous to vision. The inner and outer hair cells of the cochlea are comparable to the rods and cones to the eye. The cerebral hemispheres are accessed through the right and left hemifields of each eye. By what means may we access auditory cognitive areas without bilateral interference? The left-right dichotomy that marks the visual system may be, in the auditory system, analogous to high-low and fast-slow continua.

This paper has mentioned several authors who were investigating 'successive processing' skills. Luria (1973), and subsequently Das, Kirby, and Jarman (1975), have proposed a 'simultaneous-successive processing' model with which we might recast our thinking. Luria's model suggests that information is processed, according to stimulus characteristics, in a sequential (successive, temporal) or simultaneous (spacial) manner which diminishes in specificity of sensory modality from receptor to cortex. Applied to audition, which principally (although not exclusively) uses successive processing, the characteristics of speech and the the auditory system processor present us with new appreciation for the unity and concordance of our internal and external realities.

In information processing terms, successive and simultaneous processing systems work much like a computer's disk operating system. The computer uses different programming 'languages' to analyze different types of data. Perception, then, would be facilitated by a type of processing appropriate to the characteristics of the stimuli. One might speculate as to whether there are other types of processing. Or do we use parallel processing or switch from one mode to the other? Perhaps, with a new theoretical model, we will be able to bring order to the voluminous research already in our coffers.

Finally, due to features such as redundancy, reduplication, single channel capacity, and perceptual 'trading'[21] disruption of auditory processing should be no more than temporary. The brain of man is capable of perceptual re-coding following insult. As the brain re-codes visual-perceptual information and reorganizes the reaction systems following virtiginous triggers to altered visual-proprioceptive information, so should the brain engage compensatory strategies to handle auditory-perceptual aberrations. This might explain why the literatures of several disciplines (Education, Psychology, Audiology) reflect lack of consensus when dealing with auditory learning disabilities. Numerous studies have been unable to answer the seemingly simple question, "Is there an ear difference in speech comprehension?".

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[21], Variables may substitute for one another, e.g. lacking sufficient frequency resolution, increased intensity renders the information intelligible, and visa-versa.

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Appendix A

SUBTEST A 22 Word Stories BEFORE TEST - CHECK HEADSET DIRECTION

10.1 **Kitten**
L
R
B

The children O were watching O a policeman O climbing O up a tree. O He was rescuing O a white O kitten O that was sitting O on a branch. O

10.2 **Channel**
L
R
B

A 12 year old O boy O from Washington O broke O a world record O on Saturday. O He swam across O the English Channel O in four O hours. O

10.3 **Birthday**
L
R
B

Kathy's O father O gave her O a present O for her birthday. O She had expected O some chocolates O but in the box O there was O a dress. O

10.4 **Arrest**
L
R
B

A 15 year old O girl O stole O some jewelry O from a department O store. O A detective O followed her O into the street O and arrested her. O

10.5 **Zoo**
L
R
B

The children O spent an hour O looking at O animals O in the Zoo. O One gorilla O reached out O of his cage O and touched O the teacher. O

10.6 **Charity**
L
R
B

Twenty-seven O Canadian O children O collected O over $1000.00 O for charity. O The money was sent O to a school O for the blind O and the handicapped. O

SUBTEST B 26 Word Stories

10.1 **Christmas**
L
R
B

The presents O were opened O on Christmas day. O Peter O got a bicycle O from his father O and Annie O got a video game O from her great-uncle O in Scotland. O

10.2 **Holiday**
L
R
B

John O and Mary O went on holiday O with their parents. O In the aeroplane O they sat O near a window O and looked down O at the ships O in the sea. O

10.3 **Classroom**
L
R
B

Michael O was sitting O at the back O of the classroom. O When the teacher O turned around O and wrote O on the blackboard O he took a bite O from his sandwich. O

10.4 **Dog Show**
L
R
B

Janet O entered O her terrier O in a dog show. O The first prize O went to a bull dog O with no tail O but Janet's dog O won O the second prize. O

10.5 **Squirrel**
L
R
B

A squirrel O came down O from an oak tree O into the garden O and found O some peanuts. O Now the grey squirrel O comes back O every day O for more food. O

10.6 **Circus**
L
R
B

Roger O went to the circus O with his mother O and his sister O on Sunday. O They saw a monkey O on a trapeze O and a dog O riding O a horse. O

SUBTEST C 33 Word Stories

15.1 **Wolves**
L R B

Young O animals O play games O in order to practice O skills O which they will need O to survive. O Packs O of young wolves O sometimes capture O a deer O but instead of O killing it O they allow it O to escape. O

15.2 **Baby**
L R B

Jack O was going O to school O when he saw O a baby carriage O rolling O toward the road. O Dropping O his bag, O he ran O to save the baby O from rolling O into the path O of a speeding O truck. O

15.3 **Puppies**
L R B

When Roy O came home O he found O a basket O full O of clothes O on the porch. O When he took it O into the house O he heard O a squeak. O Inside the clothes O there were two O black O puppies. O

15.4 **Camping**
L R B

Carol O and Doug O were camping O near a river. O While they were cooking O their supper O they heard O a splash. O A fisherman O had fallen O out of his boat. O Doug O waded out O and pulled him O ashore. O

15.5 **Bears**
L R B

Car drivers O and motorcyclists O had stopped O on the roadside O in the park. O They were watching O a mother O bear O and three O cubs O which had come O from the forest O to eat O berries O in the ditch. O

15.6 **Strike**
L R B

Many O holidaymakers O were disappointed O when they arrived O at the airport O this weekend. O Passengers O on flights O to Florida O and Spain O were told O that the air traffic O controllers O had gone on strike O for higher pay. O

SUBTEST D 45 Word Stories

20.1 **Fishermen**
L R B

Three O fishermen O were stranded O when their engine O broke down O in the Atlantic. O Air Force O Helicopters O searched O for a week O but were unable to find them. O After 90 days, O two O survivors O were washed ashore O in their boat. O They had been living on O fish, O rain O and seawater. O

20.2 **Kidnap**
L R B

A month ago O a German O businessman, O who was staying O at an hotel O in Rome O was kidnapped. O This week O his wife O flew to O Italy O and announced O in a television O interview O that she would pay O the million dollar O ransom O if her husband O was returned to her O unharmed. O

20.3 **Caffeine**
L R B

The drug O caffeine O which is present O in coffee O can lead to O loss of sleep, O headaches O and depression. O These symptoms O can last O up to 2 days O after the last drink O of coffee. O Caffeine O is also found O in chocolate, O some cola drinks, O headache tablets O and frozen O puddings. O

20.4 **Racquetball**
L R B

Scientists O at the University of O Toronto O have been studying O hundreds O of eye O injuries O in racquetball players. O In 70 cases O the ball, O travelling O at 100 mph O had hit the eye directly, O causing damage O requiring a week O in hospital. O The players O had not been wearing O protective O glasses. O

20.5 **Prime Minister**
L R B

An Austrian O man O was arrested O when he was banging O on the Prime Minister's O door O with a rock on Thursday. O He was protesting O about being unemployed O and homeless. O The judge O found him O guilty O of causing O a public O nuisance O and sentenced him O to one month O in prison. O

20.6 **Pope**
L R B

While escaping O from detectives O a guerilla O suspect O was hit O by a car. O He told O security O forces O that there was a plot O to kill O the Pope O on his tour O of El Salvador. O Then he handed over O the passports O of 18 O sharpshooters O who had entered O the country. O

SUBTEST E 56 Word Stories

25.1 **Hijack**

L
R
B

The pilot O of a hijacked O Libyan O D.C. 10 O airliner O was told O to fly O to Malta. O When the plane landed O in Paris O to refuel, O a blizzard O grounded the aircraft O for 24 hours. O Eleven O children O and one woman O were allowed to leave O the plane. O Minutes later, O the hijackers O surrendered O after a surprise O assault O by an anti-terrorist squad. O

Railway

B

murder O suspect O drove a O stolen O red O convertible O at high speeds O after escaping O from police O on Saturday. O It sped toward a railway crossing O at the same time O as an express O train. O The engineer O braked O but the track O was icy. O The car O was thrown O across the road O and stopped O in the flower bed O of a children's O hospital. O

25.3 **Fire**

L
R
B

Many people O watched O the Fire Department O using ladders O for the rescue of O office O workers O from a burning O building O on McDonald Street. O As the fire chief O helped O an injured O man O into an ambulance O an explosion O threw him O to the ground. O A woman O who lit O a cigarette O near a damaged O gas pump O was accused O of starting the fire. O

25.4 **Airbrakes**

L
R
B

The co-pilot O of a medium-sized O plane O caught sight O of the airfield O when he noticed O that he was flying O too low. O He had to act quickly O to avoid O collision O with a skycraper. O He banked O right O sharply, O then circled O the airport. O Sighing O with relief, O he pulled O a lever O to lower O the wheels O and touched down O safely. O

25.5 **Bank**

L
R
B

Mary Robinson O of south O Calgary, O a bank O manager, O arrived first O on Friday O morning. O In the entrance O there were three O men O wearing masks O and carrying O shotguns. O They forced her O to open the safe O and then they tied O her hands. O At the rear exit O the police O stopped O the bank robbers O while questioning O the driver O of the getaway car. O

25.6 **Storm**

L
R
B

Expecting O the sunny O weather O to last all day, O a group O of inexperienced O climbers O proceeded O to the top O of the mountain. O Though they sheltered O behind a wall, O they were cold O and frightened O when a storm O arose. O For two O hours O they suffered O wind O and rain O and they came very close O to being struck O by lightning O near the peak. O

University of Alberta
Edmonton
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Faculty of Education
Clinical Services
1-135 Education North, Telephone (403) 43

August 8, 1986

Dear Mr. and Mrs. [redacted]:

Marlene Spencer-Noble, a graduate student in our department, is conducting a study to determine if some children have more difficulty understanding speech with one ear than the other; or if understanding is poorer when listening with both ears than with one ear. Several children between the ages of seven and ten years of age are needed as volunteers to participate in the study.

The study will involve screening each child's hearing to verify normal hearing sensitivity. If a child does not pass the hearing test, assistance will be given in referring the child to the appropriate agency or medical authority for further investigation of auditory function, if the parents so desire. Each child whose hearing is within normal limits will be fitted with headphones and asked to listen to several tape-recorded stories. He will then be asked to repeat what he has just heard. The elements of the stories that have been recalled and repeated will be analyzed according to the ear to which the story was presented. The entire proceedure should take between 1 and 1 1/2 hours. All information obtained on your child will be treated in the strictest confidence.

Testing will be done in the North Education Building on the University of Alberta campus. Mrs. Noble hopes to complete testing by the end of September. A copy of the results of the study will be available to parents by the end of the year.

If you would be willing to allow your child to participate in this study, please contact Mrs. Noble during the day by leaving a message at 432-5213, or call 455-2066 after 3:00 p.m. for an appointment or further information.

Thank you for your consideration.

Sincerely,

J. G. Paterson, Ed.D.
Coordinator

University of Alberta
Edmonton
Canada T6G 2G5

Department of Educational Psychology
Faculty of Education
6-102 Education North, Telephone (403) 432-5245

I understand that assessment of hearing in this laboratory is conducted by and for the primary benefit of students of the University of Alberta who are not qualified audiologists.

Information may be used for teaching purposes, but my privacy will be respected and confidentiality maintained. Information may be released upon my request to persons of my designation.

Client: [redacted]

Date: Aug 16/86.

Address: [redacted]

Phone: [redacted]

To Whom It May Concern:

I, ______________________________, give my permission to Marlene S. Noble to include my child, ________________________________, as a subject in her thesis study. She may publish the results, but will maintain our privacy and use good taste in her representation of the data. I authorize my child's school and/or doctor to make available any information that might relate directly to Mrs. Noble's study.

____
Name

____
Relationship to subject

____
Date

UNIVERSITY OF ALBERTA

Hearing Impaired Program

AUDIOMETRIC EVALUATION

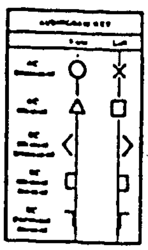
Name____________________ Phone________ B.D.________ Date________

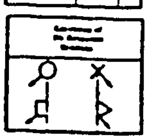
Address ____________________ City__________ Examiner________

Parents ________ Referred by ________________ Address________

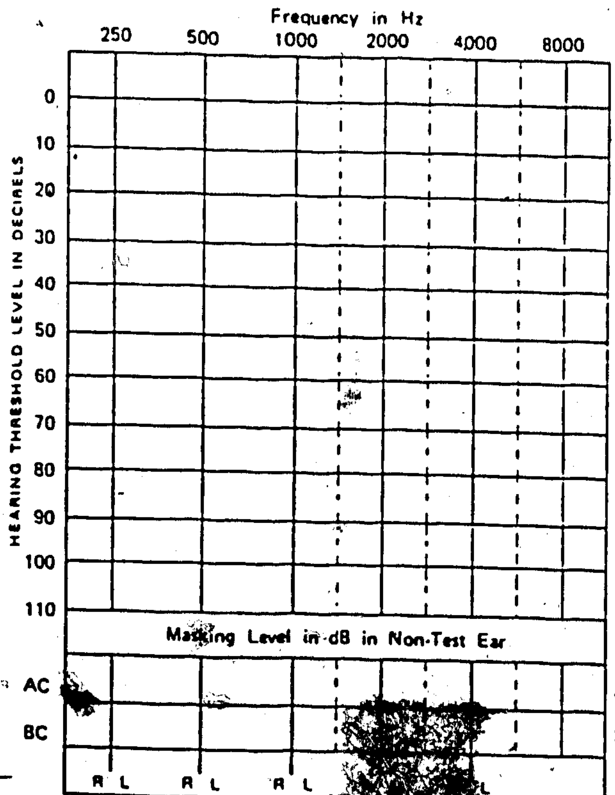
SPEECH AUDIOMETRY

	R	L	SF
AVE. P.T.	dB	dB	
SRT	dB	dB	dB
MCL	dB	dB	dB
Sp. Disc			
Disc/ Noise			
UCL	dB	dB	dB





PURE TONE AUDIOGRAM (ANSI 1969)



SPEECH DISCRIMINATION

WIPI W22 PBK OTHER LV REC

R ______ % at ______

L ______ % at ______

Field ______ % at ______ db (una

______ % at ______ db (aide

SPEECH RECEPTION / AWARENESS THRESHOL

LIVE VOICE SPONDEES OTHER

RT ______ dB Lt ______

FIELD: ______ dB (unaided)

______ dB (aided)

90

100

110

AC

BC

RELIABILITY: ________

AUDIOMETER: ________

COMMENTS: ________

IMPEDANCE AUDIOMETRY

Frequency

	500	1000	2000	4000
R	dB	dB	dB	dB
L	dB	dB	dB	dB

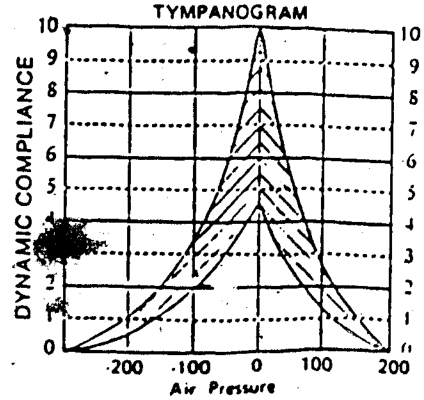
ACOUSTIC REFLEX

STATIC COMPLIANCE

	C_1	C_2	C_x
R	cc	cc	cc
L	cc	cc	cc

Normal Range For C_x: .27-1.5cc

TYMPANOGRAM



AMPLIFICATION ________

SUBJECT SUMMARY SHEET

Name: ____________________ Date of Testing: ____________

Date of Birth: ____________

Exact Age: ____________

Parents Name: ____________

____

Phone Number: ____________

Sex: ________ Grade: ________

School: ____________

Special Program: ____________

Address: ____________

____

WISC-R VS= ______ PS= ______ FS= ______

History: ____________

____

____

PTA(L) = ______ dB HL; PTA(R) = ______ dB HL

SRT(L) = ______ dB HL; SRT(R) = ______ dB HL

SRT (Both) = ______ dB HL; FF= ______ dB HL

SD-Q(L) = ______ %; SD-Q(R) = ______ %

SD-Q(Both) ______ %; FF= ______ %

SD-N(L) = ______ %; SD-N(R) = ______ % (s/n-0)

Tymps(L) ______ Tymps(R) ______

Reflex(L) ______ dB; Reflex(R) ______ dB Cont.

Otoscopic: ____________

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				

Total Score = ______ %

Ear Difference = ______ %

Binaural quotient = ______ %

	FREE FIELD		
	OCC	ØOCC	
A			
B			
C			
D			

FREE FIELD

SRT dB		SDQ - %		ACT	
Occ	ØOcc	Occ	ØOcc	Occ	ØOcc

Ear occluded: L R

Lead Condition: occ Øocc

Blank Score Sheets

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				

Total Score = ______ %

Ear Difference = ______ %

Binaural quotient = ______ %

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A				
B				
C				
D				
E				

Total Score = ______ %

Ear Difference = ______ %

Binaural quotient = ______ %

Perfect Scores Tabulated

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A	10	10	10	30
B	10	10	10	30
C	15	15	15	45
D	20	20	20	60
	55	55	55	165

Total Score = 100 % $\frac{100}{165} \times 165 =$

Ear Difference = 0 % $\frac{R-L}{R+L} \times 100 =$

Binaural quotient = 0 % $\frac{B-H.S}{B} \times 100 =$

ACT RESULTS

Test	Under Headphones			
	L	R	B	
A	10	10	10	30
B	10	10	10	30
C	15	15	15	45
	20	20	20	60
	25	25	25	75
	80	80	80	240

Total Score = 100 % $\frac{100}{240} \times 240 =$

Ear Difference = 0 % $\frac{80-80}{80-80} \times 100 =$

Binaural quotient = 0 % $\frac{80-80}{80} \times 100 =$

Appendix B

SUBJECT DATA

(N=18)

AGE

Months	Freq.	%	Cum.%
80	1	5.6	5.6
82	1	5.6	11.1
89	2	11.1	22.2
99	1	5.6	27.8
103	1	5.6	33.3
114	2	11.1	44.4
115	1	5.6	50.0
118	1	5.6	55.6
119	3	16.7	72.2
122	1	5.6	77.8
123	1	5.6	83.3
126	1	5.6	88.9
132	1	5.6	94.4
142	1	5.6	100.0

Mean=111.39, SD=17.39

DIQ

Value	Freq.	%	Cum.%
89	2	11.1	11.1
90	1	5.6	16.7
93	1	5.6	22.2
96	1	5.6	27.8
98	1	5.6	33.3
100	1	5.6	38.9
101	2	11.1	50.0
103	1	5.6	55.6
105	1	5.6	61.1
107	1	5.6	66.7
109	3	16.7	83.3
110	1	5.6	88.9
111	1	5.6	94.4
114	1	5.6	100.0

Mean=101.89, SD=8.01

VERBAL

Value	Freq.	%	Cum.%
84	1	5.6	5.6
85	1	5.6	11.1
87	1	5.6	16.7
95	1	5.6	22.2
96	1	5.6	27.8
98	1	5.6	33.3
100	2	5.6	44.4
101	2	11.1	55.6
103	1	5.6	61.1
108	2	11.1	72.2
112	2	11.1	83.3
113	1	5.6	88.9
115	1	5.6	94.4
119	1	5.6	100.0

Mean=102.06, SD=10.29

PERFORMANCE

Value	Freq.	%	Cum.%
78	1	5.6	5.6
87	1	5.6	11.1
90	1	5.6	16.7
92	1	5.6	22.2
93	1	5.6	27.8
95	1	5.6	33.3
96	2	11.1	44.4
100	1	5.6	50.0
104	2	11.1	61.1
108	1	5.6	66.7
109	1	5.[illegible]	72.2
111	1	5.6	77.8
112	1	5.6	83.3
118	1	5.6	84.9
120	1	5.6	94.4
123	1	5.6	100.0

Mean=102.00, SD=12.24

LEFT EAR

Score	Freq.	%	Cum.%
32	1	5.6	5.6
34	1	5.6	11.1
36	3	16.7	27.8
39	1	5.6	33.3
44	1	5.6	38.9
47	1	5.6	44.4
49	1	5.6	50.0
50	1	5.6	55.6
51	2	11.1	66.7
56	1	5.6	72.2
57	2	11.1	83.3
58	1	5.6	88.9
65	1	5.6	94.4
72	1	5.6	100.0

Mean=48.33, SD=11.36

RIGHT EAR

Score	Freq.	%	Cum.%
23	1	5.6	5.6
32	1	5.6	11.1
37	1	5.6	16.7
38	2	11.1	27.8
45	1	5.6	33.3
47	1	5.6	38.9
48	2	11.1	50.0
50	1	5.6	55.6
51	1	5.6	61.1
52	1	5.6	66.7
54	1	5.6	77.2
55	1	5.6	72.8
57	1	5.6	83.3
61	2	11.1	94.4
66	1	5.6	100.0

Mean=47.94, SD=11.03

BOTH EARS

Value	Freq.	%	Cum.%
30	1	5.6	5.6
32	1	5.6	11.1
33	1	5.6	16.7
34	1	5.6	22.2
36	1	5.6	27.8
41	2	11.1	38.9
43	1	5.6	44.4
44	1	5.6	50.0
47	1	5.6	55.6
51	2	11.1	66.7
53	1	5.6	72.2
55	1	5.6	77.8
58	2	11.1	88.9
60	1	5.6	94.4
61	1	5.6	100.0

Mean=46.00, SD=10.34

TOTAL SCORE

Value	Freq.	%	Cum.%
87	1	5.6	5.6
96	1	5.6	11.1
106	1	5.6	16.7
108	1	5.6	22.2
125	1	5.6	27.8
132		5.6	33.3
140	[illegible]	11.1	44.4
148	1	5[illegible]	[illegible].0
151	1	[illegible]	[illegible]1.6
157	1	5.[illegible]	[illegible]6.6
159	1	5.6	62.7
160	1	5.6	77.2
162	1	5.6	73.8
165	1	5.6	84.3
167	1	5.6	84.9
178	1	5.6	90.4
180	1	5.6	100.0

Mean=142.28, SD=27.91

EAR DIFFERENCE

%Score	Freq.	%	Cum.%
-30.9	1	5.6	5.6
-19.3	1	5.6	11.1
-07.7	1	5.6	16.7
-06.9	1	5.6	22.2
-06.6	1	5.6	27.8
-05.5	1	5.6	33.3
-03.0	1	5.6	38.9
-02.1	1	5.6	44.4
00.0	1	5.6	50.0
01.4	1	5.6	55.6
02.7	1	5.6	61.1
03.1	1	5.6	66.7
03.3	1	5.6	72.2
03.4	1	5.6	77.8
07.3	1	5.6	83.3
11.1	1	5.6	88.9
13.8	1	5.6	94.4
16.1	1	5.6	100.0

Mean=-01.10, SD=11.36

BINAURAL QUOTIENT

%Score	Freq.	%	Cum.%
48.8	1	5.6	5.6
41.5	1	5.6	11.1
-36.1	1	5.6	16.7
-30.9	1	5.6	22.2
-29.4	1	5.6	27.8
-16.3	1	5.6	33.3
-14.9	1	5.6	38.9
-13.3	1	5.6	44.4
-12.1	2	11.1	55.6
-11.8	1	5.6	61.1
-07.8	1	5.6	66.7
-02.7	1	5.6	72.2
-01.7	1	5.6	77.8
00.0	1	5.6	83.3
03.4	1	5.6	88.9
03.7	1	5.6	94.4
16.6	1	5.6	100.0

Mean=-14.21, SD=17.26

Appendix

Green had assessed 36 learning disabled children who had been referred to him by various sources, primarily parents who had read about his work. The children were distinguished by the fact that they were "...thought by school staff or parents to have prominent auditory discrimination or memory deficits..."(personal communication, February, 1987). Of these thirty-six children, eighteen were boys of similar age to the subjects of this study. These eighteen were used as a comparison group in post hoc analyses.

Of the 132 normal Edmonton school children originally reported by Green (1986), thirty-five were males between the ages of 7 and 11 years. Raw ACT scores were also made available to this author for use as control data. Thus, three groups of data were available for post hoc analyses:

<u>Group 1</u> - Experimental learning disabled

<u>Group 2</u> - Normal control (EPSB)[22]

<u>Group 3</u> - Green's learning disabled (St.A)[23]

Permission to use the data for thesis purposes was given. The information was unanalyzed, and was from a larger study. Selected data were used in this report, some of which have been transformed to be comparable with the abbreviated (A through D) ACT scores obtained for the experimental group reported in the body of this paper.

The purpose of analysis was to determine if the experimental group (Group 1) performed significantly

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[22] Edmonton Public School Board students.
[23] St. Albert school students.

differently than a group of academically normally functioning boys matched for age (Group 2), or from a group of boys selected for auditory learning disabilities, matched also for age (Group 3). Differences, by group, were analyzed according to ear condition (L,R,B) using a two-way analysis of variance (ANOVA) with repeated measures. Post hoc multiple comparison analysis was accomplished using the Scheffe Procedure so that group effects could be maintained and delineated.

A. Methods

Control subjects were selected by elementary teachers in two Edmonton Public School Board schools who had been requested to send normal children from their classrooms to participate as controls for a research study. Testing was conducted by a research assistant who had been trained by Green in the administration and scoring procedures of the ACT. The environmental conditions that prevailed at each school, is unknown. However, the research assistant used a portable tape recorder, headphones and a switching box to deliver the stimulus to L, R, or B headphone(s). There was an effort to produce a "blind" test situation for comparison of learning disabled verses control children in data collection, but the class and school designations of each child was known to the assistant prior to testing, therefore, group association was known (personal communication, Green, April, 1987).

Green himself collected the data for Group 3 (18 boys with auditory learning disabilities). A portable tape recorder, switching box and headphones were used in a quiet room. Average intelligence or greater was specified by Green (unpublished paper, 1987) and learning disabilities were defined as being an "auditory processing problem" reported by either parent or school authorities. Green typified his learning disabled sample as being more homogeneous than other groups studied. In this respect they differed from both the unpublished Edmonton School Board learning disabled sample and from the children studied in this report.

B. Results

Distribution by Age

The data that was provided by Green grouped subjects by age in years. The half-year mid-point was calculated in months for each subject. Group 2 mean age was 113.657 months (9yr,6mo); median=114mo (9yr,6mo); SD=15.804mo (1yr,4mo). Table 1. shows all three groups by age.

Table 1.

AGE OF GROUPS

	Group 1	Group 2	Group 3
Mean	9yr 3mo	9yr 6mo	9yr 3mo
Median	9yr 8mo	9yr 6mo	8yr 6mo
SD	1yr 5mo	1yr 4mo	1yr 6mo
Range	6yr9mo-11yr10mo	7yr6mo-11yr6mo	7yr6mo-11yr6mo

As with Group 2, the half-year mid-point was calculated in months for each of the eighteen Group 3 subjects, because raw data were collected in 'years of age'. Mean Group 3 Age was 110.667 months (9 years, 3 months), SD=17.368 months (1 year, 6 months).

Distribution of ACT Scores

Green's subjects were administered all sections of the ACT (Sections A through E) for a possible score of 160 per ear condition.[24] Group 2 scores (and those of Group 3 as well) were pro-rated over four, not five, sections. Percentage correct responses were also calculated.

L scores provided M=58.971, median=63.000 (range=23-89), SD=15.529; R scores, M=59.514, median= 59.000 (range=34-81), SD=13.118; and B scores, M=61.057, median=63.000 (range=29-83), SD=14.361. Total ACT scores (pro-rated)ranged from 86 to 248. M=179.543, median=190, SD=39.889. ED ranged from -14.8% (left ear superiority) to 19.6% (right ear superiority); M=1.083%, median=-0.500%, SD=8.198%. Mean BQ reflected a slight advantage of binaural listening over single ear listening of 3.197%, median=-4.400%, SD=15.790%. Group ACT score distributions are shown in Table 2.

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[24] The experimental group (Group 1) was administered Sections A through D for a possible score of 110 per condition. Pilot testing had indicated that the ammount of material perceived, retained and repeated reached ceiling long before Section E and that the scores on Section E did not diminish from earlier sections.

Table 2.

MEAN (SD) GROUP ACT SCORES

	Group 1	Group 2	Group 3
Left	48.3 (11.3)	59.0 (15.6)	48.9 (16.9)
Right	47.9 (11.0)	59.5 (13.1)	50.1 (50.0)
Both	46.0 (10.3)	61.1 (14.4)	39.1 (14.7)
Total	142.3 (27.9)	[illegible]9.5 (39.9)	133.1 (35.1)
ED	-1.1%(11.3%)	1.1%(8.3%)	3.1%(15.0%)
BQ	-14.2%(17.3%)	3.2%(15.8%)	-35.7%(39.4%)

Like Group 2, all five sections of the ACT were administered to Group 3. Scores reported here were prorated for comparison with Group 1 who were administered an abbreviated version.

Left scores were M=48.889, median=52.000 (range=25-74), SD=16.845; R scores were M=50.167, median=50.00 (range=38-73), SD=9.990; B scores, M=39.056, median=35.500 (range 16-79), SD=14.719. Total prorated ACT scores ranged from 16-79, M=133.111, median=129.500, SD=35.138. ED ranged from -17.7% (left ear advantage) to 33.3% (right ear advantage); M=3.1%, median=1.000%, SD=15.045%. Mean BQ of -35.66% reflected a deficit in listening over single best ear conditions, median=-35.250%, SD= 39.373% (See Table 2.).

Correlations

Unlike Group 1 results, all Group 2 ACT scores except BQ (r=.0475;p=.393) correlated significantly with age (Table 3). R and ED scores were not highly correlated (r=-.0498; p=.388), but left ear and difference scores were related (r=.5995; p=.000) indicating that the performance of the left ear generated the difference. The reverse was found to be true of Group 1.

Table 3

PEARSON CORRELATION COEFFICIENTS

GROUP 2 - NORMALLY FUNCTIONING STUDENTS (N=35)

	Age	Left	Right	Both	Total	ED
Left	.538					
Right	.368	.816				
Both	.397	.803	.746			
Total	.473	.947	.915	.918		
ED	-.412	-.600	-.050	-.375	-.385	
BQ	.048	-.126	-.268	.326	-.020	-.170

Table 4

PEARSON CORRELATION COEFFICIENTS

GROUP 3 - GREEN'S LEARNING DISABLED STUDENTS (N=18)

	Age	Left	Right	Both	Total	ED
Left	.327					
Right	.398	.578				
Both	.401	.653	.395			
Total	.438	.917	.727	.844		
ED	-.135	-.834	-.056	-.488	-.620	
BQ	.281	.346	.429	.212	.377	-.194

BQs did not correlate well with either L or R ear performance and were only significant when both (B) ears were receiving stimuli (r=.3263;p=.028). Age:ACT score correlations were significant only in the listening condition with Both(r=.4012; p=.049) and with Total scores (L+R+B)((r=.4379; p=.035). See Table 3. B and ED scores failed to relate significantly with L, but did with R scores as they had for Group 1. However, ED scores did correlate negatively with B (r=-.4882; p=.020) and Total score (r=-.6199; p=.003).[25]

C. Comparison of Groups

Correlations

In all three groups, L performance correlated below the .05 level of significance with all ACT variables except the BQ calculation. The pattern of R ear responses differed between groups (See Table 3). Group 1 ED scores were significantly correlated with R as well as L performances; R correlation slightly stronger (r=-.4946; p=.018). R performance failed to correlate significantly with Ed for either Group 2 (r=-.04989; p=.388) or Group 3 (r=-.0557; p=.413). This indicated that the variability of L accounted for the variation of ED for Groups 2 and 3, but Group 1 ED was affected by either ear, slightly more the right than the left.

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[25] This pattern would be consistent with peripheral hearing loss and/or headphone artifact, wherein fusion failure occurs due to callibration error of one or both headphones or the stimuli phase differences exceed 80 degrees. Such electronic artifacts would be undetectable in single ear listening conditions. Neither confounding condition was controlled in the Group 2 or 3 studies.

Scores in the B condition and Total ACT scores were significantly correlated with ED for Groups 2 and 3 as well, supporting the notion that aberrant L ear behavior was responsible for the difference found between the two ears. Group 1 ED did not correlate well with B (r=-.0437; p=.432) nor Total scores (r=-.0068; p=.489). This lack of consistancy would be predicted if there was no clear dominance, some fusion failure, or competition from failure to supress a lagging stimulus when listening with both ears in the binaural condition.

The Binaural Quotient, is derived by subtracting the highest single ear score (H), be it right or left, for each individual, from the B score. The result is then divided by the B score (BQ=B-H/B x 100) to arrive at the percentage of advantage or disadvantage (negative result) of listening with both ears compared to a single best ear. By looking at the correlations between elements of the equation, some hypotheses may be generated. Group 2, the normally functioning subjects, BQ significantly correlated only with the B condition (r=.3263; p=.028). The B score, then, was the element that controled BQ. The two-ear listening condition (B) improved scores over single ear listening conditions by 3.197%.

Total ACT Score

An analysis of variance (ANOVA) was performed on Total scores (L+R+B) to determine whether the mean differences between groups were significant. Significance exceeded the .05 level (F=10.637, p=.0001).

Post hoc pair-wise comparison analysis using the Scheffe Procedure indicated Group 1 and 3 means differed significantly from that of Groups 2. No difference between Groups 1 and 3 were found.

Single Ear and Binaural Performance

A two-way analysis of variance with repeated measures was conducted to compare single ear and binaural performance score means (L,R,B) between Groups 1, 2 and 3 (See Table 5).

Table 5.

ANALYSIS OF VARIANCE FOR GROUP AND EAR CONDITION

Source of Variation	SS	df	MS	F	P
Between Subjects	38650	70			
A	7452	2	3725.93	8.605	0.000
Subjects Wthn Group	29440	68	432.97		
Within Subjects	9373	142			
B	563	2	281.72	4.847	0.009
AB	1142	4	285.39	4.911	0.001
B X Subj Wthn Group	7904	136	58.12		

The ANOVA reached significance for Factor A, Groups variance (F=8.605;df=70,2;p=0.000), Factor B, L,R, and B (F=4.847; df=142,2;p=0.009), and Factors AB within subjects (F=4.911; df=142,4;p=0.001). The Scheffe comparison of unweighted main effects indicated, as did the Total performance Scheffe, significant differences between Groups 1 and 2 (F=6.345, p=0.003) and between Groups 3 and 2 (F=7.855, p=0.001). As Total performance is a figure derived from the sum of L, R, and B scores, the result is redundant. The relationship between L and R scores was not significant. However, L and B (F=3.449, p=.035) and R and B (F=4.498, p=0.013)was significant. This is consistent with the observations reported using the correlation matrices.

Factor analysis maintained the interrelationship between independant variables L, R, and B. Both groups of LD children suffered performance decrement when listening with both ears. Group 1 had a 14.2% decrement and Group 3 had a 35.7% decrease over best single ear listening (BQ). Conversely stated, Group 1 *improved* recall of verbal material by 14.2% when listening with a better ear. Group 3 improved 37.7%. Decrement could occur from fusion failure caused by inability to control stimuli phase differences and/or subject processing disorders. Groups 1 and 3 differed from Group 2 in all three listening conditions and on Total performance, although they did not differ one from the other.